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Global change

Past, present and future

By THOMAS F. MALONE*, *St. Joseph College, 1678 Asylum Avenue, West Hartford, CT 06117, USA*

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ABSTRACT

A major international effort is now underway to understand in quantitative terms the interacting physical, chemical and biological processes that govern the global environment. The contributions of Professor Bert Bolin to this initiative are noted. It is now timely to incorporate the social processes into the triad of natural phenomena that determine global change. If society is to cope successfully with global change generated by an exponential growth in both population and economic production, society itself must change—in its way of thinking and in its institutions. A dynamic and creative interaction among science, technology and society must be fostered worldwide. The UN Conference on Environment and Development in 1992 provides an opportunity to take a decisive step toward this end.

1. Bolin and global change

It is appropriate to reflect on progress in the atmospheric sciences in the context of global change as we gather in Stockholm to honor Professor Bert Bolin. The topics of general circulation of the atmosphere, numerical weather prediction, biogeochemical cycles and climate are at the leading edge of global change. Professor Bolin's distinguished scientific career has been notable through his involvement at the forefront of each of these topics. Many of the seminal papers on the general circulation and numerical weather prediction appeared in the pages of *Tellus*, with which he has been closely associated. It was on the island of Shepparholmen near Stockholm that the foundations of the Global Atmospheric Research Program (GARP) were laid. The Study of Man's Impact on Climate (SMIC) was conducted in a suburb of Stockholm. GARP and SMIC were the precursors of the World Climate Research Program (WCRP). The Scientific Committee on Problems of the Environment (SCOPE) made its commitment to study biogeochemical cycles in Stockholm. SCOPE's work provided the foundation for the International Geosphere-Biosphere Program (IGBP) which traces its origins back to a meeting of the ICSU Executive, Stockholm in January 1983. Bert Bolin was a central figure in the initiation of GARP, WCRP, SCOPE's biogeochemical studies and IGBP.

Bolin's evolving professional interest from professor and scientist, to scientific leader of global research projects, and then to scientific statesman advising his government and intergovernmental organizations, suggest a pattern of involvement in the affairs of the world that is a model for the scientific community as it seeks to forge a dynamic and creative interaction with society in the 21st century. Global change in an increasingly interdependent world is powered by science and technology. No longer can the scientific community luxuriate in splendid isolation from the problems and opportunities that face humankind. These problems and opportunities have their origin in scientific and technological progress in the understanding and utilization of matter, energy, life pro-

* Scholar in Residence at Saint Joseph College, West Hartford, CT, and Distinguished University Professor at North Carolina State University, Raleigh, NC. Secretary General of the Committee on Atmospheric Science of the International Council of Scientific Unions (ICSU), 1964–68, and Secretary General of the ICSU Scientific Committee on Problems of the Environment, 1970–76. Foreign Secretary of the US National Academy of Sciences, 1978–82, and Co-convenor of the ICSU Syposium on Global Change in Ottawa in 1984.

cesses and information and their interrelationship. Scientists therefore have special responsibilities.

Several decades ago, Pierre Teilherd de Chardin began his prescient little book, *Building the Earth* (De Chardin, 1965), with these words: "There is now incontrovertible evidence that we are entering a period of the greatest change the world has ever seen." The challenge of this era was summarized succinctly in an address (Schultz, 1989) in 1989 by former USA Secretary of State George Schulz to the National Academy of Engineering:

> The world is shifting gears. Enormous changes are underway, affecting everything from super-power relations to science. In a time of profound change, one of the most difficult adjustments to make is the intellectual adjustment. We must discard outdated habits of thinking and make room for new possibilities.

Bert Bolin's career has been exemplary in making this kind of intellectual adjustment.

To probe the linkage between the atmospheric sciences and global change, it is useful to consider the five questions Conference Chairman Henning Rodhe put to us as we gathered in Friiberghs Herrgåård to ponder: "Atmospheric Sciences—Quo Vadis." He asked us to consider, Where are we now? Where did we come from? Where are we going? What are the issues for the future? How do we organize our research? In terms of global change, we can recast these questions within the broad framework of three even broader questions: What kind of a world do we have? What kind of a world do we want? What must we do to get what we want?

