SCOPE 27 - Climate Impact Assessment

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18 Global Modeling and Simulations

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18.1 INTRODUCTION

Climate impact assessment often requires foresight and examination of complex patterns of events on a global scale.

For example, a global warming manifesting itself over the next 50 years could well occur in the context of a doubling of world population and a transition away from the present petroleum-based industrial system. How might this evolving context relate to the effects of climate change? Would international trade mitigate or amplify climatic influences on agricultural production? What might happen if climatic disturbances were to occur simultaneously with major disruption of the global energy system? Such questions naturally arise, particularly when general circulation models (GCMs) are used to produce climatic scenarios, and drive researchers to look for tools to evaluate the societal consequences of these scenarios.

Can currently existing global social systems models be used for such climate impact assessment? Might the social system models be linked to GCMs? What more limited applications might be feasible? To help answer these questions, this chapter offers a description of available models, how they work, what their purposes and capacities are, and how they do or might represent climate.

Here `global model' is used to mean a computerized model representing one or more aspects of social systems on a global scale. About 20 models are discussed, all those for which documentation could be acquired at the time of writing. These range from short-term (less than one year) agricultural buffer stock models to very long-term (more than a century) models of interaction among population, resources and environment. Emphasis is on the possibilities, opportunities and difficulties of adapting these existing models to explore globally questions of the effects of climate variability and change. This global analysis should be seen as a companion to the regional and sectoral approach discussed in many chapters of this volume.

18.1.1 Limitations of Global Models

At the outset readers should be cautioned against inflated expectations. Several factors place strict limits on the value of global models for climate impact studies.

The first major limiting factor is that global models have generally not been designed with climate impact analysis in mind. Spatial and temporal resolution and subject matter boundaries render many of them problematic or inappropriate for many climate impact questions. For example, in many models the Soviet Union or all of North America is represented as a single entity, so that calculation of the impacts of changes in finer scale midlatitude precipitation patterns would be difficult or impossible. Similarly, trade models with a time horizon of 1─5 years may provide insight relevant to the examination of a change taking place over 30 years, but they are far from ideal for the purpose. And, obviously, models that do not represent soil fertility or differentiate between forest and desert cannot be used to study desertification. Most models do not represent soil, forest or marine systems, and the few that do provide rather simplistic descriptions.

A second limiting factor is the general scientific basis of global modeling. Although global models are remarkable as pioneering efforts, they are in need of improvement from many sides. Global modeling is scarcely more than a decade old. The disciplines on which it draws, such as economics, demography, ecology and political science, have not achieved great predictive power.

Moreover, the policy and popular audiences to which the results of global models have been addressed have not held modelers to the highest scientific standards of hypothesis formulation, documentation and testing, and the modeling community has yet to agree upon or enforce standards. Global models are often unreliable black boxes; in most cases it is impossible to place confidence limits on their predictions. Realistically, one should not count on global models to accomplish more than

> `... organize existing data in such a way that it provides new insights and facilitates interpretation of the data'.
>
> `... pose new questions and call ... for new facts'.
>
> `permit us to make important, verifiable predictions'.
>
> `provide the basis for collecting accurate measurements'.

(Mason, 1976, 3)

A third limiting factor is that global models, like other large, complex models, are difficult to construct, understand, operate, test and maintain. Understanding them, even to gain insight, may be hard work. For example, international trade is extremely complex, and models use various simplifications for attempting to describe it (Neunteufel,1977,1979). In assessing how a change in climate or an extreme climatic event may be transmitted through the international trade system, there is little hard evidence to go on as to which trade formulation is most appropriate. Once model results are presented, it may be difficult to sort out whether the findings are artifacts of the model's simplifying assumptions or attributes of the real system.

Liverman (1983) illustrates well the kind of difficulties that arise in applications of global models. Liverman investigated the ability of the International Futures Simulation Model (Hughes, 1982) to replicate the price and trade patterns of 1972─75, given appropriate forcing to represent weather patterns of those years. She concluded that the model did relatively well in estimating slowly changing phenomena such as population, production trends and land in cultivation over 1970─80, but that simulation of crop prices and stocks was poor. This, she concluded, was open to two interpretations: either the model structure inadequately described trade, price and food stock mechanisms, or the observed behavior resulted from distortions of price─trade mechanisms by political decisions and price speculation (p. 266). Such ambiguities are likely to be inescapable in many attempts to employ global models for climate impact analysis.

18.1.2 Ways of Using Global Models

In light of their limitations, how might global models be used in climate impact analysis? The option mainly discussed here is to employ or modify existing models. Two other options deserve mention, however. One is to use no formal global model. The second is to develop a new model specifically for climate impact analysis.

The strongest reasons to refrain from using formal global models arise from critiques of the current state of the art. The refusal to employ and experiment with them, however, may well result in yet weaker development of geographically comprehensive and internally consistent global perspectives of climate impacts.

