INITIAL SCIENCE PLAN

of the

MONSOON ASIA INTEGRATED REGIONAL STUDY

CONGBIN FU and FRITS PENNING DE VRIES

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The diagram on the front cover illustrates the conceptual framework of the MAIRS program.

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CONTENTS

PREFACE

It gives me great pleasure to introduce this Initial Science Plan.

The Initial Science Plan identifies key environmental changes that affect the people and societies of the monsoon Asia region and feedback to the global system. It then pinpoints vulnerable zones, people and environments, which will be or could be affected most severely, and presents key research questions that logically follow. The plan ends with a reflection on important scientific issues to answer these questions and lists a number of actions that the Monsoon Asia Integrated Regional Study (MAIRS) will undertake in the near future. This framework is meant to serve as a road map for the next few years.

The plan lays out the foundations for an ambitious long-term research effort to meet the challenges posed by environmental changes. The plan also promotes capacity building in earth system science and broad international cooperation to increase the efficiency and the ultimate impact of the research. It is meant to be a living document; it will be debated and discussed in various scientific fora and refined over time. The framework encourages initial actions to be taken in collaboration with projects of the Earth System Science Partnership and projects of the four Global Change programs, the regional networks of System for Analysis, Research and Training, the networks formed by the Asia-Pacific Network for Global Change Research and many others. The MAIRS International Program Office will facilitate this collaboration and overall program implementation. We are proud to present this Initial Science Plan for MAIRS and hope that it will serve to facilitate and catalyse reflections, discussions and actions to understand, manage and adapt to environmental changes in monsoon Asia.

Members of the MAIRS Scientific Steering Committee, and others, have contributed to the development of the plan, which was approved by the Scientific Steering Committee in September 2006. We thank all individuals for their contributions and look forward to a productive and fruitful collaboration over the next decade to expand our scientific knowledge and contribute to sustainable development strategies for this very important and unique region of the world.

Beijing, 25 September 2006

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The Initial Science Plan was written and edited by the MAIRS Drafting Team. Congbin Fu and Frits Penning de Vries were the main editors, with substantial assistance from the other team members: Chen-Tung Arthur Chen, Louis Lebel, Michael Manton, Anond Snidvongs (members of the MAIRS Scientific Steering Committee), Ailikun (IPO) and Hassan Virji (START).

This Initial Science Plan was developed on the basis of results from the MAIRS drafting workshop held in April 2006 in Kunming, China. In addition to the editors, the following SSC-members, scientists and experts participated: Xuezhi Bai, Dushmanta Dutta, Roland Fuchs, Yukihiro Imanari, Shinjiro Kanae, Kanehiro Kitayama, Jingshi Liu, Nobuo Mimura, A.P. Mitra, Anni Reissell, Rakshan Roohi, Liqin Shao, Kedar Lal Shrestha, Shigong Wang, Yang Ying, and Renjian Zhang. Their suggestions and contributions are much appreciated. After the workshop, the SSC-members Pavel Kabat and Toishio Koike were involved in discussion of the main points of the plan. Comments and suggestions on early drafts of the Science Plan were given by Pramod Aggarwal, Penelope Canan, Howard Cattle, Eric Craswell, Jürgen Hagmann, Ian Hannam, John Ingram, Felino Lansigan and Peter Tyson. Their ideas and experiences were very welcome.

EXECUTIVE SUMMARY

Almost all aspects of societal and economic activities in monsoon Asia are critically dependent on the monsoon and its variability. There are also indications that human activities, globally and regionally, may be having a detectable impact on the monsoon system. Our understanding of the implications of these multi-level environmental changes has progressed substantially in the last decade and there is now a real potential to address critical questions about the monsoon Asia region and its interactions with the Earth System.

Key questions for MAIRS

Is the Asian monsoon system resilient to this human transformation of land, water and air? Evidence for historical changes in the monsoon system has not yet been systematically fragmented into those components which can be attributed to human activities and which cannot. Through better histories and models we are now in a position to begin exploring relative contributions or at the very least major causal clusters.

Are societies in the region becoming more, or less, vulnerable to changes in the Asian monsoon? Changes in the monsoon could have profound impacts on social development, human well-being and health. At the same time rapid economic and social development, which drive environmental changes, may also be helping to reduce vulnerabilities.

What are the likely consequences of changes in monsoon Asia on the global climate system? Environmental change in the monsoon Asia region is not independent of global changes, and vice versa. There is still little knowledge about how and how much the regional and global environmental systems are coupled.

To start answering those critical questions, we distinguish four research themes. Each theme addresses key integrated issues with a primary focus on a vulnerable geographic zone.

The research Themes of MAIRS

- Rapid transformation of land and marine resources in *coastal zones*.
- Multiple stresses on ecosystems and biophysical resources in *high mountain zones*.
- Vulnerability of ecosystems in *semi-arid zones* due to changing climate and land use.
- Changes in resource use and emissions due to rapid urbanization in *urban zones*.

Compared to inland areas, coastal zones generally offer a more gentle terrain and fertile soil, are richer in freshwater and ocean resources and offer more efficient transportation and easier access to waste disposal — aside from milder weather and attraction for tourism and recreational activities. For these reasons, coastal zones are generally more prosperous than inland areas and consequently more densely settled. The coastal zones of the monsoon Asia region are unique as they have often been shaped by millenia of human activities apropos agriculture and urban settlement. The overarching question for this zone is: *What affects rapid transformation of land and marine resources in the coastal zones in the context of global change?* We identify four priority research areas: coastal morphological changes, sustainability of coastal resources, vulnerability of coastal society and adaptation, coastal management.

The mountains of monsoon Asia and their role in the dynamics of the Asian monsoon have a profound effect on global weather and climate. Research for this zone will take into account its climatological, hydrological, ecological and social features. The overarching research question is: *What are the drivers and impacts of global environmental change on the fragile natural and human systems of the mountain zone of monsoon Asia?* We identify six priority research areas: hydrology and water availability; ecosystems and biodiversity; agriculture, forestry and food security; energy; natural disaster management; and air quality and human health.

The semi-arid region is a transitive zone between arid and humid monsoon regions; it is very sensitive to natural and human disturbances. Climatic and water cycle variations are highly correlated with the fluxes of the Asia monsoon system. This leads to the high frequency of extreme events and climatic anomalies. The overarching science question is: *How will the semi-arid zone change over the next two to three decades in the context of changes in water availability, air quality, food production, provision of ecosystem goods and services as well as occurrence of natural extremes and hazards?* We propose three priority areas for research: global warming monsoon variability increasing aridity; atmosphere-land-ecosystem interaction under changing land-use patterns; and dust aerosols regional hydrological cycle.

Urbanization is one component, and one lens through which to analyse the remarkable social development and environmental transformations of Asia in the past few decades and into the future. It is potentially very important for policy because the process of change is still unfolding and could be redirected along more benign and safe pathways. There are also significant opportunities for the rest of the world to learn lessons about non-motorized transport, high density settlements and other aspects of urban form, function and transformation in the monsoon Asia region. The overarching research question is: *Is urbanization contributing to changing, or altering the vulnerability of societies to potential changes in the Asian monsoon?* We identify three priority research areas: energy, emissions and urban air quality; urbanization, flood regimes and disaster management; urbanization and water security.

The Initial Science Plan addresses a number of issues related to the implementation of integrated research studies: data acquisition, modeling, regional studies, capacity building, international linkages and contributions to sustainable development. In this context, we address the opportunities and challenges associated with the conduct of research across the Asian region, as well as the potential benefits of interaction with the broader research community and with policy-makers and other stakeholders.

What is MAIRS?

MAIRS is the new international research program of the Earth System Science Partnership. It is established to address the questions about the coupled human and environment system in the monsoon Asia region. The program is guided by a Scientific Steering Committee and supported by an International Program Office. MAIRS will have many partners in research and other activities. Research projects and working groups are the primary producers of research results. This Initial Science Plan is the first concrete plan for research in the MAIRS program and has been approved by its SSC.

Readers are invited to contact us to explore ways and means in which we can collaborate.

CHAPTER 1

ENVIRONMENTAL CHANGE AND RESEARCH CHALLENGES IN MONSOON ASIA

This chapter highlights the significant role of the monsoon Asia region in the Earth System, and conversely, the region's vulnerabilities to global environmental changes.

1.1 Regional Perspectives on Global Environmental Change

Different regions of the world interact with the Earth System in different ways. Some regions may function as choke or tipping points (Figure 1.1) in larger biogeochemical processes. The monsoon Asia region has been postulated as important to the global climate system, among others because the Tibetan Plateau exerts considerable influence on atmospheric circulation and the Himalayas are the source of most of the major rivers of Asia.