2. What kind of a world do we have?

Our world today is on the threshold of an era in which human activity is becoming a planetary force affecting the global climate and environment. The number of people on planet Earth has doubled over the past 50 years. The world economic output has quadrupled and the total energy used to achieve that output has increased more than 4-fold, growing from 3 to 14 terawatts. The present situation is summarized in approximate numbers in Table 1 from selected social and economic data complied by the World Bank (World Development Report, 1990).

We have a world in which the total number of people and the world production of goods and services are growing exponentially. Each has a doubling time on the order of decades. In contrast to earlier millenia, more than 80% of this growth is powered by energy extracted from fossil fuels. The rate of withdrawal is 100,000 times faster than the rate of formation (i.e., it cannot go on indefinitely). The other significant potential source of energy, nuclear power, provides only about 4% of the world's needs. Energy from the sun provides roughly 1/10 of our energy needs (hydropower, biomass, etc.). We are using, or diverting 40% of the terrestrial photosynthetic productivity of our planet (Vitoussek et al., 1986). In the aggregate, then, the world we have is in a rather precarious balance among population, the economic output that produce goods and services to meet human needs and aspirations, the technology for combining energy and material to support the economic output, and the carrying capacity of the biosphere. Currently the process of transforming natural resources into goods and services is leaving residues of materials (CO_2, CFC's, NO_x, SO_2, etc.) in the atmosphere that threaten to erode the life-supporting capacity of the biosphere. This is now becoming a matter of worldwide concern.

The problems of the aggregate demand on planet Earth's capacity are exacerbated by disparities in the individual economic productivity which is a measure of a person's command over the

Table 1. *Population and economic output in 1988*

Countries	Number	Population (billions)	GDP* (trillion US$)	GDP per capita (US$)
low income	42	2.9	1	300
middle income	54	1.1	2	2000
high income	25	0.8	14	18000
total	121	4.8	17	...

* Gross Domestic Product.

resources to enjoy a decent standard of living (Human Development Report, 1990). The 60-fold difference between the Gross Domestic Product per capita in the high income countries and that in the low-income countries in Table 1 represents an inequity that is socially destabilizing. The fact that over a billion people live in a condition of absolute poverty is untenable, as is the statistic that the wealthiest 1/5 of the global population receives about 70% of the world's economic output, while the poorest 1/5 receives less than 3%. This disparity is paralleled by data showing that the energy use per capita in all developing countries is only 1/7 of that in developed countries. This inequity has obvious environmental and climatic implications for the future.

3. What kind of world do we want?

It is possible to construct a scenario of population and economic production for 50 years from now by starting from the data in Table 1 and selecting growth rates which are a compromise between what is likely and what is desirable. A scenario is given in Table 2. It is based on an annual population growth of 2.1% in low and middle income countries and 0.5% in high income countries. The population growth rates in this *scenario* are higher than the current *projections* of The World Bank (Bulatao et al., 1990). The annual growth of gross domestic product in low income countries begins at 8% and declines to 6% in the last decade of the 50-year interval. Annual growth of gross domestic product in middle income countries begins at 6% and declines to 3% in the final decades; in the higher income countries, it is 2% in the 1st decade declining to 1% in the 5th decade. These growth rates have been selected to reduce the disparities in economic production among nations at different levels of socioeconomic development.

The population of the world would more than double. The *increase* in the population of the low-income countries would exceed the present *total* world population. This disparity in the GDP per capita between the high-income countries and the low-income countries would be reduced from 60 to 9. A decent standard of living would be attained in the low-income countries. Total energy use would likely more than double with a concomitant increase in the stress of the environment and climate. The increase would be several-fold in developing countries, but would decrease in development countries because of more efficient technology. The challenge is clear to increase energy efficiency and to seek alternative sources of energy. While increasing GDP per capita is *not* a sufficient condition for human development, it is a necessary condition in countries near the poverty threshold.

It should be clear that the human prospect is influenced by more than population dynamics. The stress on natural resources and the environment by each new person in the high income countries is approximately 10 times greater than that imposed by a new resident in the low income countries. This disparity has to be considered in relation to the more than tenfold difference in population growth. Thus the interests of both groups of countries are converging in ensuring continued habitability of Planet Earth. New paradigms are needed and new alliances need to be forged.

Table 2. *Population and economic scenarios for 2038*

Countries	Number	Population* (billions)	GDP** (trillions US$)	GDP per capita (US$)
low income	40	8	24	3000
middle income	54	3	16	5000
high income	25	1	28	28000
total	121	12	68	

* 2.1% annual growth for low and middle income countries; 0.5% for high income countries.

