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Global-Regional Linkages in the Earth System




Springer

Peter Tyson · Roland Fuchs · Congbin Fu · Louis Lebel · A. P. Mitra
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With 154 Figures and 43 Tables

Springer

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Dedicated to
Tom Malone, who inspired so many,
and
developing country scientists who strive against the odds.

Preface

Global environmental change occupies a central niche in the pantheon of modern sciences. There is an urgent need to know and understand the way in which global biogeochemical cycles have changed over different time scales in the past and are likely to do so in the future. Equally important, it is necessary to determine the extent to which natural variability and that induce by anthropogenic activities are bringing about change. A number of international co-operative scientific programmes address these issues. Chief among them are the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP) and the International Human Dimensions Programme (IHDP) for global change. This book is one of a series of IGBP syntheses drawing together findings in global environmental change over the past decade or so.

One focus of IGBP activities is the System for Analysis, Research and Training (START). Co-sponsored by the WCRP and IHDP, START establishes regional research networks for global change science in developing countries, stimulates and carries out global change research in developing regions of the world, and builds capacity to undertake such research at personal, institutional and regional levels. Several regional global change networks have been established, and much regional research has been accomplished in the last five years or so. In this book, work relating to four of the older START regions, Southern Africa, South Asia, Southeast Asia and East Asia, will be used as case studies to illustrate regional-global linkages in Earth System Science.

The results of START regional research form a major component of the synthesis and reflect in part the outcome of research-led START capacity-building efforts. In addition, all other relevant and accessible global change research has been considered. As far as has been possible, only published research has been considered. No claim is made that all the research integrated into the syntheses has been sponsored or fostered by START. The synthesis itself is, however, that of the developing country scientists involved in START. While every effort has been made to include as much relevant material as possible, undoubtedly some will have been missed depending on the willingness of individuals to become involved, and on a variety of other normal human oversights.

Inevitably, coverage within and between regions is uneven, being a function of the interests and support given to regional scientists, the degree of IGBP, WCRP and IHDP core-programme regional involvement and the degree of national global-change-research carried out by national institutions (particularly universities) and individuals in regions. Case studies, and in some instances transect work, provide the foundation of the integration. Extensive use is made of modelling to interpolate between local findings and to gain maximum regional coverage. In global studies, the interests of individual scientists become subsumed in the greater whole. In contrast, the nature of the work undertaken in regional studies often depends upon the interests of individuals and research groups, however cohesive and comprehensive regional science planning may have been. This diversity is reflected in the four regional syntheses offered in this book. Two examples make the point. In the case of Southern Africa, it is argued that regional change is mainly the consequence of natural driving forces of global change, modulated substantially by anthropogenic influences. In the instance

of Southeast Asia, a case is made that the primary control of regional change is the human impact of economic globalisation, modulated by natural forces of change. Such contrasting approaches are a great strength and result in fascinatingly different regional insights into the way in which global change may be impinging on regions and the way in which regional change may be contributing to the global system as a whole.

Undoubtedly a regional approach is going to add substantially to understanding the future of the global system in all its complexity. It is hoped that in a small way this book on regional-global linkages in the Earth System will point the way to a sound alternative way of studying the global system as a whole.

It is appropriate to acknowledge with gratitude the considerable assistance given by many in the preparation of the book. At the Climatology Research Group, University of the Witwatersrand, Johannesburg, Wendy Job prepared the figures; Kristy Ross checked all the references. At the International START Secretariat, Washington, DC, Amy Freise helped edit the East Asia chapter; Mayuri Sobti assisted with compilation of the South Asia chapter and together with Ching Wang helped with cover design, layout, references, tables and the seeking of permissions to use copyright material. Regional maps were prepared by the US State Department. Referees of individual chapters and readers of the book as a whole are thanked for their time, effort and constructive comments.

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Washington, DC, January 2002

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Contents

Chapter 1

Regional Studies and Global Change

The phrase, 'the future of the past,' is in many ways the epitome of Earth System science and global change. For the natural component of the system, the statement is to a large extent true; for anthropogenically induced change, it is true only for the Anthropocene – the latest era in Earth's history in which the influence of humanity has come to rival that of nature. While humans have modified their environment from earliest times, the scale of that modification only assumed global proportions after the Industrial Revolution. Initially, global change science was concerned only with the global dimensions of natural and human-induced change. Increasingly, however, scientists have come to recognise that regional processes must be taken into account in global change science.

Understanding the Earth System requires that the two-way linkages between regions and the global system be well understood and predictable. Most studies of global change are undertaken thematically across limited disciplinary boundaries; few are attempted holistically across many disciplines within regions. The regional approach offers many advantages. Here several diverse linkages from four regions are presented to illustrate the power of a regional approach to Earth System science.