From a researcher's perspective, the option of developing a new model is highly attractive. Literature on the use of mathematical models has strongly favored *ad hoc* model development with strong user involvement, while repeatedly cautioning against the difficulties of using `off the shelf' models (see Holcomb Research Institute, 1976; Linstone and Simmonds, 1977). Building a global model is a major effort, however, Assembling data bases, developing theory, and testing and documenting a new model can be expected to take at least 2 years and several hundred thousand dollars. An effort of such scale should be framed around the sharp designation of questions to be explored and the context in which they are to be explored. How it should be done is outside the scope of this chapter.

18.1.2.1 Off-line Use

Global models may be used without new computational work. For example, published model results can be used to establish background scenarios for economic, demographic and resource trends that are to be anticipated concurrently with possible climatic change over the next 2–12 decades. Appropriate models for this purpose could be broadly focused models, such as World 2 (Forrester, 1971), World 3 (Meadows *et al.,* 1972), the World Integrated Model (Mesarovic and Pestel, 1974), the Latin American World Model (Herrera *et al.,* 1976), and the Coevolution Model described by Moisseiev *et al. ,* in Chapter 19. Despite disagreements about particulars, global modelers have come to broadly similar findings about agriculture, energy and relationships between rich and poor nations (Meadows *et al.,* 1982; Office of Technology Assessment, 1983).

All global models that have represented limits to land availability and diminishing returns for agricultural inputs (for example, fertilizer) have shown increasing food prices and increasing numbers of people with insufficient food. Regionally disaggregated models tend to show particularly severe agricultural stress in South Asia and non-OPEC Africa. Presuming climatic change has adverse agricultural consequences, one can expect it to amplify incumbent agricultural stress. Also, stressed agricultural systems tend to be associated with intense exploitation of the unmanaged biosphere, shrinking total biomass, and desertification. Reduced biomass also implies transfer of carbon from living organic matter and soil to other pools—predominantly, the atmosphere and the oceans.

Global models generally show the petroleum economy beginning to give way to other energy systems in the next few decades. Model results indicate that most every known non-petroleum energy form is expected to expand, but there are large disparities in the relative rates of growth for coal, nuclear, solar and other renewable energy supplies, and in the growth rates and composition (such as liquid *vs* solid fuel *vs* electricity) of future energy demand.

Lastly, where global models have been used to explore the development prospects of the poorer nations, model results have generally shown that extreme measures will be required for the poor to keep pace with the rich. Many models show the continuation of present trends leading to stagnation or even decline in the poorest nations. As the poorer nations are in general tropical, this finding suggests that climate-induced stress may be harder felt in the tropical than in the temperate or boreal regions.

18.1.2.2 Global Models as Data Sources

Lining up an internally consistent and globally comprehensive body of data is a large chore that may be necessary for some sorts of climate impact analysis. For example, to develop first-order approximations of the susceptibility of various nations to climatic influences in agriculture, fisheries and forestry, one might want to know the fractions of gross national product (GNP) coming from agriculture, fisheries and forestry. Such data are not conveniently assembled on a global basis in common statistical sources (for example, FAO, World Bank, or OECD Annual Yearbooks), but have been assembled in part by several global modeling efforts (for example, Leontief *et al.,* 1977; Bottomley *et al.,* n.d.). Similarly, the analysis of policy options for reducing CO_2 emissions might have use for data on energy capital infrastructure that has accrued in construction of the World Integrated Model or the IIASA energy models (International Institute for Applied Systems Analysis, 1981).

If one is interested in detailed investigation of the agroecological implications of climatic change for developing nations, the UNFPA/FAO/IIASA work is helpful (Food and Agriculture Organization/UN Fund for Population Activities, 1979; Shah *et al.,* 1981). The project, in essence simple models operating on an agroclimatological geographical information system, was established for detailed assessment of the earth's population support capacity, and to date it has absorbed around 500 person-years of labor. It now covers all developing countries except China (which was not in the United Nations when the project began) at a spatial resolution of 1:5,000,000 and a temporal resolution of one month. The data base includes soils and topographical, meteorological, crop-requirement and production data for three levels of technological inputs, all computerized to a common format. Adapting it to look at the changes in production potential for a specified set of climatic parameter changes would be straightforward. Alternately, it might be used as a data base from which to develop samples stratified by soil type, topography, and precipitation regime, for example, in monitoring desertification.