** 8% annual growth for low-income countries initially, decreasing to 6% in the final decades; 6% decreasing to 3% for middle-income countries; 2% decreasing to 1% for high-income countries.

4. New paradigms needed to obtain the world we want

One paradigm that is receiving increasing attention is the concept of *sustainable development*, articulated persuasively in the 1987 report of the World Commission on Environment and Development, *Our Common Future* (WCED, 1987). Currently, this is evolving into the idea of a *sustainable and equitable society* as the kind of world we want. That would be one that meets the needs and aspirations of the present generation without foreclosing options for future generations. In this sense, it addresses directly issues of *intragenerational* and *intergenerational* equity. It emphasizes a qualitative change in a socio-economic system in dynamic equilibrium with the environment. This requires a profound change in the traditional approach to socioeconomic development that has focused sharply on growth in national income accounts and economic productivity through human capital formation and human resource development. These aspects of the process remain important but become *means* rather than *ends*. The parameters that measure this new concept of human development include: (1) command over resources needed for a decent living, as measured by real GDP per capita; (2) adequate nutrition and good health, as measured by life expectancy; (3) access to the quality education necessary for productive life in modern societies, as measured by literacy (Human Development Report, 1990). Refinement of this concept is underway and it is likely to become an integral part of the strategy for achieving a sustainable and equitable society.

An important dimension of sustainability and equitability is in the explicit recognition that (1) stewardship of natural resources, (2) care for the quality of the human environment, and (3) socioeconomic development are inextricably linked by virtue of the fact that each is now tied to a global commons. Issues of environment, economics, energy, equity and ethics need to be treated as integral parts of a total system, rather than in isolation. This places a great burden on the need for changing our "way of thinking" (*metanoia*) as pointed out by Schulz, and for adapting our institutions to become capable of a holistic approach to contemporary issues. New modes of interdisciplinary cooperation will be required.

As we address the delicate balance among population, technology, and carrying capacity of the biosphere, new or renewed institutions will be necessary for bringing together in a grand convergence the natural sciences, engineering, social sciences, humanities, policy analysis and decision making in both the public and private sectors. Measures must be explored to stabilize population during the next century and to transform the present process of industrial metabolism into an industrial ecosystem that minimizes energy and material inputs and residues in a maner that approaches the functioning of the natural ecosystems that have supported human life over tens of thousands of years.

Among the changes in our way of thinking that will be required is a new perspective on the issue of international security as described by Jessica Tuchman Matthews (1989). The power of modern weaponry, which has grown a million times since World War II, has escalated military measures beyond a level that is useful as a means of resolving conflicting interests. Moreover, the issues which give raise to that conflict need to be addressed multi-laterally since it is now clear that the survival and well-being of the human species can be ensured most effectively by action in concert.

5. The challenge to the scientific community

Response to Henning Rodhe's charge underscores an urgent need for the world scientific community to move with alacrity and imagination in developing the knowledge base upon which global decisions can be made during the 21st century. A splendid start has been made with the International Geosphere-Biosphere Programme: A Study of Global Change (IGBP). Its objective is:

> To describe and understand the interactive physical, chemical, and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human activities.

Five projects have been approved:

- The International Global Atmospheric Chemistry Project (IGAC)
- Joint Global Ocean Flux Study (JGOFS)

- Biospheric Aspects of the Hydrological Cycle (BAHC)
- Global Change and Terrestrial Ecosystems (GCTE)
- Past Global Changes (PAGES)

Five additional projects are under consideration:

- Global Ocean Euphotic Zone Study (GOEZS)
- Land-Ocean Interactions in the Coast Zone (LOICZ)
- Global Analysis, Interpretation and Modeling (GAIM)
- Stratosphere-Troposphere Interaction and the Biosphere (STIB)
- Global Change and Ecological Complexity (GCEC)

Supporting activities include (1) development of data and information systems and (2) the establishment of Regional Research Centres for global change studies in developing countries.

It is intended that these programmes will be pursued through the combined efforts of (presently) 47 national IGBP committees. Coordination among national committees, with the Scientific Committee for IGBP (SC-IGBP) and with other ICSU Members is accomplished through a Scientific Advisory Council which meets periodically and advises on the development of the research program. Coordination with UN bodies is maintained through an Interagency Coordinating Committee. IGBP and WCRP are complementary: the former addresses the biogeochemical aspects of global change while the latter addresses the physical aspects of the climate system.