Global environmental change is manifested in many different ways at sub-global scales. Traditionally, the Earth System and its perturbation by humans are studied by deconvolution of the whole into functional physical and biophysical component parts (the climate subsystem, the oceanic subsystem, the carbon cycle, etc). After research into these, synthesis of the results leads to a better understanding of the fully integrated system.

An alternative approach is offered by regional decomposition. Regions are a natural scale for such assessments, as regions are often defined by shared cultural, political or biogeographical contexts, or by common resource bases and pollution sources and sinks. Regions, moreover, offer the opportunity for holistic, systems-based studies of linkages between regional and global change and so provide significant insights into the functioning of the Earth System itself.

In this book, it is demonstrated that an integrated approach to studying *regional* environmental change in its own right is a powerful tool for enhancing understanding of the Earth System at the *global* scale. Regional-global linkages are ubiquitous, bi-directional and critical for system functioning. Four case studies of individual aspects of integrated regional studies are presented to illustrate how their outcomes may contribute to a better understanding of the Earth System as a whole. The four regions are Southern Africa, South Asia, Southeast Asia and East Asia (Fig. 1.1).

Depending on the interests and backgrounds of the contributors in the different regions, different approaches have been used in the various regional syntheses. They vary significantly. On the one hand, arguments are based on the notion that regional change is mainly the consequence of natural driving forces of global change, modulated substantially by anthropogenic influences. On the other, it is proposed that a primary control of regional change is the human impact of economic globalisation, modulated by natural forces of change. Such contrasting approaches are a great strength. They result in important different regional insights into the way in which global change may be impinging on regions, and the way in which regional change may be contributing to the global system as a whole.

In the Southern African case study, the production, prolonged atmospheric recirculation of trace gases and aerosols within the region before subsequent transport out of the region are shown to have significant effects on far-removed areas of the globe. An example is given of how atmospheric circulation can link particulate nutrient sources with distant biospheric sinks to affect ecosystem functioning at the regional scale and planetary metabolism at the global scale. It is also shown how rapidly evolutionary change in lacustrine biota took place in the last few millennia and how changes in *gradients* of climatic change across the region affect water resources and agro-pastoral activities.

In the South Asian region, the frequency and magnitude of South Asian monsoon failures over the last millennium is demonstrated using high-resolution Himalayan ice-core records. These show that during the twentieth century the increase in anthropogenic activity in the regions and its adjacent neighbours to the west is recorded by a doubling of chloride concentrations and

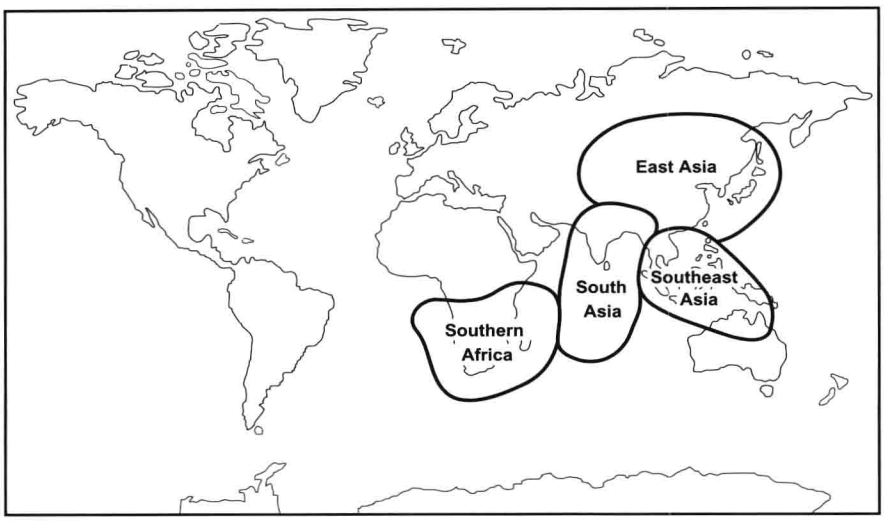

Fig. 1.1.
The four regions considered in this book

a fourfold increase in dust. Over the Tibetan Plateau it is shown that surface twentieth-century warming appears to be amplified at higher elevations. To the south, global warming appears to be manifest in an increase in near-surface maximum, rather than minimum, temperatures over large parts of the region. It is argued that changes in trace gas emissions in South Asia may have impacts on the global distribution of tropospheric ozone. Alterations in the biogeochemical balances of the Arabian Sea and Bay of Bengal following atmospheric and land transport of material offshore, and the effect of global change and climate variability on crop production are also considered.