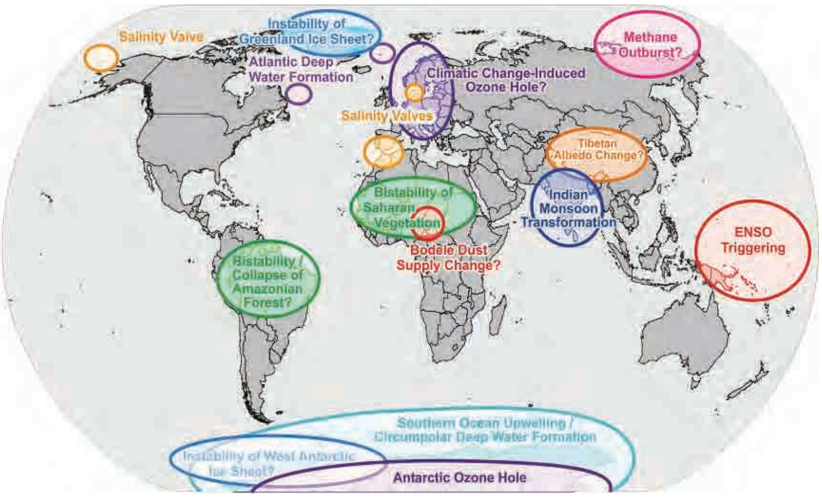

Figure 1.1 *Tipping points in the Earth System (from IGBP : GAIM Special Issue Summer 2002).*

An international, regional perspective is important to achieving a better understanding of both the Earth System and sustainable development (Tyson *et al.,* 2002). Regions whether defined by common biophysical characteristics, by shared patterns of history, language, and culture, or by the strength of recent economic relations like trade and investment, are important complementary levels of analysis to focus on nation states and biogeographical zones for the study of environmental change. In the case of the monsoon Asia region, a long history of adaptation and transformation of landscapes has resulted in perhaps a greater co-evolution of biophysical landscapes and social organization than most other locations in the world. This requires studies aimed at understanding both the region's role in the Earth System and, conversely, how societies in the region may be impacted and be vulnerable to changes largely beyond their control. For example, there have already been several important investigations at large spatial levels on the vulnerability of food systems (Aggarwal *et* *al.,* 2004), identification of hotspots and syndromes of environmental degradation, environmental threats to security (Khagram *et al.,* 2003) and consideration of regional strategies for managing these risks and impacts.

1.2 Environmental Changes in Monsoon Asia

In this document monsoon Asia region*[1] is defined as the contiguous region of Asia, including East, Southeast and South Asia, that is affected by the seasonally varying Asian monsoon circulation (Figure 1.2). The Monsoon Asia region supports the largest populations on earth, being home to 3.6 billion persons (FAO, 2006). Societies in Monsoon Asia are critically dependent on the variability of the monsoon circulation system. Seasonal food regimes underlie agricultural land-use systems and the evolution of human-dominated land-scapes. Floods also maintain ecosystems that support inland fisheries, but at the same time, constrain or make more costly, urban-industrial development in seasonal food plains.

Many of these relationships between the monsoon and human activities and well-being are once again, and even more rapidly, transformed in the current wave of industrialization and urbanization. Notably increasing intensities of energy and land use are contributing to increased levels of aerosols with implications for air quality and human health (Imura *et al.,* 2005; Ezzati *et al.,* 2004), as well as regional biogeochemistry (Lelieveld *et al.* 2000).

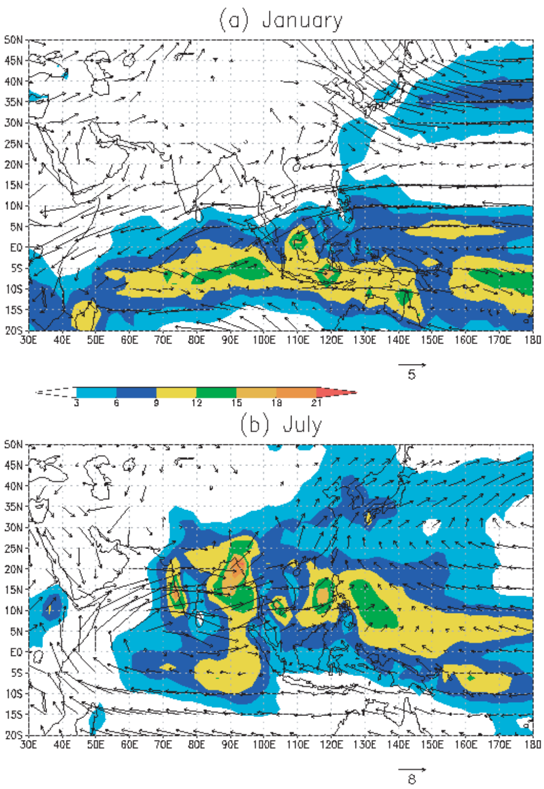

Figure 1.2. *Long term mean precipitation (mm d^{-1}) and wind (m s^{-1} at 850 hPa) in (a) January and (b) July in monsoon Asia. The scale for precipitation is in color, the scale for wind is indicated by the arrow below the figure. Precipitation dataset is from CMAP (Xie and Arkin, 1997) and wind data is from NCEP (Kalnay et al., 1996).*

The region is characterized by diverse geography that includes the world' s highest mountains and longest rivers. These rivers have been extensively modified by canals and dams to support irrigation systems, produce electricity and reduce risks of fooding in builtup areas. As in other parts of the world, riparian ecosystems, freshwater lakes and wetlands have been modified and transformed. The region has

[1] Words marked with an asterisk are explained in the glossary.

diverse habitats ranging from glaciers to deserts, extensive semi-arid zones to tropical rainforests. Significant fractions of these habitats are fragile for various reasons, including highly variable rainfall, frequent droughts and floods. Dust storms and soil erosion are endemic in the region. A long coastline with major deltas and ports includes most of the largest urban conglomerations.

Humans have extensively modified the landscape, sometimes maintaining significant levels of biodiversity and other ecosystem functions, for example, in complex agro-systems with significant conservation value in their own right (Long *et al.,* 2003; Xu and Wilkes, 2004) , and in other cases following conventional intensification approaches with their associated problems where inputs or land are not well managed.

The region is also well-known for its biodiversity that supplies the inhabitants with essential ecosystem goods and services (Millennium Ecosystem Assessment, 2005). Several major zones appear to be highly vulnerable to the combination of global environmental changes and more locally wrought transformations of land and water use. In particular, mountain zones, coastal-urban corridors and semi-arid areas are under considerable stress generated by human activity and incipient global warming impacts (IPCC, 2003).

The intensification of human activities, evident in per capita resource-use and emission levels well below those of the United States or the European Union, will in aggregate have a major impact on the global environment. How urbanization and industrialization unfold will be critical. The technologies used by firms can, and sometimes have, had major impacts on environmental performance (Rock, 2002; Rock and Angel, 2005). Urbanization creates substantial opportunities to improve energy efficiency in buildings and transport as well as reducing pressure on valuable agricultural land through higher densities of human settlement (McGranahan and Satterthwaite, 2003; Lebel, 2005). Demographic trends are also likely to be hugely important for future landscape change. Very rapid declines in fertility rates in most countries across the region, combined with high levels of rural-to-urban migration are leading to scenarios of ageing populations and local de-population in rural areas, while massive increases in densities in others.

Nevertheless, there is substantial evidence of environmental degradation, in terms of worsening air pollution in the larger cities, losses of biodiversity, desertification, disappearing wetlands, grassland overexploitation, water pollution, salinization and soil degradation. The need for further economic development underlines the prospect that many of these pressures are likely to continue rather than decline in the foreseeable decades, indicating the need for major changes in development trajectories if they are going to ever become sustainable. Decoupling social development gains from their adverse environmental impacts is going to be critical for the region and the globe.

Current scientific understanding suggests that global warming will significantly affect the variability of the monsoon system, especially the hydrological components. There are recent indications that anthropogenic impacts caused by enhanced greenhouse gas emissions and large-scale changes in land cover might be responsible, at least in part, for regional impacts such as attenuation of surface heating (Ramanathan *et al.*, 2005), declining crop production (Chameides *et al.,* 1999) and changes in precipitation (Fu *et al.*, 2002, Endo *et al.,* 2006). Extreme events, such as typhoons, may also be increasing in intensity (Emanuel, 2005). Monsoon circulation may also be important, because it transports aerosols, for example, from the urbanizing regions of Delhi through the Himalayas or out over the Indian ocean (Lelieveld *et al.,* 2000) .

The impacts of changes to the Asian monsoon are unlikely to be felt evenly across the region. Parts of society and some ecosystems are much more vulnerable than others (Adger, 2000, Adger *et al.,* 2005). Mountains, arid regions and coastal zones appear to be particularly also be vulnerable. Urban zones may also be though they often have the political power and economic resources to protect, insure and repair themselves.

However, at present there is still no strong direct evidence that the dynamics of the regional monsoon circulation system have been altered. Moreover, little is known about potential changes that might occur in the physical monsoon circulation system itself — including its variability and stability — due to global warming induced by anthropogenic activities, especially global-scale emissions and accrual of greenhouse gases in the atmosphere, regional landscape changes and associated aerosol generation. Hence, a comprehensive regional research effort is needed to understand the conjoined physical-biogeochemical-human interactions in monsoon Asia**.** Recent advances in modeling climate in the region (e.g. Fu *et al.,* 2005) augur well for such investigations.

Clearly, a dedicated effort to understand and anticipate the interactions between regional development and the Earth System could be very valuable for developing decision tools, alternative policy options and sustainable development pathways for the region.

1.3 Integrated Regional Studies in Monsoon Asia

Integrated regional studies can contribute to understanding of regional processes, regional-global linkages and overall global dynamics in the Earth System. They also provide excellent opportunities for mutual capacity building and international scientific collaboration.

The concept of monsoon Asia-based integrated regional studies was developed by Fu (1997) and was subsequently discussed at various System for Analysis, Research and Training (START) and Asia-Pacific Network for Global Change (APN) meetings, as well at a meeting of the Earth System Science Partnership (ESSP) following the Amsterdam Global Change Congress of 2001. Tyson (2001) argued the need, rationale, broad objectives and principles for framing integrated regional studies in critical regions of the world at the meeting of the scientific committee of the International Geosphere-Biosphere Program (IGBP). The Southeast Asia Regional Committee for START (SARCS) Integrated Study Plan and the Regional Integrated Environmental Modeling System for Asia (TEACOM Scientific Report 1, 2000) were early attempts in this direction.