Table 18.1 General attributes of different global models

Model	Authors	Time horizon (years)	Method	Focus	Model	Authors	Time horizon (years)	Method	Focus
Coevolution Model	Moisseiev *et al.* (Chapter 19, this volume)	Hundreds of years	Dynamic simulation	Society, atmosphere, biogeo-chemical balances	UN World Model	Leontief *et al.* (1977)	25	Input-output (static)	Requirements for pollution generated by UN development targets
World 2	Forrester (1971)	200	System dynamics	Population, food, soils, industry, pollution	Interactive Agricultural Model	Enzer *et al.* (1978)	20	Cross impact, interactive projection	Global food problem, grain trade
World 3	Meadows *et al.* (1972) Meadows (1974)	200	System dynamics	Population, food, soils, industry, pollution	Optimal grain reserves	Johnson and Sumner (1976)	~20	Dynamic stochastic optimization	Management of grain reserves
Latin American World Model	Herrera *et al.* (1976)	100	Dynamic optimization	Allocation of labor and capital to meet	FUGI	Kaya Onishi (various dates)	~10—15	Econometric, input-output (dynamic)	Macroeconomic detail, energy and resources

				basic needs	USDA Grains, Oils and Livestock	Rojko and Schwartz (1976)	10–20	Econometric (static)	Production, exports, imports, trade of oils, grain and livestock
SARUM	Roberts (1977) SARU (1978)	90	Dynamic simulation, input-output, econometric	Food and mineral resource adequacy					
					Input–output	Bottomley *et al.*, (n.d.)	~10	Input–output (static)	International inter-dependence
MOIRA 1	Linnemann *et al.* (1979)	45	Algorithmic, optimization, econometric	Hunger, food production, food trade, trade policies					
					FAO price equilibrium		~10	Econometric (static)	World agricultural market pries, trade flows
World Integrated Model	Mesarovic and Pestel (1974) Hughes (1980)	25–50	Dynamic simulation, input-output	Population, capital, energy, food, trade, inter-sectoral flows					
					World Food Economy Model	Takayama *et al.*, (1976)	1–2	Econometric, quadratic programming	Global agricultural markets and trade
International Futures Simulation	Hughes (1982)	25+	Dynamic simulation	Population, economic development, energy, agriculture					
					UNFPA/FAO/ IIASA	FAO/UNFPA (1979)	1975, 2000	Agroecological analysis, linear programming	Population support, land resoures, food production
Grain buffer stock	Eaton *et al.* (1976)	~25	Dynamic stochastic simulation	Rules for managing grain buffer stocks					

The difficulty of gaining access to model data varies. Although some groups (such as Sichra, 1981; Bottomley *et al.*, n.d.) may regard making their data bases available as an important part of their work, not all model data will be accessible. Poor documentation, organizational problems, or modelers' proprietary interest in maintaining control of the rewards from data bases that have taken them many years to put together may make it difficult to extract data from other models. For example, portions of the US Department of Agriculture's Grains, Oils and Livestock Model (Rojko and Schwartz, 1976) were accidentally erased from USDA's computer archives and no backup existed (personal communication, Patrick O'Brien, USDA). Furthermore, the models' data bases may be outdated (for example, energy data may come from 1975 and before).

18.2 MODELS AND MODEL ATTRIBUTES

The following section addresses the question of which models may serve what purpose. It is organized around a two-dimensional matrix, listing models and various attributes of the models (for example, time horizon, method, degree of aggregation). The matrix is presented in Tables 18.1, 18.2 and 18.3. The text describes model attributes in the groups.

18.2.1 Temporal Resolution, Time Horizon, Method, Focus

Table 18.1 lists models in order of increasing time horizon, giving for each model a brief description of method and problem focus. Table 18.2 describes geographical, sectoral and agricultural sector aggregation, while Table 18.3 gives the treatment of climate and food stocks in each of the models. From Table 18.1, one can see that time horizons of existing global models range from 5 to 200 or more years. The character of models, the methods employed, the problems treated, and the model's possible utility for climate work change with time horizon.

Parenthetically, it may be noted that temporal resolution is seldom discussed in the global modeling literature. Most dynamic simulation models are solved at yearly increments and thus ignore seasonal events, an omission that may be significant for agricultural stock, trade and price mechanisms. The system dynamics models, World 2 and World 3, operate with a time increment set sufficiently small as to approximate continuous behavior. The static models are solved for an instantaneous point in time and in some cases, their exogenous parameters are projected forward and new solutions are derived for future points in time. For example, the UN World Model (Leontief *et al.*, 1977) and the USDA Grains, Oils, and Livestock Model (Rojko and Schwartz, 1976) are solved this way at 5-year intervals. Careful analysis of a model's temporal resolution should be made before applying it to problems involving seasonality.

Table 18.2 Treatment of climate and food stocks in different global models

Model	Geographical aggregation	Sectoral aggregation	Aggregation of agriculture sector
Coevolution Model	Land by 500 km^2 grid, coverage of ocean	Agriculture, pollution abatement, mineral,	Unclear

		basic capital	
World 2	Aggregate world	Agriculture, industry resource extraction	1
World 3	Aggregate world	Agriculture, industry resource extraction	1
Latin American World Model	5-region; 20-region may exist	Agriculture, education, housing, capital, other	Livestock, crops
SARUM (1976)	3 regions	10 sectors	4 agriculture products, 1 food product, 3 agriculture inputs
MOIRA 1	106 nations	Agriculture, non-agriculture	1 commodity
World Integrated Model	12 regions (basic), 17 regions (subregional)	7 or more, varies for different regions	5 commodity, 3 land types
Grain buffer stock	Aggregate world	Agriculture only	Aggregate grain
UN World Model	16 regions	40 economic sectors	4 agricultural commodities
Interactive Agricultural Model	10 regions	Agriculture only	Grain as proxy for all foods