In the East Asian case study, the most important finding to emerge is based on regional modelling. It shows how human modification of land cover over a long period of time may have resulted in changes in albedo, surface roughness, leaf area index and fraction of vegetation cover significant enough to have altered the complex exchanges of water and energy from the surface to the atmosphere. Without any changes due to greenhouse gas forcing, changes in land cover alone are shown to have had the potential to alter both vertical and horizontal moisture transport over the region and to have brought about significant changes in the East Asian monsoon.

In the Southeast Asian chapter, the importance of the human forcing of global change is taken further. Here it will be argued that globalisation of economic activity, especially through its effects on industrialisation and the commercialisation of agriculture and forestry, has been a primary driving force for change in the region. Rapid development in the region, responding to and part of economic globalisation, has lead to a situation where the trace gas and aerosol contents of the atmosphere are increasing much more rapidly than the gross domestic product, in some places at up to ten times the rate. The consequences for global change are examined.

The common message from the contrasting perspectives of the different regional syntheses undertaken is that the regions are being significantly affected by environmental change, with different impacts in different regions. At the same time, changes originating in the regions are having impacts that transcend the regions and may affect the planetary metabolism at a global scale.

Chapter 2

Regional-Global Change Linkages: Southern Africa

Peter Tyson · Eric Odada · Roland Schulze · Coleen Vogel[1]

2.1 Introduction

Unravelling the skein of global change effects in southern Africa is a non-trivial task. It is made all the more interesting since Africa is the birthplace of humanity. Southern Africa preserves an impressive five-million-year record of human-environmental interaction. From the evolutionary cradle onwards, environmental change has profoundly affected the development of the early and later hominids into *Homo sapiens* (Vrba et al. 1995). More recently, over the past two millennia, environment was a major factor affecting migrations of Bantu people into southernmost Africa. Until as late as the nineteenth century, environment continued to be a dominant factor affecting the settlement and survival of the population of the region.

Over the past few centuries the influence of environment on human activities has weakened and in many instances reversed as humans have increasingly been modifying the environment, often irreversibly. The synergies between the effects of environmental change on humans and *vice versa* are subtle, complicated and ever changing. They affect not only the manner and degree of global change taking place, but also the way in which regional manifestations of global change are expressed. This is particularly so in southern Africa, here defined as all countries in Africa south of the equator, including all of Kenya and none of the Congo (Fig. 2.1). Southernmost Africa will be taken to mean South Africa, Lesotho and Swaziland.

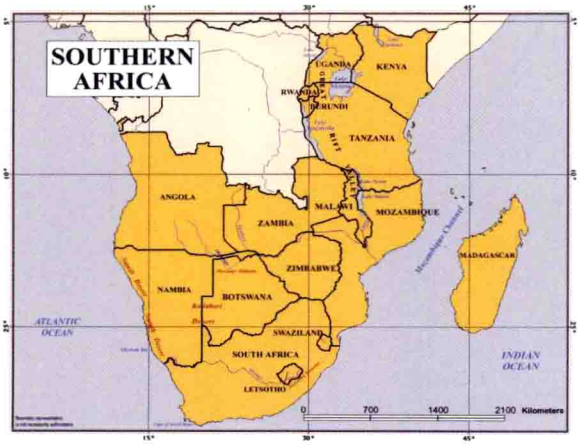

Fig. 2.1. The southern African region

One of the factors that gives regional unity to so much of southern Africa is its climate and the subcontinental circulation that maintains it and transports air, and whatever trace gases and aerosols it carries, over the region. However, regional change arising out of global change is much more than just the effect of climatic change; it is the interaction of a variety of forcings, the human dimensions of which are of fundamental importance. Nonetheless, whichever way one looks at it, a large component of the regional manifestation of global change inevitably turns out to be driven by changing climate, which is in turn driven by a changing atmosphere and land surface. In this regional study, changing atmospheric circulation, and all its consequences, will be a primary focus for the integration and synthesis that will be presented.

A synopsis of what is to be discussed may be useful. In working from the distant past to the present and future, the increasing role of human activity as a major driver of regional change is an underlying theme. After considering changing environmental conditions over the past half million years, present-day regional transport of air over southern Africa will be considered. Fluxes of trace gases into the lower troposphere, transport of these gases and aerosols, their recirculation and consequences over the region and adjacent oceans will be examined. Thereafter the oceans around southern Africa will be considered, as too will be regional changes in the hydrological cycle and terrestrial ecosystems. Human acceleration of regional change and impacts of natural and human-induced change on small-scale and commercial agriculture will be considered before finally presenting scientific surprises and major findings from the synthesis.