Box 1.1 Integrated regional studies.

"Regional studies can contribute substantially to the reconstruction of the global dynamics from regional patterns; in effect integrated regional studies represent a unique way to reconstruct the Earth System from its components and are thus an essential part of the Earth System science toolkit".

From: Steffen *et al.* (2004).

The Earth Science System Partnership comprising the IHDP, IGBP, WCRP and DIVERSITAS designated START to further develop a research program on Monsoon Asia Integrated Regional Study (MAIRS). "Integration" in this context includes at least two types of analysis: (i) "horizontal integration", involving the integration of elements and processes within and across a region; and (ii) "vertical integration", involving the two-way linkages between the region and the global system. This must include considerations of regional — across national boundaries — issues and interdisciplinary implications of physical, chemical, biological and socio-economic processes and be of relevance to indigenous populations and policy communities. A range of activities, including process studies field experimentation, numerical model development and acquisition of consistent quality-controlled databases is of paramount importance.

Clearly such an ambitious effort must not only transcend disciplinary boundaries across natural and social sciences, but must also address all relevant aspects of terrestrial, atmospheric, marine, social, economic and cultural components of the Earth System. The effort must include a capacity building component that leads to sustained collaborative research partnerships. It also must engage not only START's regional networks in East Asia, South Asia and Southeast Asia and various other components of the ESSP family, but also many others not directly involved in the suite of activities of the ESSP in a research collaboration involving combined field experiments, process studies and modeling activities.

START organized a number of planning workshops on MAIRS from 2003 to 2005. These workshops concluded that, the MAIRS program should focus on a set of major challenges (Box 1.2).

Box 1.2. Major challenges for MAIRS

Is the Asian monsoon system resilient to the human transformation of the region's land, water and atmosphere?

Are societies in the region becoming more or less vulnerable to potential changes in the Asian monsoon?

What are the likely consequences of changes in monsoon Asia on the global climate system?

Meeting the main challenges requires consideration of:

- The major demographic, socio-economic and institutional drivers for change, including the development of scenarios for changes related to urbanization and industrialization, energy production and biomass burning, land-use/cover change and water resource harvesting, including dam construction.
- The effects of these drivers on regional air quality, water quality and availability, coastal resources and natural land-based ecosystems and biodiversity.
- The impacts on biogeochemical cycles and the physical climate system, including its variability at different scales.
- The impacts of global and other feedback effects on the regional biospheric life-support system, including food systems, water resources and health.
- The possible effects of these regional drivers on the global Earth System.

Therefore, MAIRS will initially focus on interactions between development and multi-level environmental changes in four key geographical zones, namely: (i) coastal zones; (ii) mountain zones; (iii) semi-arid zones; and (iv) urban zones. Within these zones, studies will be conducted related to the major societal issues of biodiversity loss, water availability, air pollution and human health, energy and transport, and natural disaster management.

The MAIRS effort will build on a set of subregional assessment exercises, undertaken jointly by START and its regional programs, and the Scientific Committee on Problems of the Environment (SCOPE). Three subregional rapid assessment projects for East Asia, South Asia and Southeast Asia have systematically reviewed current knowledge regarding regional aspects of global change in monsoon Asia. These studies are currently being published by START in different volumes recognizing that substantive work is needed to identify drivers, control points and policy levers, the workshops associated with the rapid assessment exercises recommended designing a comprehensive set of studies for the MAIRS program; these studies should be carried out under the broad theme of human well-being, vulnerability and sustainability in the rapidly changing monsoon Asia region and should focus on the most vulnerable critical zones.

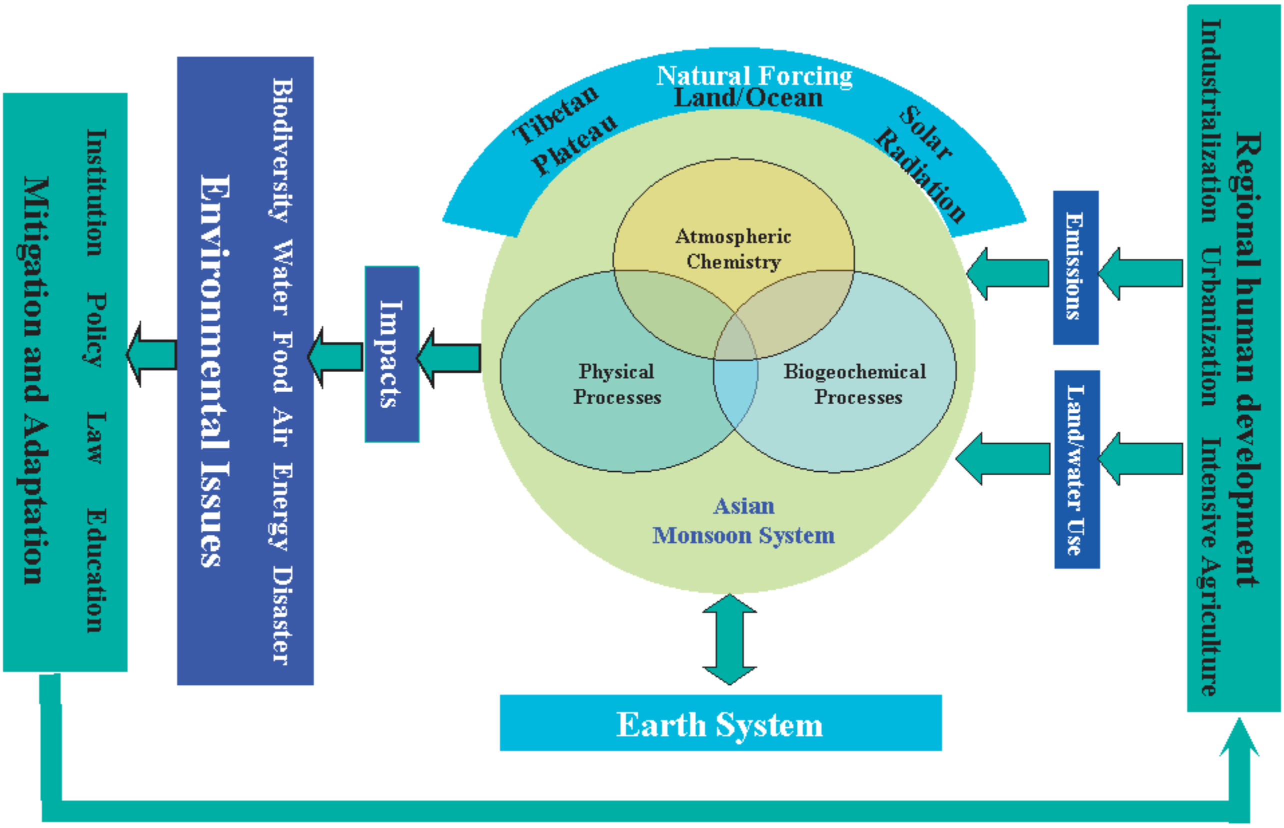

Figure 1.3. *The conceptual framework of MAIRS*

The conceptual framework for the MAIRS program (Figure 1.3) takes into account the complex relations between development pathways and their impacts on key resources (land, air, food and water) and consequences for the regional monsoon and global climate systems. It highlights that environmental change in the region is due to both natural forcing* and to anthropogenic forcing*.

1.4 Linkages to International Research on Global Environmental Change

The MAIRS program must interact with and take into consideration relevant ongoing and substantive activities under various international, regional and national agencies. These include, for example, activities of the ESSP-related projects and activities, such as GECAFS[2], GWSP, GCP, LOICZ, IGAC, iLEAPS, GEWEX/WCRP's CEOP and MAHASRI, CLIVAR/WCRP's Asian - Australian Monsoon Panel (AMMP), Clic/WCRP, as well as MRI, ABC and the CGIAR. Collaboration with such ongoing projects will ensure synergies and relevance of the MAIRS program.

The most pertinent activities and projects are described in the next chapter devoted to the critical zones of monsoon Asia where the initial MAIRS activities will occur. Subsequent sections of this document describe the strategy for implementation and the structure of MAIRS.

[2] Acronyms are spelled out in Chapter 6.

CHAPTER 2

THE RESEARCH THEMES

This chapter presents the core of the Initial Science Plan. It outlines research to be done. We propose four research themes. Each theme addresses key integrated issues in a critical geographic zone. Each issue is specific for monsoon Asia due to its biophysical, geographic and socio-economic context.

The picture of a coast line upper left is from the internet, the one showing mountains right from I. Hannam, the lower left from CNES/internet, and lower right from China Xinhua News Agency.

Section 2.1

Introduction to the Research Themes

This section presents the rationale for the research foci of MAIRS.

There are indications that human activities, especially those associated with economic development, may be having a detectable impact on the monsoon system (Giorgi *et al.,* 2001, Fu *et al.,* 2002, Ashrit *et al.,* 2003, Ramanathan *et al.,* 2005). Examples of such activities are increasing emissions of greenhouse gases and aerosols and large-scale human-induced land cover changes. Increases in emissions of greenhouse gases and aerosols and shifts in their detailed composition are being driven by rapid urbanization and industrialization in previously low-input agriculture-dominated economies. Our understanding of the implications of these major social transformations for environmental changes has progressed substantially in the last decade and there is now a real potential to address larger Earth System questions — *is the Asian monsoon system resilient to this human transformation of land, water and air?* Changes in the monsoon could have profound impacts on social development, ecosystem goods and services, human well-being and health.