FUGI	14–62	15 sectors	4 sector (?)
USDA Grains, Oils and Livestock	28 regions	Agriculture only	Up to 14 commodities
Input-output	90 countries	6 economic	1 agriculture, fisheries and forestry
FAO price equilibrium	28 regions	Agriculture only	18 commodities
World Food Economy Model	20 regions	Agriculture only	8 groups
UNFPA/FAO/ IIASA land resources	Much of developing world, 10,000 ha units	Agriculture only, livestock	18 food crops

Table 18.3 Treatment of climate and food stocks in different global models

Model	Treatment of Climate	Treatment of food stocks
Coevolution	Includes detailed climate model and mechanisms describing anthropogenic climate change	Probably excluded
World 2	Omitted	Excluded
World 3	Omitted	Excluded
Latin American World MOdel	Omitted	Excluded
SARUM	Generally omitted	Held in regions
MOIRA 1	Production limits = *f* (photosynthetic potential). potential estimated from	Stocks assumed to be held at world market level

	soil maps; past annual harvest variation repeats	
World Integrated Model	Omitted	
Grain buffer stock	Random perturbation of yields	?
UN World Model	Omitted	Excluded
Interactive Agricultural Model	Extremes in variation from trend line in past production series ('60–'75) define maximum deviation of random perturbation of yields	
Optimal grain reserves	Estimates made of yield as *f* (rainfall); model driven with synthetic time-series with mean, variance, auto-correlation structure of past rainfall data (sample years not specified)	Stocks of commodities determine prices in each region
FUGI	Omitted	Unclear
USDA Grains, Oils and Livestock	'Good ' or 'bad' weather investigated by raising and lowering yields (for Global 2000 runs)	Regional stocks for each commodity; levels policy controlled
Input–output	Omitted	Excluded
FAO price equilibrium	Exogenous	Unclear
UNFPA/FAO/IIASA land resources	Production functions based on climate inventory and assessment of climate responses of different crops	Excluded

18.2.1.1 Short- to Medium-term

Models in the 1 to 15-year range are more appropriate for looking at the economic effects of climate variability than for looking at climate change. Such models are typically built by economists and treat economic growth, international trade, balance of payment problems, monetary system behavior and intersectoral flows. They are built to provide detailed and precise descriptions of the global market and monetary systems, and it is logical to look to them for information on the ramifications of climate events through supply, demand, and price and monetary effects for specific commodities and countries or regions.

Such models measure many variables in monetary units, and in many cases use no physical or biological units. Their logic generally combines causality, extrapolation and accounting. They tend to be econometric, are often static, and a large portion of their mathematical operation tends to involve simultaneous equations and linear matrix operations.

These attributes tend to impart the assumption that the biophysical system will remain unchanged, and that most trends observed in the recent past will endure into the future. Linearization inherently assumes either that functional relations are indeed linear, or that systems changes will not be so great as to drive systems relationships far off a line of linear extrapolation. It may, thus, be inappropriate for describing extreme events or for making long-term forecasts.

Caution must be used if short-term models are to be used for looking at either shocks to the system—such as extreme climate events—or deeper underlying change. * Either temporary shocks or underlying change may violate assumptions of temporal and behavioral continuity often implicit in linearization and econometric modeling. To deduce whether a system handles shocks reasonably, it might be well to examine (or ask the modelers to look at) the behavior of climate-sensitive model variables in past years of climatic anomalies to see whether they fit within the model's explantory power, or merely add to the magnitude of its error terms.

* Experience with using large econometric systems to forecast the consequences of the tripling of oil prices of the early 1970s—an event analogous, in some ways, to climatic disturbances—suggests that such models are reasonably good at predicting short-term market effects, but inadequate for representing long-term adjustments. (Personal communication, Bert Hickman, Stanford, California).

18.2.1.2 Longer-term

Models with time horizons of over 50 years are generally built by interdisciplinary groups (engineers, systems analysts, economists, demographers, agronomists, and the like) and focus on biological and physical processes such as population dynamics, resource flows, and creation of physical capital stock. These models generally aspire to describe essential trends in system behavior—not to make point predictions.

Long-term models tend to ignore prices. Hence short-term models are probably preferable for investigating the market-related details of climatic variability and extreme climatic events, while long-term models are preferable for looking at climatic change and at the biological and/or physical consequences of climatic events. For example, while long-term models may be useful for studying the evolution of food scarcity conditions, shorter-term models allow one to study the effect of scarcity on prices and on trade and consumption patterns.