The activities within the international efforts and among the national initiatives are diverse and in a dynamic and evolving state. An imaginative conceptual framework for the Canadian program in Global Change has been prepared by The Royal Society of Canada. The full gamut of issues from population, technology, environment, energy economics, equity, and ethics and on to international security are addressed in masterful fashion in *Planet Under Stress* (Mungall and McLaren, 1990).

The USA Global Change Research Program, for example, has three principal thrusts: (1) documentation of global change, (2) integrated modeling of the earth system, and (3) focused studies which include:

- Earth system history and modeling
- Human interaction
- Water-energy-vegetation interaction
- Fluxes of materials from terrestrial systems
- Biogeochemical dynamics in the oceans

The USA program is under joint development by the Committee on Global Change of the National Research Council and the Committee on Earth Sciences of the Federal Coordinating Council on Science, Engineering and Technology.

The activities described above are only a few discrete segments of the total worldwide effort within which the atmospheric sciences are embedded. Specific issues for the future that requires attention include:

- Integration of the various segments of research activity in the physical and biological sciences; incorporation of social sciences.
- Reconceptualization of the overall objective for studies of global change in the light of the emerging understanding of the exponential growth in population and economic activity as the driving force of that change on a finite planet with a resilient but not limitless biospheric carrying capacity.
- Incorporation of the enormous power of remote sensing from space into a long-term global observing system, with complete internationalization of space vehicles, sensors and information systems.
- Institutional innovation to provide an effective framework for an interdisciplinary effort that transcends traditional approaches.
- Ensuring that the level of effort is commensurate with the magnitude of the task.

Perhaps the single most important step that can be taken to achieve integration would be to modify slightly the objective of IGBP to read:

> To describe and understand the interactive physical, chemical, biological *and social* processes that regulate the total earth system and determine the unique environment that it provides for life and the changes that are occurring in that system.

The overall objective would be embraced by the concept of a sustainable and equitable society, in which environmental considerations and issues of human development are treated together.

With respect to institutional innovations, it would seem appropriate to explore expansion of the Regional Research Centres under consideration to fulfill a function in response to issues of global change that the international research institutes of the Consultative Group on International Agricultural Research (CGIAR) carried out so successfully in addressing the global food problem. There is already in existence at the International Institute for Applied Systems Analysis (IIASA) a model which might be adapted to other parts of the world. At IIASA, studies are underway in depth on population dynamics, alternative energy sources, sustainable development of the biosphere, systems analysis and decision theory, agriculture and food, etc. Formal organizational links to developing countries would be essential.

It is important that the scale of the international effort not be under-estimated. If the funding proposed for the USA Global Change Research Program is extrapolated to the international level, an annual funding of the order of four billions of US dollars would be a first approximation to the financial needs, gradually trebling during the 1990s. Currently, the annual defense expenditures in the interests of national security in both developed and developing nations averages out to be 5.5% of their aggregated Gross National Product. This expenditure is now in the neighborhood of one trillion US dollars. A knowledge-generating research program in global change on the scale suggested here would be only about 0.4% of that figure and could be considered as a prudent investment in international security as we cross the threshold into the twenty-first century. Clearly, the imminent issue of global warming as a manifestation of the forces generating global change points to a major role for the atmospheric sciences.

There is a sense of urgency in delineating in a persuasive manner the research activity that will undergrid policy decisions that will be required during the next several decades. In June 1992, the UN Conference on Environment and Development will be convened in Brazil. This will be a unique opportunity for the world scientific community to present its views on the scope, structure and scale of research activities that should be undertaken during the crucial decade of the 1990s.

Reflection on the initiatives and accomplishments of the past three decades, intended to illuminate the role of the atmosphere as a critical element in global change, and the part played by the cumulative contributions of Professor Bert Bolin, leads one to recall the conclusion in an article by John von Neumann (1955) in *FORTUNE* Magazine, entitled, "Can We Survive Technology?" After a lengthy dissertation on military instability, nuclear technology and automation, Von Neumann concluded that the only safeguard for human survival lay in "... a long sequence of small, correct decisions ... intelligent exercise of day-to-day judgment ... patience, flexibility, intelligence." Is it too much to hope that the world community of atmospheric scientists is prepared to follow the prescription of this individual who played such an important part in bringing us to where we are today? Nothing less than the human prospect is at stake!

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