At the same time rapid economic and social development that is driving environmental changes might also reduce certain kinds of vulnerabilities. The range of technologies available to governments and communities has grown tremendously. Institutional innovations like insurance and better accountability, data and information systems, better communication infrastructure and better observation systems could further reduce key vulnerabilities or be the basis of adaptation to future changes in the monsoon in Asia and the global environment. But involuntary risks are also modified and shifted by development (Lebel *et al.,* 2006). The improved understanding of social change at multiple levels in the region needs to be directed at new questions — *are societies in the region becoming more, or less vulnerable to potential changes in the Asian monsoon?*

Environmental change in the monsoon Asia region is not independent of global changes, and vice versa. There is still little knowledge about how and how much the regional and global environmental systems are conjoined. The third overarching question is therefore: *What are the likely consequences of changes in monsoon Asia on the global climate system?*

The way societies in the monsoon Asia region use land, water and energy in the coming decades will make a difference. MAIRS will focus its research efforts on four research themes. These were selected because they cut across resource management issues directly and are potentially impacted by changes in the monsoon system and other global environmental changes (Table 2.1.1). The research themes are:

- Rapid transformation of land and marine resources in the coastal zones.
- Multiple stresses on high mountain ecosystems and biophysical resources.
- Degradation of land and water resources in semi-arid regions as a result of changing climate and use.
- Changes in resource use and emissions resulting from rapid urbanization.

The geographic location of the four zones in monsoon Asia is shown in Figure 2.1.1. The four research themes cast geographical shadows that partially overlap. For example, there are many significant "urbanizing" regions along coasts, but also some in more inland areas surrounded by mountains or in semi-arid regions. At the same time the overlaps draw attention to different geographical regions: the major delta areas, the semi-arid zones and the Tibetan Plateau and Himalayas. Agriculture and its transformation is an important feature of all four zones.

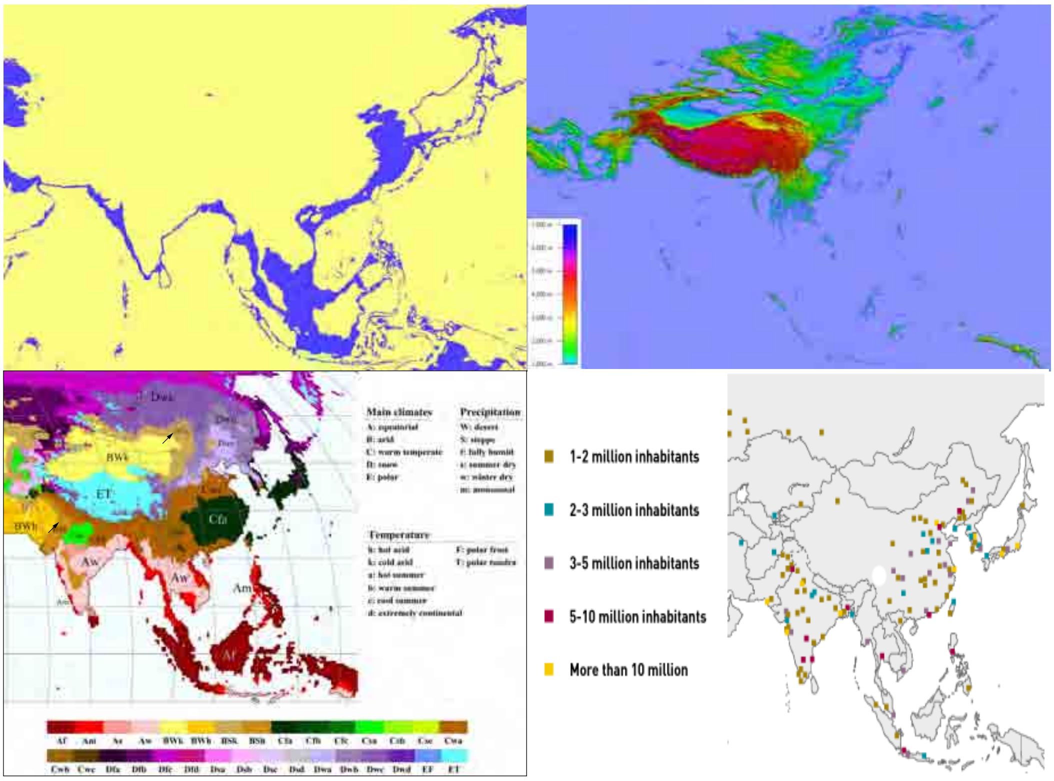

Figure 2.1.1. *Approximate location of four zones in the monsoon Asia region: Upper left: the water-part of the coastal zone is shown in blue, the land part is not shown. Upper right: mountain zones are shown in brown, red and deep blue (source: see Figure 2.3.1). Lower left: semi-arid zones are shown by codes BSh and BSk according to the Köppen-Geiger climate classification (from Kottek* et al., *2006). Lower right: Location of major cities is a proxy for the urban zones.*

Water, energy and food security are cross-cutting issues of the MAIRS program, but each has its own set of special features in each zone. Air quality and health as well as disaster risk are important in each zone but they involve different phenomenon respectively. Biodiversity is important in all zones except the urban zone. Urbanization as a process of change, however, may have significant implications for biodiversity elsewhere — both positive and negative (Table 2.1.1).

The following sections describe the initial science plans for the research themes: Key issues and scientific questions are identified and actions are proposed for near-, mid- and longer-time scales. Within each theme the emphasis is on the interaction of components of the Earth System, including human activities, through combined activities that involve enhanced observation and measurement programs, field experiments and numerical modeling.

Table 2.1.1. *The key issues for environmental change in monsoon Asia occur in all zones but with different aspects and relative importance. A "zone*" is the total geographic area with particular biophysical and socio-economic characteristics. Each of the four zones is not contiguous and together they do not cover the total surface of the region.*

Zone / Issue	Coastal Zone	Mountain Zone	Semi-arid Zone	Urban Zone
Water	• Saline intrusions • Reduced river outflow • Eutrophication	• Increased vulner-ability of "water towers" monsoon asia	• Larger variability in precipitation • Decline in ground-water • Pollution	• Urban and industrial pollution
Energy	• Flooding of coastal oil and gas fields • Destruction by oil and gas platforms • Reduced man - grove area and other woody fuel biomass	• Deforestation for energy use		
Food security	• Red tides and harmful algal blooms • Declining fish catches • Less farmland	• Increased vulner-ability of subsis-tance farming	• Reduced crop pro-duction	• Competition for prime agriculture land
Air quality and health	• More heat related and tropical dis-eases	• Urbanization in isolated areas	• Damaged by dust aerosols	• Air pollution from transportation, manu-facturing
Disasters	• Sea-level rise • Land subsidence • Coastal erosion • Stronger typhoon	• Risk of glacia lake outburst floods	• Drought • Dust storms • Snow storms	• Increased vulnerab-lility; protection cost; • Modified flood re-gimes
Biodiversity	• Hypoxia and an-oxia • Dams blocking migration of aquatic biota • Loss of ecosystem functions and serv-ices	• Vulnerability of ecosystems to cli-mate change		

Section 2.2

Coastal Zones: Rapid Transformation of Land and Marine Resources

This section contains the Initial Science Plan for MAIRS Coastal Zones' research.

2.2.1 Introduction

The coastal zone is where the land, rivers, atmosphere, seas, sediments and biota meet. The spatial and temporal heterogeneity is considerable. There is evidence that the food resources in the coastal zone may have been important for the evolution of the human brain (Crawford *et al.,* 2001) and that humans dispersed themselves around the earth primarily along coastal zones (Stringer, 2000). Thus, riverine transport of material to the coastal zone may actually have created the conditions necessary for human evolution (Steffen *et al.,* 2004). Approximately, 40 to 60% of the global population live within 100 km of the coasts (Shi and Singh, 2003; Steffen *et al.,* 2004). In many countries of monsoon Asia, the percentage is even higher, especially for most island nations. For the sake of simplicity, *the coastal zone is here defined as the region between 100 km landward from the coast and 200 m in water depth seaward of the coast.*

Compared to inland areas, coastal zones generally offer a more gentle terrain and fertile soil, are richer in freshwater and ocean resources and offer more efficient transportation and easier access to waste disposal — aside from the milder weather and attraction for tourism and recreational activities. For these reasons, coastal zones are generally more prosperous than inland areas, and impoverished people are consequently often drawn to the coast. But the coastal zones of the monsoon Asia region are unique because they are subject to the influence of monsoons. Monsoon rains sustain the lives of millions of people and nurture the local plants, animals and freshwater biota. Too much rain, however, results in floods and mud flows. Conversely, failure of the monsoon rains often means droughts and spells disaster for humans and other lifeforms.

Currently the 440,000 km of the world's coastal zones are threatened by the combined effects of population growth, urban and agricultural development, industrial expansion, recreational pressures, offshore waste disposal, the exploitation of freshwater and marine resources, coastal erosion, overextraction of groundwater and the impacts of rising sea levels. It is here that many of the ill-effects of current economic growth and associated activities are particularly intense.

In coastal regions, the documentable evidence of environmental changes attributable to the explosive growth of human populations and their drive to alter their environments can be quantified in terms of reduced water quality (saltwater intrusion, eutrophication, toxic contamination and alterations in volume and timing of freshwater inflow); destruction and degradation of such critical habitats as estuaries, coastal wetlands, coral reefs and beds of macrophytes; the collapse of stocks of important fish and shellfish; deforestation; land subsidence; and erosion of topsoil. These threats will grow in the future as the populations of coastal zones continue to increase rapidly.