Between the short-term and the long-term models are a variety of trade and/or intersectoral flow models with some feedback between economic development and resource depletion, population growth, and other processes. These typically include both monetary and physical variables and are built by a mixture of economists and experts in physical and natural sciences.

18.2.2 Intersectoral Flows

Intersectoral flows may be important to climate impact analysis, first because they are routes by which indirect implications of climate variations may be felt, and second because intermediate flows (the products that are created in the process of making products rather than meeting end use demand—for example, fuel used in agriculture and industry) account for a large proportion of all economic activity, and it is difficult to keep track of such activity without a device such as an input–output matrix (see also Chapter 12).

Starting from the UN World Model described by Leontief (1977), one branch of global modeling has concentrated on the linkage between intersectoral flows within a country and international trade flows. One might gain information on intersectoral transmission of climate impacts using the UN World Model, the models assembled by Bottomley *et al.*, FUGI (Kaya and Onishi), or the World Integrated Model (Mesarovic and Pestel, 1974). For greater intersectoral detail, the UN model (Leontief *et al.*, 1977) might be preferred. If one simply wants data on intersectoral flows, Bottomley *et al.* have assembled what is probably the largest collection of input–output models in the world. The World Integrated Model (Mesarovic and Pestel, 1974; Hughes, 1980) or its simplified and most accessible version, the International Futures Simulation Model (Hughes, 1982), may be used for looking at intersectoral flows within the context of complex dynamic feedbacks.

18.2.3 Agriculture

The impact of climatic change and variability on agriculture can be observed from many perspectives: management of grain reserves; food and nutrition; trade and balance of payments; or ecological sustainability. Different global models are appropriate for different perspectives.

The section must commence with a caveat. Global agricultural models' market behavior depends heavily on the formulations used for international trade and for reserve management. Systematic comparisons of the various formulations that have been used and their respective strengths and weaknesses have not been published. It is beyond the scope of this paper to address the question of how good a model formulation is—or whether the real system is so complex that no simplification can capture its behavior.

18.2.3.1 Buffer Stocks and Grain Reserves

Grain reserves are an ancient defense against climatic variability. Numerous models have been developed specifically to examine the economics of buffer stock management. Some of these, including the models of Eaton *et al.* (1976) and Cochrane and Danin (1976), are designed to look at global reserves of all grains, others at specific grain commodities. A good review of buffer stock management models is found in Eaton (1980). In addition, as described in more detail below, disaggregated production and trade models have been used to look at stock management questions. An excellent review on this subject is found in Adams and Klein (1978).

To date, buffer stock modelers have tested their models mostly on yield variability such as observed in the recent past. The time-series employed seldom extend back past 1950. Variability has been characterized by such parameters as variance around expected production volume, lagged covariance behavior, and form of random behavior (Eaton, 1980). The problem of bad years occurring in sequence is considered by Eaton, but not by most studies.

The extent to which yield variation is caused by weather, the possibility of climate change, or the possible occurrence of extreme climate events not present in the period from which the model was parameterized are rarely mentioned in the buffer stock model documentation. It would be relatively easy and perhaps rewarding to use existing buffer stock models to look at how actual and/or optimal reserve holding strategies might operate under extreme climate events by altering the yield variability parameters used to drive the model. Under the assumption that climate change will be perceived as variability around a moving average, it may also be possible to use buffer stock models to look at climate change.

18.2.3.2 Production and Trade

Trade patterns are extremely complex (see, for example, descriptions of grain trade in Morgan [1980] and of commodity markets in Labys [1978]) and modeling them necessarily entails simplification. Part of the complexity is institutional and political. Agricultural production and trade policies vary greatly among countries and over time, and they significantly influence national and global agricultural markets.

The physical realities are also complex. Different crops and regions vary greatly in the structure and dynamic behavior of agricultural production. For example, coffee flows from mountainous tropical regions to temperate zones. Coffee production is frost-sensitive and, largely due to the fact that a coffee tree takes 3–4 years to bear fruit, the coffee market is prone to 7- to 8-year price and volume fluctuations. Wheat comes largely from temperate, semi-arid countries, is exported to both developed and developing countries, has much shorter production cycles than coffee, and is affected most by drought. Livestock slaughtering and meat prices are sensitive to grain prices; high grain prices induce increased slaughtering and meat supply in the short term, with meat shortage typically following in a matter of months or years (see, for example, Meadows, 1970).

Further, population and income affect trade. Come `riches' and the hungry eat more staples (per capita), while those above subsistence are apt to substitute luxuries and animal proteins for staples. Both income fluctuations and secular trends thereby affect the quantity and mixture of food demanded and hence the food that must be imported or may be exported. For many (if not most) regions of the world food demand is changing more rapidly than agricultural production, and the effects of climate change may tend to compound rapidly changing trade balances.

