A METHODOLOGY CALLED 'MINK' FOR STUDY OF CLIMATE CHANGE IMPACTS AND RESPONSES ON THE REGIONAL SCALE

An Introductory Editorial

Scientists engaged in research on the greenhouse effect differ considerably in their estimates of the extent of global warming and the rate at which it will occur for any particular scenario of continued greenhouse gas emissions. Indeed there is some disagreement as to whether warming will occur at all. About one aspect of the problem, however, there seems to be almost universal agreement and that is that our knowledge of climate dynamics, general circulation models, and paleoclimatic reconstructions do not yet allow reliable regional-scale forecasts of greenhouse-induced climate change.

Perhaps for the media and some politicians, as well, it may be sufficient to know that global warming and climate change is likely. But what I term the 'so-what? crowd' – agri-businessmen, railroad managers, hydroelectric plant operators and planners, economists, and all kinds of decision makers and policy makers – wants to know a good deal more than that. "How will climate change in my region?, when?, how fast?". Unfortunately, we scientists are unable to answer such questions now and it may be many years (see e.g. Schneider *et al.*, 1990) before we can. And the matter becomes even stickier because even if we could provide answers to the questions posed above, the 'so-what? crowd' really wants to know what climate changes might mean for the workings of particular industries, enterprises and the economy and social well-being of the regions in which its interests lie. Sadly, we lack not only the answers to these questions, but even the methodology to properly addres them.

It was recognition of the need for a methodology to study the possible impacts of climate change on the regional scale that led the Carbon Dioxide Research Division of the Department of Energy (now the Office of Health and Environmental Research) in mid-1988 to commission Pacific Northwest Laboratories (PNL) to organize a program, *Process for Identifying Regional Influences of and Responses to Increasing Atmospheric Carbon Dioxide and Climate Change*, that would help develop such methodology. The program consisted of three component activities: 'analysis of response', 'information systems', and 'knowledge transfer'. PNL selected Resources for the Future (RFF) to lead the first activity. The Carbon Dioxide Information and Assessment Center of Oak Ridge National Laboratories (ORNL) and the Society of Sigma Xi were chosen to lead the other activities. ORNL provided data from a geo-ecology data base for the RFF analysis, Sigma Xi organized an international workshop at which the program analyses were reviewed prior to completion and PNL and Sigma Xi were also involved in study of the uncertainties that accumulate in analyses based upon simulations. Papers in this special issue of Climatic Change report the work accomplished under the 'analysis of responses' component of the project. The papers draw primarily, but not entirely, on a set of very detailed reports to the Department of Energy which are listed below with information on their availability (see note).

The RFF team engaged to work of the project included the author of this editorial, an agrometeorologist; Pierre R. Crosson, a natural resources economist and specialist in land use issues; Kenneth D. Frederick, a water resource economist; Roger A. Sedjo and Michael D. Bowes, specialists in forest economics; William E. Easterling, III, a geographer and climatologist; and Mary S. McKenney, an ecologist and simulation modeler. These names are seen again as authors of the papers that follow. Three research assistants, Kathleen M. Lemon, Laura A. Katz and John Wingard contributed substantially to the analyses.

Our analytical approach is innovative. Three innovations generally applicable to the entire study deserve mention here; others are explained in the context of the individual papers that follow. The first innovation relates to the fact that in most prior climate change impact assessments the climate as it might be sometime in the future is imposed on the world or some regions of it as they are today. However, by the time greenhouse induced climate change is great enough for its impacts to be noticed the regions will, in all likelihood, have changed in many ways for reasons having nothing to do with climate change. Accordingly we developed a baseline of the economy of a particular region as it might be in the year 2030. A climate change was imposed on the 'region of the future'. We reasoned further that climate change impacts on any real region, now or in the future, cannot be properly evaluated without taking account of interregional connections and the impacts of climate change elsewhere. So current and possible future trends in demographics, income, trade, technology and other factors were studied for clues as to how climate change might alter inter-regional economic connections. Also in many prior studies scenarios of climate change are imposed and it is assumed in the calculation of impacts that the people affected suffer these impacts passively. We doubt this would actually happen and, therefore, made a particular effort to consider the kinds of adjustments and adaptations that might be made with both 'off-the-shelf' and new technologies as people find ways of responding to climate change.