In addition, typhoons, storm surges and tsunamis have maximum impact on coastal zones, often resulting in huge losses of human life in the monsoon Asia region. Evidence indicates that sea levels are rising and major typhoons are stronger and occurring more frequently because of warmer seawater (Emanuel, 2005). Meanwhile, humans have overexploited groundwater, which has resulted in land subsidence and seawater intrusion. Humans have also removed large swathes of mangroves and have reclaimed land from wetlands and coral reefs, resulting in a loss of natural buffers against sea-borne disasters.

In addition, construction of dams has blocked the transport of sediments, exacerbating the issue of coastal erosion. Any diversion of freshwater also results in smaller downstream transport of water, carbon and nutrients, which may reduce the buoyancy effect and result in a weaker upwelling, which is the major source of nutrients that support new biological productivity on the continental shelves. Smaller amounts of riparian discharges of carbon and nutrients also mean less food for aquatic creatures and a loss of biodiversity.

Agriculture and aquaculture on land may also affect marine biota because nutrients used in these activities are transported to the coastal zone by rivers, surface runoff and submarine groundwater discharge, resulting in harmful algal blooms, hypoxia, or even anoxia at times. These symptoms create havoc among marine animals and pose a serious threat to human health as well. Higher temperature and acidification of seawater due to the penetration of anthropogenic CO_2 (Chen *et al.,* 2006) compound the issue, especially for corals and plankton that have calcareous shells or skeletons. Needless to say, biodiversity and fisheries suffer.

Identifying and quantifying the aforesaid issues, and developing scenarios of change, including anthropogenic and natural drivers, for stakeholders require capacity building, research, analysis, interpretation, networking and synthesis that cross the interface between natural and socio-economic sciences. As the scale and intensity of human-induced changes increase, conflicts among different user groups become more intense. Such conflicts result in major equity problems that, if unresolved, may lead to increased violence and increased poverty. There is a clear need for mitigation measures, better management and enforceable regulations in order to achieve the sustainable development of coastal zones. The greatest need for coastal management initiatives is in tropical countries, because it is here that the process of environmental change is most rapid, and it is here that most of the increase in human population that is expected by 2040 will be concentrated (Olsen, 1993). Controlled development of this zone is therefore an urgent issue.

Some overlapping with sister projects such as LOICZ, SOLAS, IMBER, GCP, GWSP and GEOSS is unavoidable. MAIRS should take advantage of and build upon the results of these projects and collaborate with them whenever possible, *vis-à-vis* implementation strategies.

2.2.2 Priority Research Areas

Four priority research areas have been identified: Coastal morphological changes, Sustainability of coastal resources, Vulnerability of coastal society and adaptation, Coastal management (Box 2.2.1). Each of these research areas is subjected to global environmental influences, including the Asian monsoon, its inter- and intra-annual variabilities and possibly to any changes in these natural forcings* in the future. Moreover, local anthropogenic drivers within the coastal zone itself as well as drivers from the catchments upstream of the coastal zone could act in concert with the global atmospheric forcing and/or may reduce the capacity of the coastal zone to cope with global changes in the future. Propagation of multiple impacts, resilience, adaptation options and sustainable management of the coastal zone in the MAIRS region would be research questions in this integrated regional study.

Box 2.2.1. Priority areas in the Coastal Zone

- Coastal morphological changes.
- Sustainability of coastal resources.
- Vulnerability of coastal society and adaptation.
- Coastal management.

2.2.2.1 Coastal Morphological Changes

Rationale. Asian coasts are characterized by large and rapid changes in coastal geomorphology in many ways including erosion and the construction of large-scale engineering works (Saito, 2006). They host large deltas, many of which have suffered from coastal erosion over past decades — this opposes the natural deltaic function. The recent erosion is caused by decrease of sediment supplied by rivers, which is in turn due to river catchment development such as dam construction (Figure 2.2.1). For example, the Huanghe River in China, which was once the second largest river in the world in terms of sediment discharge, delivers less than 10% of its past discharge because of dam construction and irrigation. This reduction has caused serious coastal erosion around the river's mouth in the Bohai Sea. The rich Yangtze River Delta, deposited over the last two to three thousand years, may be devoid of its major sediment supply after the completion of the Three Gorges Dam which will trap 350×10^6 tonnes of sediment a year.

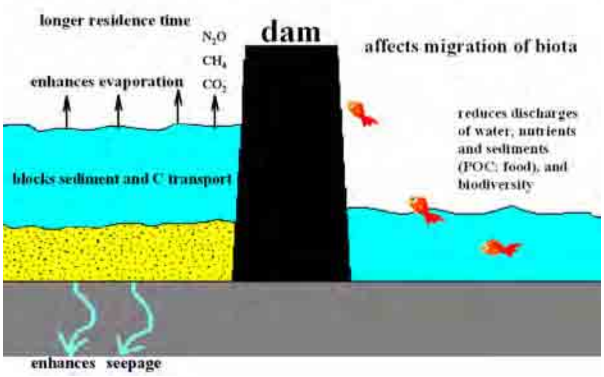

Figure 2.2.1. *Dams not only have local environmental effects but also affect the downstream transport of sediments and particulate organic carbon (POC) which nurtures the rich delta near the river mouth. (Source: C. T. A. Chen)*

From a global change viewpoint, acceleration of beach erosion due to sea-level rise is a major concern. Sealevel rise in the past has possibly contributed to the exacerbation of coastal erosion. Although it is difficult to separate effects, many areas face relative sea-level change that combines global and local changes in mean sea level relative to the land including land subsidence and crustal motion. For example along the northern coast of the Gulf of Thailand, extraction of groundwater has caused land subsidence including the river mouth of the Chao Phraya River, where more than 60 cm of subsidence occurred from the 1960s to the 1980s. This resulted in severe coastal erosion and the shoreline retreated by 700 m until the early 1990s (Vongvisessomjai *et al*., 1996). As sea levels are estimated to rise by 9 to 88 cm globally by 2100, this threat will be particularly serious on the coasts where the combined effects of ground subsidence and decreased sediment supply from rivers are manifested.

Other drivers of coastal changes are human-induced development of coastal zones such as seaport and airport construction, land reclamation for industrial and agricultural use, conversion of mangrove forests to aquaculture ponds and construction of dumping sites in the shallow waters. Even though the changes in coastal morphology in each location are only of local scale, the accumulation of such changes will have significant impacts on the physical and biological processes which support the well-being and security of the coastal environment and human society. Therefore, there is an urgent need for MAIRS research to address these issues to ensure the sustainable development of coastal zones.

Drivers for Changes. In the context of the coastal zones of monsoon Asia, the major causes related to variabilities and changes in global climate and Asian monsoon systems are: (i) Sea-level rise, (ii) Changes in air and sea temperature, (iii) Changes in the monsoon and other wind systems.

The major anthropogenic causes are: (i) River catchment development, (ii) Coastal zone development, e.g. port construction, land reclamation, groundwater pumping, land subsidence (Figure 2.2.2) and navigational channel dredging, (iii) Reduction of sediment transport.

Figure 2.2.2. *(a) A house in an area where land subsidence is severe due to overpumping of groundwater (picture by C.T. A. Chen). (b) Land with telephone poles has become submerged due to subsidence (picture by Ajira Tiangtrong).*

Monsoonal change and variability could affect the coastal circulation that is essential in the transport and redistribution of sediment in coastal areas. Coastal circulations in the MAIRS region frequently reverse between the two monsoon seasons. Changes in monsoon system, freshwater input (buoyancy forcing) and human activities would lead to changes in coastal circulation and the hydrological regime. Vice versa, changes in coastal morphology due to the construction of ports and land reclamation could lead to changes in coastal circulation.

Changes in riverine discharges of sediment due to global and local causes in the catchment may have serious impacts on coastal morphology. The decrease in sediment delivery to coastal zones on the one hand could induce coastal erosion, further exacerbated by sea-level rise. On the other hand, the increase of sediment input from land could induce delta accumulation and shoaling, resulting in the changes of pathways of rivers, which has irreversible effects on the coastal zone as well.

Research Questions. In response to these situations, MAIRS poses the following questions:

How are physical processes which control coastal morphology affected by global, regional and local environmental changes?

How do changes in coastal morphology affect the function and services of biota and ecosystems?

2.2.2.2 Sustainability of Coastal Resources

Rationale. Natural ecosystems and resources in the coastal zones of monsoon Asia that could be affected by changes in global environmental forcing and the Asian monsoon are:

Coastal ecosystems: In monsoon Asia, the coastal ecosystems are diverse, ranging through tropical, subtropical and temperate coastal ecosystems, such as mangroves, coral reefs, sea-grass beds, brackish and marine wetlands and marshlands (Ong, 2006). These ecosystems are rich in biodiversity and some ecosystems are habitats for rare and endangered species. These ecosystems also provide goods and services for human society, security and economies within and outside the coastal zone.

Coastal seawater, coastal freshwater resources and coastal groundwater aquifers: The quantity and quality of these waters (such as degree of eutrophication) will have strong impacts on the health of human residents as well as visitors to the coastal area. Living organisms and natural ecosystems could also be affected by deteriorating water quality. Tourism has become a major source of income in many coastal areas in monsoon Asia and most of the business depends on the quality of coastal resources and the environment.

Coastal biodiversity in many coastal societies in monsoon Asia is an important source of food, fibre, energy and income for subsistence livelihoods. In addition there is potential for tourism, commercial and pharmaceutical uses.