To analyze climate impacts on agricultural trade, a model must first include agricultural trade. This simple criterion selects SARUM (Roberts *et al.*, 1977; SARU, 1978), MOIRA 1 (Linneman *et al.*, 1979), the World Integrated Model (Mesarovic and Pestel, 1974), the UN World Model (Leontief *et al.*, 1977), the Center for Futures Research (CFR) interactive agricultural model (Enzer *et al.*, 1978), the GOL model (Rojko and Schwartz, 1976; US Department of Agriculture, 1978; O'Brien, 1980), and the FAO price equilibrium model (Food and Agriculture Organization, 1971). These all contain mechanisms that account for international agricultural trade.

Most global models represent agricultural demand as a function of income, and can be used to look at income effects. However, substitutions between commodities under income change can be studied only with a multicommodity trade model, such as the GOL or the IIASA/FAP model (Parikh, 1981; Parikh and Rabar, 1981).

Another area in which model structures and behaviors differ is in their handling of reserves. Both the way in which reserve sizes are determined and the way in which reserves affect prices and other behavior seem important. Here it is possible only to mention some of the ways in which representations of reserves differ. At one extreme, there are models, such as the UN World Model, in which reserves are the residual of supply, demand and trade, and where prices are unaffected by reserves. This representation will not show price instability under conditions of short supply. At the other extreme are models, such as the IIASA/FAP model and MOIRA, in which reserves are determined by complex interactions between production and demand responses, trade policies, and (in some cases) reserve policies. Relatively realistic descriptions might be achieved through such representations but, to date, documented validation of the representations is weak. Other models represent reserves as maintained at a policy-specified level through government purchases and sales of grain. In the CFR model (Enzer *et al.*, 1978), reserves are determined off-line in gaming fashion, by the decision of persons playing the role of political decision-makers.

An additional criterion is the model's treatment of the crop or crops of interest. Grain is considered in virtually all global models. In some cases, it is used as a surrogate for all agriculture. On the other hand, none of the models listed is appropriate for exploring the consequences of extreme climatic events on the export earnings of large coffee exporters such as Colombia, Kenya and Brazil.

A few other specialties and climate-relevant aspects of various models are worth a mention. The GOL Model (Rojko and Schwartz, 1976) was constructed to study the medium-term (~10 years) interaction among the global grain, oils and livestock markets from the perspective of the United States as a large grain exporter. This model has been used to study the effects of changes in mean values of climatic parameters as transformed into changes in grain production (National Defense University, 1983), although published documentation of the experiment is not very illuminating on the subject of how secondary effects of climate change were transmitted through the livestock and oilseed markets. There are, in published output, no signs that the GOL model has been run stochastically using assumptions of varying weather patterns, and without performing the experiment it is difficult to say how realistically the model would behave if it were and portions of the model's source code (as described above) were accidentally destroyed.

MOIRA (Linneman *et al.*, 1979) was constructed to study the effect of a doubling of population on the world food system. As described under demographic behavior, the model is particularly rich in its description of demand; it includes six separate income groups and calculates the dietary adequacy of each group as a function of income and price. Hence MOIRA is particularly good for studying income aspects of agricultural variations. MOIRA also attempts to model national agricultural trade policy in a more refined fashion than most other global models. However, the behavior of its trade mechanisms is essentially unvalidated and difficult to follow because more than a hundred nations are presented.

The IIASA Food and Agriculture Program (FAP) model, when complete, will be a set of mutually compatible national models, interlinked by a trade mechanism (Parikh, 1981; Parikh and Rabar, 1981). It will feature both multiple commodities (major grains, livestock, and non-food commodities) and detailed descriptions of agricultural policy levers available to different nations. The modelers intend to study the linked system's response to various shifts and disruptions, including climate shocks. The difficulty with the FAP model is that it is very large, extremely complex, and to date inadequately tested or documented. Development of the model has been slower than anticipated. Modeling work was scheduled for termination in 1984.

18.2.4 Energy

The impact of energy systems on climate, particularly on fossil fuel through CO_2 generation, has been analyzed using many models (Jäger, 1983; see also Chapter 9) and will not be described here. The tendency of firewood and dung fuel systems to contribute to local climate alteration, soil impoverishment, and desertification is outside the boundaries of existing global models because critical variables, such as firewood usage and forest growth, are not included in global models. Verbal attempts to describe and quantify such effects, however, were made in both the group IIASA energy model (International Institute for Applied Systems Analysis, 1981) and the Global 2000 study (Barney, 1980, 1981).

The main effects of climate on energy systems appear to be through the effect of weather on energy use for heating and air conditioning and on the supply of renewable energy sources, such as hydropower, firewood, and so forth (Quirk, 1981). The effect on heating fuel demand is relatively important in developed, temperate regions. The effect on renewable energy supply is most important in tropical, less developed regions.