The overall analysis involved a four-stepped approach. First we thoroughly described the region chosen for study, documenting its current demographics and economy and describing the industries and natural resource sectors most likely to be affected by climate change – agriculture, forestry, water resources, and energy. Then we imposed a climate change on the region and simulated its impacts on the sensitive industries and natural resources in order to assess current vulnerabilities as well as opportunities that current technologies and policies afford for response to the imposed climate change. Next we sketched a scenario of the regional economy in 2030 in the absence of climate change, emphasizing agriculture and other natural resource-based activities. Finally we imposed the same scenario of climate change on the region of the future and simulated the impacts on the sensitive industries and resources. We attempted to evaluate the opportunities that future technologies and policies might provide for responding to the impacts of climate change.

Thus, in our analytical framework we provided opportunity to consider how economic and technological change affect sensitivity to climate and how adaptation alters that sensitivity. We considered one additional factor – the stimulating effect that atmospheric carbon dioxide enrichment has been shown to have on plant growth, yield and water use efficiency (photosynthate produced per unit of water consumed in evapotranspiration). Two levels of CO_2 were considered: the (approximately) current 350 ppm and 450 ppm, a concentration likely to be reached by 2030.

What of the study region? We chose to concentrate this first test of our methodology on the central U.S. region comprised of the states of Missouri, Iowa, Nebraska and Kansas (hence the acronym MINK). We chose this region because GCMs generally agree that the central U.S. is more likely than not to become drier as well as warmer as a result of greenhouse forced climate change. Further, this region is relatively more dependent on agriculture than any other of comparable size in the United States, and its water resources are already strained and are likely to become even more so in the future whether climate changes or not. The region is also relatively simple from a physiographic point of view being far removed from oceanic influences and including no major mountain chains. Nonetheless, as described in the following papers, land use in the MINK region is diverse, encompassing hardwood forests in the southeast, corn and soybean production and animal feeding in the eastern prairie region, winter wheat and sorghum production in the semiarid western portion and range animal production and irrigation of grain crops in the west central and north western portions.

Climate will not change in discrete steps or in geographic discontinuities bounded by GCM gridboxes. Minimum and maximum temperatures will not change in any real region by the same number of degrees or precipitation by the same percentage everyday and everyplace. A number of climate modelers (e.g. Gates, 1985; Giorgi, 1990; Chen and Robinson, 1991) are addressing the need for ways to represent spatial and temporal variability of climate change more realistically than has been done in the past. However, it is possible to develop climate scenarios that provide natural spatial and temporal variability by drawing on the actual climate record. We chose to use the actual weather records of the decade 1931–1940 as our 'analog' of climate change in the MINK region. We took the current climate, that of the thirty year period 1951–1980, to be the 'control' against which change is compared. The decade of the thirties was the hottest and driest on record in this region. Since most GCMs predict warming and drying for the central portions of Northern Hemisphere continents, our choice of analog or surrogate climate change is reasonable. Use of these real climatic records allows us to capture that spatial and temporal variability we feel is needed for realistic assessment of how natural systems behave.

Our good readers will note in the papers that follow that our choice of a 'climate change' scenario leads, occasionally, to surprising or non-intuitive results. For example, while Kansas and Nebraska were the droughtiest of the four states in the 1930s, our simulations show that a reimposition of the 1930s climate would impact most severely on corn yields and production in a portion of southeastern Iowa. Similarly, the simulations show that despite the general droughtiness in Kansas, an important wheat growing area in the west-central part of the state would be little affected. These seemingly anomalous results reflect the fact there were islands of multi-county size whose weather during the 1930s was anomalously and significantly worse (Iowa) or better (Kansas) than in the surrounding country. Similarly, our simulated river flows in central Nebraska appear anomalously high. But weather in this particular basin was better in the 1930s (less droughty) than anywhere else, upstream or down, in the Missouri River basin.

There is another cause of anomalous or counter-intuitive results in our analysis – a cause that affects the results of all prior studies with which we are familiar. Few simulation models are capable of dealing with all the phenomena that determine response of natural systems to climatic variation. For example, our simulations of wheat yields under the conditions of the 1930s in the MINK region appear optimistically high (not just in that portion of Kansas referred to above). As the simulation model used discounts wheat yields by a fixed amount for each day of low temperature, the warming in our climate scenario relieves that particular stress and improves yield. The fact that not every year in the 1930s was dry (nor is it likely that every year in a future greenhouse-altered climate will be dry) also tended to offset some of the potential yield loss due to drought. Simulation models are imperfect for a variety of reasons, although those we used can probably stand up well against GCMs in any credibility contest.