Coastal upwelling zones are quite common in monsoon Asia. These areas have high productivity and are rich in fishery resources. Changes in monsoon strength and freshwater input from land to sea, including submarine groundwater discharge, may lead to changes in upwelling/downwelling and affect vertical nutrient enrichment in these areas.

Drivers for Changes. The main drivers of the sustainability of natural resources in the monsoon Asia coastal zone may be separated into effects directly related to global climate, including the Asian monsoon, and anthropogenic impacts that occur within the coastal zone or in catchments upstream of the coastal zone.

Forcings that are the consequences of global climate change and monsoon variabilities are:

- Change in coastal oceanographic processes that could affect horizontal and vertical transports of larvae and juveniles, supplies and distribution of nutrients and food for living organisms.
- Seawater temperature rise due to atmospheric warming and changes in the heat transport processes

in coastal and continental shelf waters.
- Change in salinity, buoyancy and vertical stratification of water due to different rainfall and evaporation patterns in coastal areas as well as surface and submarine freshwater discharge from catchments.
- Acidification of seawater due to higher partial pressure of dissolved CO_2.

Anthropogenic causes within the coastal zone or in the catchments upstream that may make the natural resources in the coastal zone more vulnerable to global and monsoonal changes include:
- Upstream/downstream transports (inflows) of freshwater, nutrients, carbon and organic materials, pollutants and sediments.
- Agriculture and aquaculture activities in the coastal zone and in the catchments.
- Unsustainable or destructive harvesting of living resources, such as clearing of mangrove forests (Figure 2.2.3), dynamite and toxic fishing, use of small mesh nets, overexploitation of reproductive stocks.
- Urbanization/mega-cities in coastal areas that fragment ecological continuums, causing pollution stresses.
- Changes in coastal morphology and morphodynamics owing to global and local causes (outcomes of Research Area 2.2.2.1).

Figure 2.2.3. *The remaining "protected" mangrove tree of a mangrove forest that existed as recent as fifty years ago. (Source: C. T. A. Chen)*

Research Questions. Based on the above issues, the following research questions have been formulated:

What are the interactions among global, monsoonal and internal effects in coastal zones and their consequences on natural resources and ecosystems in the coastal area?

What will be the degree and extent of the changes in coastal resources and ecosystems as a result of natural and anthropogenic forcing?

What will be the most appropriate system to monitor coastal resources and ecosystem changes in the monsoon Asia region?

How will construction of dams, irrigation agriculture and other diversion of freshwater on land affect the surface runoff and the submarine discharge of groundwater?

2.2.2.3 Vulnerability of Coastal Societies and Adaptation

Rationale. The presence of human society in the coastal zones of the monsoon Asia region may raise concern about the vulnerability of coastal societies and adaptation apropos several issues (Box 2.2.2):

The Asian monsoon and the El Niño Southern Oscillation (ENSO). Important atmospheric and oceanic phenomena that occur in the monsoon Asia region, such as the Asian monsoon and the ENSO, are highly variable. Within the region, the occurrence and variability of these phenomena induce a tendency for increased extreme climatic events, such as frequent droughts and heavy rains.

Climate changes and sea-level rise. Further concerns are that the threats will be exacerbated by climate change and sea-level rise in this century. Countries surrounding the Indian Ocean incurred serious damage by the Indian Ocean Tsunami resulting from the off-Sumatra Island Earthquake on 26 December 2004, which killed more than 220,000 people and destroyed the personal assets of several million people. This overwhelming event illustrated a number of aspects related to coastal vulnerability, such as the capacity for disaster prevention, the preparedness of coastal societies against disasters, the relationship of coastal protection and economic development and land-use planning.

Rapid human-induced changes in coastal topography and ecosystems. In the past 30 years, coastal resources such as mangroves, coral reefs and fisheries have been depleted on a large scale and this has become a critical issue for the region (Chen, 2002). For example, more than 60% of Asia's mangroves has been converted to aquaculture farms (Ong, 2006) while the combined effects of higher temperature and pollution of seawater threaten coral reefs; de facto more than 80 to 90% of coral reefs in some countries may already be threatened. Asia and the Pacific region are losing resource bases to support people's everyday lives and future economic development as well as rich biodiversity in the coastal zones. If such human-induced pressures are heightened and superimposed by global climate changes, the effects will be devastating for the sustainability of the coastal environment.

Large-scale and rapid growth of the coastal population and mega-cities. The Asian population has grown from 1.44 billion to 3.69 billion from 1950 to 2000 — more than half of the world's population today. Currently more than one-half of the region's population lives on the coasts, and the coastal population is rapidly increasing, thus putting a great deal of pressure on the availability of freshwater. Inland migration to the coasts is a key factor for this increase. In addition, most of the world's largest cities are located on coasts and in some areas they have expanded into coastal mega-cities, most of which are located in Southeast Asia.

Rapid coastal development. Economic development and related land-use change mean the increased exposure of human population and socio-economic activities to natural and human-induced hazards. Therefore, an important challenge in the context of sustainable development is how to reduce the vulnerability and to increase the resilience of expanding coastal societies in face of global changes such as climate change and variability.

Box 2.2.2. Multiple interacting effects contribute to the vulnerability of the coastal zones:

- Climate changes and sea-level rise including more intense or frequent tropical cyclones.
- Morphological changes in the coastal zones.
- Changes in and degradation of ecosystems.
- Implications for infrastructure.

Research Questions. Given the huge areas, diverse and rich ecosystems, high human populations and socio-economic activities in Asia and the Pacific region, it is of critical importance to study the vulnerability of coastal human societies and their sustainable development. Generally, this study consists of several components such as assessment and estimating vulnerability, analysis of the factors that affect the vulnerability and resilience of coastal societies, identification of the most vulnerable areas and adaptation to the impacts of environmental changes. The important research questions and concomitant issues that capture the specific nature of the vulnerability relevant to MAIRS are listed hereunder:

What are the vulnerability and future risks on a regional scale, and how different are they between subregions and/or countries (comparative vulnerability assessment)?
Combined impacts of multi-forcing and multi-risks.
Studies on regional and collective adaptation.

2.2.2.4 Coastal Management

This research area addresses the question of how human societies in the monsoon Asia region may better manage their coastal zones and thereby adapt and reduce their vulnerability to global environmental change. A case in point is that the maximum value of the runoff of the largest river in Taiwan, the Kaoping River, was on the rise whereas the discharge in the dry season was on the decline before 1991 (Fig. 2.2.4). The higher peak flow in the wet years and lower minimal discharge in the dry years may be a result of deforestation (Newson, 1997), which has reduced forest cover in Taiwan from around 90% to about 52% in the last century, as the precipitation pattern has no clear trend. In 1991, however, the authorities changed the orientation of the forest management policy from production-based to conservation-based activities. Perhaps as a result, the frequency of floods and droughts in the coastal plains has declined noticeably since the enactment of the order (Chen *et al.,* 2004). Clearly, the combination of high-intensity use of all natural resources in the coastal zones of the Asia monsoon region as well as the aggravating effects of the monsoon system (mainly through wind, precipitation, currents) require appropriate management of the coastal zone (Chen, 2002, Ablan, 2006; Chiau, 2006).

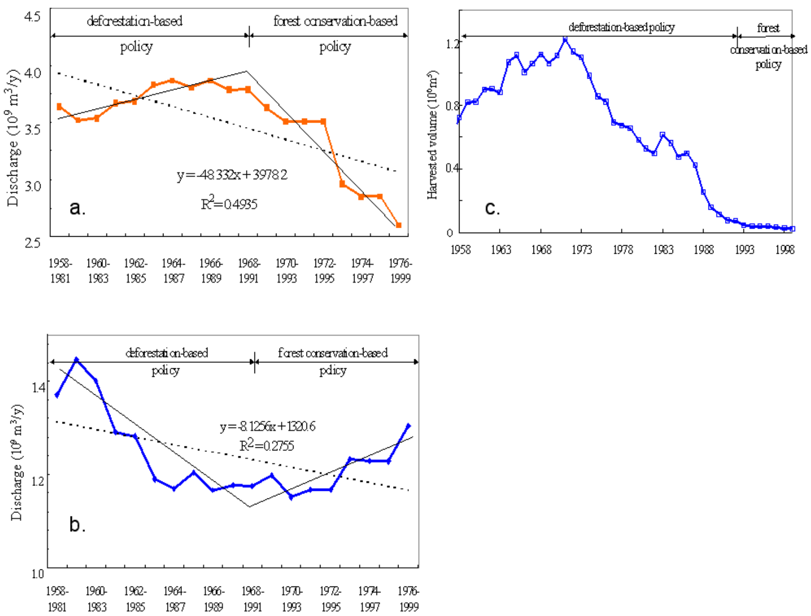

Figure 2.2.4. *Projected annual discharge of (a) flood and (b) drought of 100-year return frequency on a tributary of the Kaoping River in southern Taiwan. The solid lines show the increasing and decreasing trend, respectively, and the dashed lines show the long term decreasing trend. (c) Annual harvested volume of lumber (From: Chen et al., 2004).*

For MAIRS it is important to consider management models from different clients/stakeholders— governments (such as through policies, subsidies, monitoring and enforcement), private enterprises (such as authorities on coastal infrastructure, on nature reserves and on tourism) and local communities (for fisheries, tourism, mangrove plantation, rehabilitation of degraded coastal land). Sociological and economic research as well as research on legal frameworks is at the heart of this research area.