The 1998 population of southern Africa was around 220 million and growing at an annual rate of around 3%. This rate of growth represents a doubling about every 25 years. Since 1950 there has been a more than five-fold increase in the population of the region. To a significant degree, it is this increase in the human pressure on the

[1] *Contributing authors:* J. Arntzen, R. Chanda, C. Gatebe, T. Hoffman, J. Lutjeharms, L. Marufu, G. Midgely, P. Monteiro, D. Obura, L. Otter, T. Partridge, L. Perks, S. Ringrose, M. Scholes, R. Scholes.

land that is driving the regional environmental changes that are occurring and are likely to occur in future.

Approximately two-thirds of the regional population is rural, ranging from half in South Africa and Botswana to three-quarters in Tanzania and Lesotho, and 85% in Malawi. Throughout the region, rates of urbanisation are exceeding population growth as migration of the rural poor to cities accelerates. Most of the region's countries are among the world's low-income group, with annual per capita Gross National Product (GNP) being lowest in Malawi, Mozambique and Tanzania at around US$200 (1998 figures). Only South Africa and Botswana can be classified as middle-income countries with per capita GNP exceeding US$2 800.

With its urbanisation and industrialisation, South Africa is the largest user of motor vehicles and consumer of energy in the region. Almost all the energy used in the country derives from fossil fuel burning, mainly in large (3 600 MW) coal-fired power stations. Coal is relatively abundant in South Africa, Zimbabwe and Mozambique, while major oilfields are located offshore of Angola. Mozambique and Namibia have extensive natural gas deposits, presently unexploited. In South Africa, only 4% of electrical energy is derived from hydroelectric, nuclear or renewable sources. In contrast, several thousand MW of installed hydroelectric capacity is available on the Zambezi River at Kariba and Cahora Bassa. The countries of southern Africa share electrical power within a connected grid.

Even where electricity is available, there is a high dependence on biomass fuels (wood, maize cobs and stalks and cattle dung) for domestic energy needs. For example, in South Africa, half the households use wood as a primary fuel; this fraction rises in less-developed countries. The harvesting of fuelwood is a major factor leading to the thinning of woodlands, especially within an economically viable transport distance of urban centres. This radius is extended by the practice of reducing the wood to charcoal in primitive kilns, an activity which is a significant source of carbon monoxide, methane and other hydrocarbons. The resulting deforestation is not only threatening the stability of the environment, but also the sustainability of the biomass supply base.

The level of development and the energy mix over the region means that net carbon emissions from Southern African Development Community (SADC) countries remain low. Per capita carbon emissions are estimated to be below the global average of 1.2 t yr^{-1} (Subak et al. 1993) and are well below those of developed countries. The contribution to total global emissions is less than 2% for all greenhouse gases. With the exception of emissions from the land, South Africa emits vastly more carbon than the rest of the countries of the SADC region combined (Table 2.1). For the region as a whole, net carbon emissions from land use in the region are higher than from energy and SADC contributes about 5% to global carbon emissions from land use (Subak et al. 1993).

Given these apparently low emission figures for the region, it is tempting to minimise the contribution of the region to global change. This would be misleading. The urban and industrial emissions of aerosols and trace gases to the atmosphere, particularly in South Africa, together with those emitted by biomass burning in the tropics, have major implications for regional change. Likewise, the circulation of much natural dust over the subcontinent has the potential to bring about consider-

Table 2.1. Estimated emissions of greenhouse gases for SADC countries. First column is total carbon emissions (energy and biota) in t per capita. All other columns are gross emissions. Data apply roughly to 1988 (after Subak et al. 1993)

	Total C per capita (t)	C emissions (Mt)		CH_4 (kt)	N_2O (kt)	CFC-11 equiv. (kt)
		Energy	Biota			
Angola	1.4	2.0	12.4	334	3	1
Botswana	0.9	0.7	0.5	117	0	0
Lesotho	N/a	0.1	N/a	61	0	0
Malawi	0.5	0.3	5.2	110	2	1
Mozambique	0.5	0.5	6.5	229	2	1
Namibia	0.9	0.7	0.7	185	0	0
Swaziland	1.7	69.0	−1.1	3760	22	14
Tanzania	−0.6	0.2	−0.7	37	0	0
Zambia	0.2	0.5	6.4	1049	3	2
Zimbabwe	1.4	0.8	11.2	231	3	1
South Africa	0.6	3.7	2.3	363	2	1
SADC	1.0	78.4	43.3	6476	37	21
Global	1.2	6431.9	855.9	352398	3783	1369
SADC as % of global	82	1.2	5.1	1.8	1.0	1.5