By assuming a relationship between climate parameters and energy demand and/or supply, one could translate climate scenarios into scenarios of energy supply and demand, and use these to drive global energy models. However, for long-term climate change the effects of a change of a few degrees in average temperature are likely to be small in comparison to changes such as increased building insulation and increased efficiency of air conditioning.* It would be difficult to study the effects of climate on the supply of renewable energy sources other than hydropower (for example, wood fuel and solar energy) because treatment of the unmanaged biosphere is sparse in most global models, and representation of solar energy development remains highly tenuous. One might conceivably use the World Integrated Model (Mesarovic and Pestel, 1974; Hughes, 1980), the IIASA energy models (IIASA, 1981), the International Energy Evaluation System (IEES) (Barney, 1980, 1981), or other models containing international energy trade and fuel infrastructure development to study the impact of climate on energy demand, as transmitted through international fuel markets, intersectoral flows, and long-term effects on capital formation and resource depletion. Of the models listed, only IEES contains sufficient detail on energy demand to study the effects of short-term climate variation. IEES has not been updated since the late 1970s, and thus may not reflect adjustments made in the energy system since then.

*Personal communication, William Quirk, Lawrence Livermore National Laboratory, Livermore, California.

18.2.5 Demography

Population growth, being an important and relatively predictable part of social systems development (at least as compared to energy futures or economic growth) is accounted for in virtually all global models. How various global models treat demographic variables is shown in Table 18.4.

18.2.5.1 Migration

It appears that no global model has yet dealt with migration between nations. Both MOIRA (Linneman *et al.*, 1979) and the Latin American World Model (Herrera *et al.*, 1976) describe rural–urban migration. A peculiarity in the optimization routine in the Latin American World Model causes all regions to move towards 100 percent urban at an incredibly rapid speed,* and its formulation cannot be taken very seriously. MOIRA shows rural–urban migration as a function of relative per capita income in and outside of agriculture. In simulation, rates of rural to urban migration follow food price; when prices are high, farmers are better off and migration is less; when prices are low, farmers are poorer and there is more urban migration. It would be an interesting test of the model to see if it would, given severe weather shock in rural areas, replicate observed patterns of urban migration in times of famine.

Other than MOIRA and the Latin American World Model, global models can look at migration only by inference, as none explicitly includes migration.

One can, however, infer heavy migration as a plausible outcome of food deficits. It is possible to use most global models to look at food availability.

18.2.5.2 Other Demographic Parameters

Several global models relate population growth to economic development and food supply (World 2 and 3, some versions of WIM, the Coevolution Model described in Chapter 19), environmental conditions (World 2 and 3, the Coevolution Model), and social welfare (the Latin American World Model and World 3). Models such as these may be pertinent to climatic analyses in three ways. First, where they indicate tight food supplies, one can presume that the potential disturbance caused by the effects of climatic change and variability on yields will be amplified. Second, where they indicate population pressure, one can infer shrinkage of the unmanaged biosphere and deterioration of soil organic matter (through fire, overgrazing, and the like), and thus creation of harsher microclimates and increased CO_2 release. Third, if one had reason to believe climatic change would directly affect mortality or fertility, one could rerun the models with the changed parameter to see the consequences of the larger system.

* The model maximizes life expectancy at birth. Its functional relationships were developed by statistically relating several variables, including education, fraction of population urban, and others to fife expectancy. Because there is a strong correlation between life

expectancy and urbanization, the model favors rapid urbanization.

Table 18.4 Demographic aspects of different global models

Model	Aggregation structure	Demography	Migration
Coevolution Model	In development	Probably none	
World 2	No disaggregation	Fertility = *f* (income-cap) mortality = *f* (food, income)	None
World 3	5–15 age cohorts	Fertility = *f* (income, services)	None
Latin American World Model	By region rural–urban (*n*) age cohorts	Fertility and mortality are *f* (basic needs fulfillment); model maximizes life expectancy	Rural–urban at rate to maximize life expectancy
SARUM	Exogenous	None	
MOIRA 1	By nation (106), rural–urban income group (6)	Growth exogenous	Rural-urban *f* (income in agriculture, income outside agriculture)
World Integrated Model	By region (12+), age cohort (85)	Exogenous	None
Grain buffer stock	No disaggregation	Exogenous	None
UN World Model	No disaggregation	Exogenous	None

Interactive Agricultural Model	Probably none	Exogenous	None
Optimal grain reserves	Probably none; exogenous	None	None
FUGI	Undisaggregated	Exogenous	None
USDA Grain, Oils and Livestock	No disaggregation	Exogenous	None
Input–output		Demography excluded, implicit in demand projections	
FAO price equilibrium	Undisaggregated	Exogenous	None
World Food Economy Model	No disaggregation	Exogenous	None
UNFPA/FAO/IIASA land resources		Exogenous	None

The choice of models for looking at population–environment interaction depends on purpose. For moderately fine regional resolution, at the cost of rather difficult to interpret results, the World Integrated Model or the International Futures Simulation may be most appropriate. The WIM contains many (12 or more) regions and 1-year age cohorts; the IFS, 10 regions and 5-year age cohorts. Either could be adapted to look at the effects of food supply, income and population control on population dynamics, as well as to approximate the way in which climate change in one region might be transmitted to affect other regions through international trade. For example, suppose that a global warming causes lowered agricultural productivity in the Great Plains, but slight increases in rice yields in most tropical regions. The WIM or IFS could be used to investigate whether this will result in more or less hunger and starvation in India, Indonesia, and/or Africa. One could also use MOIRA for this purpose; this would give results that take uneven income distribution into account, but would not permit looking at the feedback to population growth, as population growth in MOIRA is exogenous.