Research Questions. Broad issues to address, all related to the Asian monsoon system, could include risk management by societies and ways of adaptation to reduce vulnerability, integrated basin and urban zone management for minimal impact on the coastal zone, community-based management of coastal resources, negotiation and confiict resolution of interests in use of coastal zone resources and the exchange of best management practices. Related research questions are:

- *What are the policies and institutional frameworks that could help to reduce vulnerability to the monsoon and hence best manage the natural resouces in the Coastal Zones?*
- *What are the needs of different clients and stakeholders in coastal zone management, in terms of human and institutional capacity. Scientific concepts and data. Monitoring to manage coastal zones using research insights from earth system science?*
- *What generic information and what monitoring information can be shared across the region?*
- *What are the integral cost and integral benefits of appropriate coastal zone management?*

2.2.3 Implementation Issues

Apart from the studies of regional characteristics as well as the processes and mechanisms involved, all implementation plans must develop suitable methods and techniques for both monitoring and investigating. Selection of key study areas for measurement/observation, design of conceptual and process models, establishment of a multilayer database and generation of appropriate scenarios of future changes are common features of the implementation plans. Details organized around the four priority research areas are given below:

Coastal Morphological Changes

Develop an observation system to monitor the changes of physical parameters in the coastal zones such as sea temperature, salinity, wave action, tides and tidal currents.

Understand the changes in physical processes such as near-shore currents, sediment transport, fresh water dispersion, sand mining, land reclamation and material circulation caused by morphological changes. Their feedback to morphological changes should also be studied.

Estimate the changes in disaster reduction functions of coastal morphology such as sandy beaches, mangroves and coral reefs.

Study the combined effects of local changes and those induced by global changes such as monsoonal changes and sea-level rise.

Compare monitored data with simulated results from appropriate models.

Develop predictive models to estimate future changes of the aforesaid function.

Monitor and determine how the morphological changes affect the functions of coastal biological systems such as water purification and primary production.

Study how coastal morphological changes affect fisheries via impacts on biological functions.

Design environmentally friendly options for coastal construction and coastal protection.

Sustainability of Coastal Resources

Develop and apply integrated approaches and models to assess integrated impacts between global and local forcings on each of the major resources and ecosystems in the monsoon Asia coastal zone.

Assess the risk/vulnerability of coastal ecosystems subjected to integrated global/local environmental changes.

Determine a "pre-global change" baseline and rate of change for each major resource and ecosystem.

Determine the capacity of each natural resource/ecosystem in the monsoon Asia region to with stand integrated global/local changes.

Develop common remote sensing and *in situ* monitoring approaches/protocols for coastal ecosystems in the monsoon Asia region.

Vulnerability of Coastal Societies and Adaptation

Discover how many people will be affected and what the level of economic losses will be according to different development paths of the coastal zones in the time-frames of 2030 and 2050.

Determine hotspots of impacts of changes (the monsoon system, climate, extreme events and sea-level rise).

- Evaluate what determines the special nature of the vulnerability and resilience of the coastal community in the monsoon Asia region.
- Study whether indigenous knowledge can be applied to increase the resilience and reduce the vulner ability to future impacts in Asia and the Pacific region.
- Determine how different forcings, such as monsoon and climate change and local changes in coastal morphology and ecosystems interact with each other in terms of their vulnerability.
- Find out whether different development paths change the degree of future risks and vulnerability of the region generally and in specific areas.
- Formulate adaptation options relevant to the monsoon Asia region.
- Compute how much the adaptation can reduce impacts and vulnerability.
- Evaluate adaptive capacities especially important to the region.

Coastal Management

- Find out the needs of different clients and stakeholders, in terms of human and institutional capacity.
- Evaluate scientific concepts and generate data.
- Discuss common and specific adaptation options with stakeholders.
- Monitor and manage coastal zones using research insights from Earth System science.
- Create generic and monitoring information that can be shared across the region.
- Calculate the integral costs and benefits of appropriate coastal zone management.
- Enhance human resilience and adaptive capacity.

2.2.4 Regional and International Links

The focus of MAIRS is on integrated studies across monsoon Asia; this clearly calls for regional and international collaboration (Box 2.2.3). For instance, monthly suspended sediment concentration has decreased significantly in several gauging stations downstream of the Manwan Dam on the Lancang River in China (the upstream of the Mekong River; Lu and Siew, 2006). The Mekong River Commission, an intergovernmental scientific body located in Phnom Penh, Cambodia has reported that fish catches between November 2003 and March 2004 were only one-half of the usual levels. The Mekong River Commission realizes that poor monsoon rains in 2003 may have been responsible for this but contends that there is "little doubt that Chinese dams upstream play a role" (Pearce, 2004). It follows, naturally, that regional and international effort is required to better understand the issues and to effectively design mitigation measures.

Box 2.2.3. Collaborative research in the Coastal Zone.

Essentially all nations in the monsoon Asia region are experiencing changes in their coastal, fluvial, marine and estuarine systems that jeopardize sustainable development, human health and safety, and the capacity of these ecosystems to provide products and services valued by society. Such trends reflect the combined effects of both global change-related processes and human uses. Because these changes, their causes and their effects often transcend national or even regional boundaries, *regional and international links and active collaboration are required for sustained, routine and reliable observations of fluvial, coastal and oceanic systems on various scales ranging from local to regional.* Implementation of this study will make an important contribution to sister global change-related projects such as LOICZ, IMBER, SOLAS, GCP, GWSP and even GEOSS. Capacity-building programs will boost the research capacity of many developing nations in the MAIRS region.

Monsoon Asia coastal zone projects should demonstrate a strong linkage with global coastal zone research programs and their core/joint projects, especially LOICZ. This is to be expected as LOICZ is the key coastal program of its type. There should also be linkages with IMBER, SOLAS, GWSP, GCP and GEOSS where a coastal component either exists or is under development. For instance, GCP and GWSP are already co-sponsoring with SARCS the project on Carbon and Water Issues in Southeast Asia. In addition, the APN and SARCS have funded projects related to fluvial, coastal and oceanic systems and coordination or exchange of information is called for. Linkage with the regional networks of START (SASCOM, SARCS and TEACOM) is particularly important in the area of capacity building.

Section 2.3

Mountain Zones: Multiple stresses on high mountain ecosystems and biophysical resources

This section contains the Initial Science Plan for MAIRS Mountain Zones' research.

2.3.1 Introduction

The mountainous regions of monsoon Asia extend from the tropics to mid-latitudes. They can be delineated by a range of factors involving climatology, hydrology and ecology. For simplicity, for MAIRS *the monsoon Asia Mountain Zone is defined as those areas lying more than 1,000 m above sea level* that are affected in some way by the Asian monsoon. Thus, the region includes the mountains of the Himalayas, Karakorams, Hindu-Kush, Pamires, Kunlun, Tienshan, Qinling, Daxinganling and Changbaishan from southwest to northeast, and the mountainous maritime areas of China including Taiwan, Indonesia, Japan, Korea (N&S), Malaysia, and the Philippines (Figure 2.3.1).

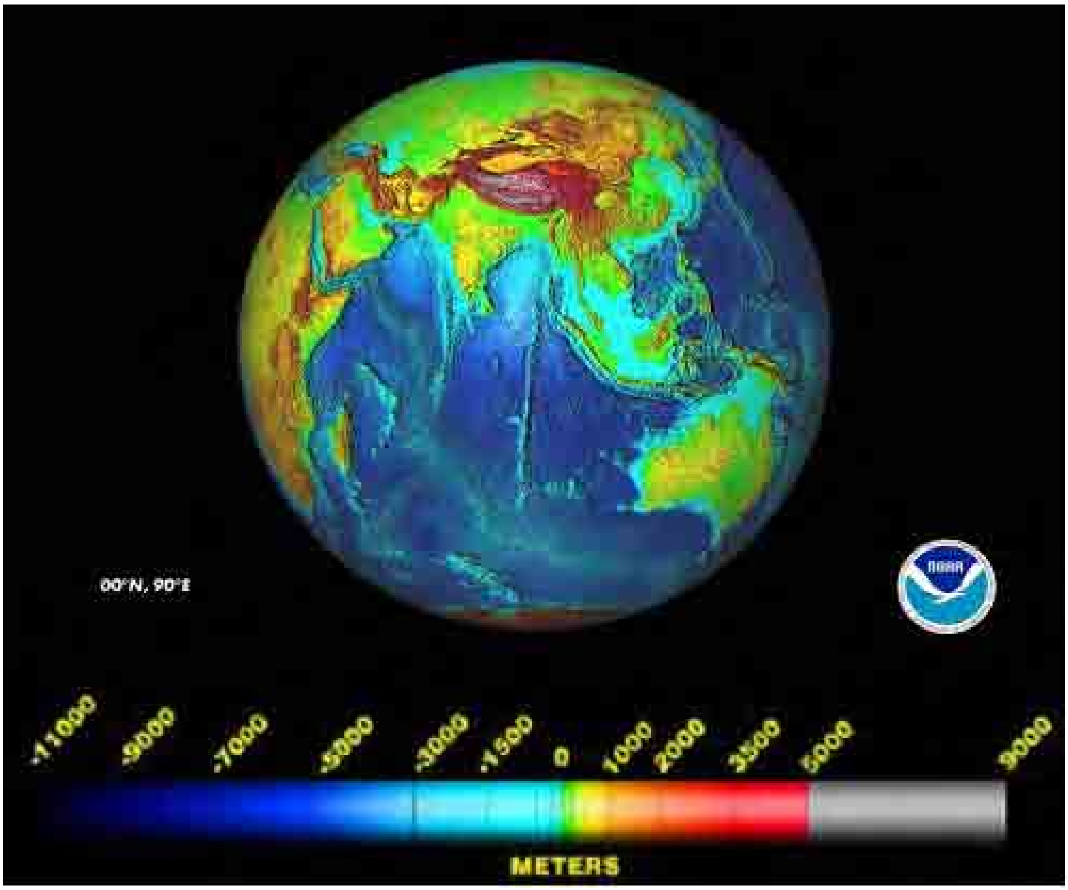

Figure 2.3.1. *Map of the orography of monsoon Asia; areas above 1000m are colored brown, red and grey. (picture source: http://www.ngdc.noaa.gov/mgg/image/relief).*

The mountains of monsoon Asia have a profound effect on the weather and climate of the world, particularly as they include the Himalayan-Tibetan Plateau, which is the largest high-elevation region of the world. With an average elevation of more than 4,000 m, the plateau has a direct effect on global circulation patterns by causing perturbations in the prevailing westerlies. The region, covering about 2,500,000 km^2, is also a major determinant of the Asian monsoon, acting as an elevated heat source in the summer and a source of cold air in the winter. Paleoclimatic studies show that the interaction between the atmosphere and the cryosphere on the Tibetan Plateau leads to significant variations in global climate (Jin *et al.,* 2005).