Enough of the caveats!!. *Paper 1* in this series provides detail on the analytical structure of the MINK study and also details on the physiography of the MINK region, its soils and climate. *Paper 2* reports the results of simulation modeling of crop yields and regional crop production under the analog and control climates with both current (1984–87) and future (2030) agricultural technologies and with current and future CO_2 concentrations (350 and 450 ppm, respectively). Possible impacts on animal production are also considered. Opportunities for adaptation to the climate change under current and future conditions are also tested by simulation. The overall impact of the climate change, CO_2 concentration and adaptations on the agricultural and total economies of the region are also assessed in this paper. *Paper 3* deals with the impacts of the analog climate on the forests of southeast Missouri. Changes, both in biomass production and species composition, are modelled. Response strategies for the forest industry in this region are evaluated under today's conditions and as we speculate conditions may be in 2030, taking into account emerging technologies likely to be important by then. The modifying effects of an increased atmospheric CO_2 concentration are also considered. In *Paper 4* the impacts of the analog climate change on the water resources of the

MINK region are evaluated. Actual streamflows in the few remaining basins unaffected by human development since the 1930s are used to estimate what the impact would be today and in the future if the climate of the 1930s were to return. The declining availability of groundwater in the region is taken into account. Current demands for water for purposes other than irrigation are also growing, reducing the resilience of the region's agriculture to drought. In the future these non-irrigation demands will be still greater and supplies, particularly of groundwater, will also be smaller. *Paper 5* deals with the prospective changes in supply and demand for energy that might follow a return to the conditions of the 1930s. Here, too, current economic conditions and future developments are considered in the analysis. In *Paper 6* an attempt is made to estimate the region-wide economic consequences of the climate change impacts on agriculture, forestry, water resources and energy under current and future economic and technological conditions. The estimates rely primarily on a regional input-output model. *Paper 7* is a summary or 'overview' dealing with the principal findings of the study, with the policy implications of the findings and, more generally, with methodological questions answered and still to be addressed in climate impacts research.

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References

Gates, W. L.: 1985, 'The Use of General Circulation Models in the Analysis of the Ecosystem Impacts of Climate Change', *Clim. Change* 7, 267–284.

Chen, R. S. and Robinson, P. J.: 1991, 'Generating Scenarios of Local Surface Temperatures Using time Series Methods', *J. Clim.* **4**, 723–732.
Giorgi, F.: 1990, 'Simulation of Regional Climate Using a Limited Area Model Nested in a General Circulation Model', *J. Clim.* **3**, 941–963.
Schneider, S. H., Gleick, P. H., and Mearns, L. O.: 1990, 'Prospects for Climate Change', Chapter 3 in Waggoner, P. E. (ed.), *Climate Change and U.S. Water Resources*, Wiley, New York, pp. 41–73.

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Note 1

Reports prepared for the United States Department of Energy
Office of Energy Research
Office of Health and Environmental Research
Carbon Dioxide Research Program

Title: *Processes for Identifying Regional Influences of and Responses to Increasing Atmospheric* CO_2 *and Climate Change – The MINK Project**

– An Overview. Prepared by Norman J. Rosenberg and Pierre R. Crosson. DOE/RL/01830T-H5(TR052A), 38 pp.
Report I – Background and Baselines.
Assembled by N. J. Rosenberg, with contributions by P. R. Crosson, K. D. Frederick, W. E. Easterling, III, M. S. McKenney, R. A. Sedjo, M. D. Bowes, J. Darmstadter, L. A. Katz, and K. M. Lemon. DOE/RL/01830T-H6(TR052B). 113 pp., tables, figs.
Report IIA – Agricultural Production and Resource Use in the MINK Region Without and With Climate Change.
Prepared by Pierre R. Crosson and Laura A. Katz with John Wingard. DOE/RL/01830T-H7(TR052C), 123 pp., figures tables.
Report IIB – A Farm-Level Simulation of the Effects of Climate Change on Crop Production in the MINK Region.
Prepared by William E. Easterling, III, Mary S. McKenney, Norman J. Rosenberg and Kathleen M. Lemon. DOE/RL/01830T-H8(TR052D), 222 pp., figures, tables.
Report III – Forest Resources.
Prepared by Michael D. Bowes and Roger A. Sedjo. DOE/RL01830T-H9(TR052E), 123 pp., figures, tables.
Report IV – Water Resources.
Prepared by Kenneth D. Frederick. DOE/RL/01830T-H10(TR052F), 153 pp., figures, tables.
Report V – Energy.
Prepared by Joel Darmstadter. DOE/RL/1830T-H11 (TR052G), 60 pp., figure, tables.
Report VI – Consequences of Climate Change for the MINK Economy: Impacts and Responses.
Prepared by Michael D. Bowes and Pierre R. Crosson. DOE/RL/01830T-H12(TR052H), 58 pp., tables.

* All published in August 1991.

Copies are available from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.