For less detail, but more inclusive structure, World 2 and World 3 might be recommended. Both see longevity and fertility as affected by food supply, economic resources per capita, and pollution. Neither disaggregates the world into regional populations. World 3 normally uses five age cohorts, and has, in structural testing, been disaggregated to 15 age cohorts, leading to the finding that model results are not sensitive to the degree of age disaggregation (Meadows, 1974).

The pollution term in World 2 or World 3 could be adapted to describe the effects of anthropogenic climate change on morbidity and mortality. The part of model structure describing soil deterioration might be expanded or adapted to show shrinking of the biosphere, thus CO_2 generation and desertification. The Coevolution Model described in Chapter 19 employs demographic formulations similar to that of World 2 and World 3, and may eventually be expanded to account for population─resource-environment interaction on a 500 kM^2 grid.

Theoretically, the Latin American World Model, which finds the allocation of labor and capital among various sectors (housing, education, agriculture, capital formation and other) that maximizes life expectancy at birth, might be used to study strategies for meeting basic needs in the face of climate variability or change. However, introducing climate parameters into the Latin American World Model might not produce meaningful results. Its representations of trade and agricultural production are probably unequal to the problem, and it has some wildly unrealistic tendencies (Office of Technology Assessment, 1983).

18.2.6 Political Ramifications

Climate change is generally expected to benefit some and cost others. The costs of anthropogenic climate change are apt to be borne by groups other than those causing the change. Control of many of the economic and social forces contributing to climate change (for example, deforestation, CO_2 emission) will in many cases require cooperation. Because these considerations have strong political implications, one might want a formalized model to examine them.

The importance and difficulty of representing political decisions is almost routinely discussed at global modeling conferences (see Meadows *et al*., 1982). The Wissenschaftzentrum group in West Berlin, under the directorship of K. Deutsch, has been working on a politically oriented global model that deals with both domestic stability and international economics and politics. According to recent reports (Bremer, 1981; Ward and Cusack, 1981), it will employ a five-sector aggregation within which it would be very difficult to specify climate impacts (the sectors represented are household, government, capital production and foreign trade). However, extension and adaptation of the model will eventually be possible.

The Center for Futures Research (CFR) (Enzer *et al*., 1978) has constructed an interactive food model, in which persons playing policy-makers adjust production targets, reserve targets, import, export, aid, and other features in each year of simulated time. The model divides the world into ten regions, each of which is represented by a decision-maker. It has introduced stochastic weather effects on yields, and political responses to weather variation on the order of that observed over 1950─75 have been studied. The model, which is used in conjunction with the `player's' decisions about political reactions to changing circumstances, might be described as a simple simulation model (it can be simple, as modeling social and political decision-making is one of the more difficult aspects of social system model building, and the CFR model's interactive format absolves modelers of the need to be sophisticated in their human behavioral equations). It is parameterized using Delphi survey techniques.

The Climate Task of the Resources and Environment Group at the International Institute for Applied Systems Analysis tried a gaming approach to look at strategic and political aspects of CO_2-induced climate change. Two games were constructed, a computer game and a board game. They consider the strategic and economic aspects of coal extraction and trade and policy measures available for containing and/or adapting to CO_2 in the context of the evolution of highly uncertain and unevenly distributed costs and benefits arising from climate change (Stahl and Ausubel, 1981; Robinson and Ausubel, 1983). The games might be regarded as initial attempts to build interactive 'climate-centered' global models.

18.3 CONCLUSION

A crude model used with good scientific practice is more enlightening than poor scientific practice and a good model. Existing models are pioneering efforts, not perfected tools. Both imagination and scientific discipline are needed to obtain meaningful results for them. Essential activities include:

1. Defining the problem one wishes to explore and translating it into terms that are consistent with an existing model or models.
2. Critically examining model method, structure, and parameters, perhaps extending the criticism to include structural testing and model validation not produced by the modelers themselves, and comparison of the model with other models.
3. Analyzing model output, studying it both mathematically and in terms of real world significance, and comparing it to what is known from other sources.
4. Documenting one's findings in a fashion that makes them accessible to critical review and examination by others.

If one prefers to contract research with an existing global modeling group, much of the work mentioned above can be conducted by the modelers themselves. It must be realized, however, that global modeling has not generally adhered to (or been rewarded for adhering to) rigorous scientific standards. Unless one is willing to insist on—and pay for—upgrading the standards of practice, one is likely to end up with results that will not withstand critical review.

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