In ecological terms, the mountains in monsoon Asia are characterized by the distribution of continuous forest vegetation from foothills to the tree line across latitudes from the equator to the boreal zone. The upper limit of evergreen broad-leaved forest here corresponds to the thermal line of -1°C of the coldest month (corresponding to the upper limit of the upper montane zone in Figure 2.3.2). Forest ecosystems are characterized by diverse tree species. In contrast, the mountains in western monsoon Asia demonstrate arid biomes in the lee of the Tibetan Plateau, namely, in upslope sequence, the montane shrub-grass tussock or shrub-steppe, and montane desert with shrubs. The uniqueness of the overall zone is marked by the vertical gradients in ecosystems.

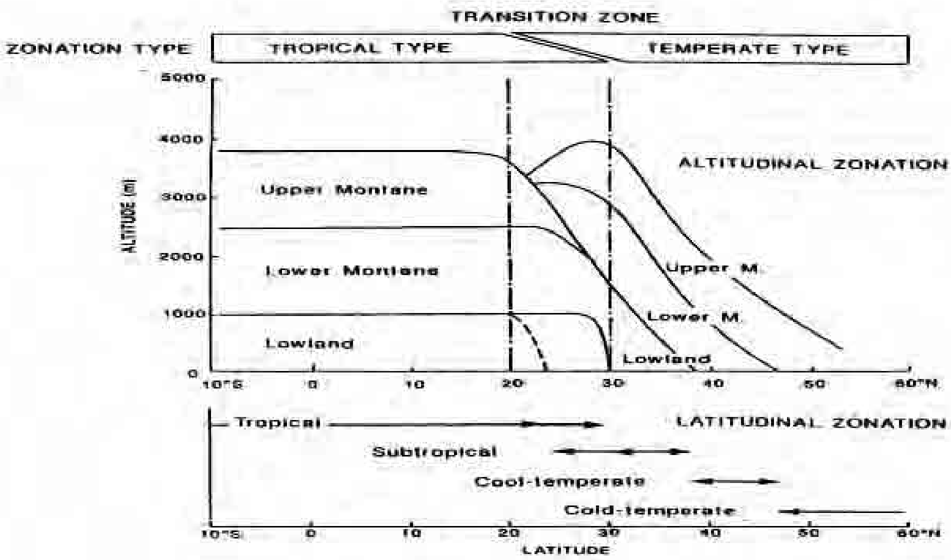

Figure 2.3.2. *Ecosystems on the mountains in maritime monsoon Asia (From K. Kitayama).*

In meteorological terms, the mountainous regions are characterized by the interactions between orography and the seasonality of the monsoon. While much of the region has subzero temperatures for at least part of the year, the tropical influence of the monsoon means that the mountains of monsoon Asia tend to have higher snow lines than those under mid-latitude synoptic influences.

Box 2.3.1. Mountains of Asia

The Himalayas, as the highest range in the world, make the mountain regions of monsoon Asia unique. All of the world's mountains above 7,000 m are in Asia and all peaks above 8,000 m are in the Himalayas and Karakorams. The ice and snow volume of the Himalayas and the Tibetan Plateau is similar to that in each of the poles. In hydrological terms, the mountains of monsoon Asia are the sources of all the major rivers of the region. For instance, the glaciers of the Tibetan Plateau are the source of most of Asia's great rivers: the Ganga, Indus, Brahmaputra, Ayeyarwadi, Salween, Mekong, Yangtze (Changjiang River) and Yellow River (Huanghe River). These rivers provide a year-round water supply to many millions of people. In humid parts of the world, mountains provide 30 to 60% of downstream freshwater, and in semi-arid and arid environments this figure increases to 70 to 90%.

The relatively harsh conditions of mountains have tended to limit the population of this zone, and the population density has been rather low. However, in recent decades, there has been a trend towards both depopulation and urbanization, leading to the development of dense urban areas. Mountains often have great spiritual, cultural and historical value for people.

The Initial Science Plan takes into account climatological, hydrological, ecological and social features of the zone. In Section 2.3.2, six priority research areas are identified and key research questions proposed for each area. The priority areas are: Hydrology and water quality, Ecosystems and biodiversity, Agriculture, forestry and food security, Energy, Natural disaster management, Air quality and human health (box 2.3.2).

It is important to ensure that the proposed science issues are both relevant and feasible. In Section 2.3.3, there is therefore a brief analysis of some of the critical implementation issues for this plan.

Box 2.3.2. The priority areas for the mountain zone:

- Hydrology and water availability.
- Ecosystems and biodiversity.
- Agriculture, forestry and food security.
- Energy.
- Natural disaster management.
- Air quality and human health.

2.3.2 Priority Research Areas

2.3.2.1 Hydrology and Water Availability

Rationale. One of the most important services from mountain ecosystems is the provision of freshwater. Hydrology is therefore a crucial node in mountain ecosystems. It is directly affected by changes in climate, by land use and land cover change and by variations in the cryosphere. These impacts in turn influence the quality and quantity of freshwater supplied to the adjacent areas, as well as other goods and services such as slope stability, biodiversity and energy production. Thus both climate variability and human pressure have an impact on mountains and their role as "water towers" for the surrounding region (Messerli and Yves, 1997).

Mountains also have a direct effect on weather and climate. For instance, the Himalayas, the highest and largest mountains on Earth and home for over 100 million people, trigger orographic precipitation and influence the South Asian monsoon, store water as snow and ice and provide the source for three main river systems namely the Indus, the Ganga and the Brahmaputra in South Asia. These systems form the most important water sources for almost half a billion people in the southern plains, and thus they constitute the "water tower" for almost one-fifth of the world's population living downstream on the Indo-Gangetic plains.

Precipitation is the primary driver for hydrological processes. Global environmental change can affect the spatial and temporal patterns of precipitation, the nature of precipitation (solid or liquid) at higher elevations and consequently the surface and subsurface water flows, upon which the lives of natural systems and of mountain and lowland people depend (Aizen *et al.,* 1997). Moreover, while mountain slopes capture water and guide it to the plains, runoff and sediments carried with it are both a benefit (through water supply and mineral nutrients) and threat (through floods and debris slides) to downslope societies.

Figure2.3.3 *Retreating Glacier No.1 at the headwaters of Urumqi River in Tianshan Mountain (From: Yang H. et al., 2005).*

The dramatic retreat of high-mountain glaciers as a result of global warming (Figure 2.3.3) has led to increasing flows at the beginning of the snow-melt period followed by flow reductions as the snow mass decreases or disappears later in the season. In many mountain regions and mountain fore-lands this process will result in a reduction in annual river flow in the long term. Thus mountain regions are now the hotspots of impacts of global change; they are associated with the rapid retreat of glaciers, producing climate change and variability with more extreme climatic events.

In order to sustain freshwater supply in the future, full understanding is necessary of the climatic and hydrological coupling in mountain regions, as well as their sensitivity to changing environmental conditions and land use. Major challenges for research in the mountain regions of monsoon Asia are to better document, understand and model the impacts of the ongoing global change processes on the mountain hydrology as well as their complex interrelations in order to make informed decisions on sustained freshwater supply across the region.

Research Questions

Can past and current changes in the cryosphere be characterized and its future behaviour projected in monsoon Asia mountains?*

The interactions between the cryosphere and the atmosphere play a significant role in global as well as regional weather and climate. It is therefore important to understand past variations and changes in order to provide the basis for estimates for future change. The harshness and remoteness of the environment of monsoon Asia mountains mean that it is difficult to obtain direct or even indirect observations of the varying cryosphere. Focused research as well as more long-term monitoring is needed to improve our documentation of the cryosphere in the region.

What are the impacts of climate change on water resources as a whole and in particular the contribution of glaciers and snow to river runoff?

The mountain areas provide the source of much of the water used for human settlement as well as natural ecosystems across the whole of monsoon Asia. It is therefore important that studies are conducted to improve our understanding of the impacts of global climate change on the water budget of the mountain regions. In particular, the impacts of rising temperatures on the cryosphere need to be monitored and understood.

Can the impact of local human activities (rather than global climate change) on water resources in the monsoon Asia mountain zone be identified and understood?

As the needs of human settlement in the mountain regions have extended, there have been changes in land use associated with agriculture and forestry, as well as urbanization. All these changes may be affecting the distribution of surface and groundwater. Studies are required to document and understand these impacts.

Can regional biogeochemical transport be identified in the high-altitude hydrological systems of monsoon Asia?

The nutrient budget in rivers is very complex and is affected by in-stream processes as well as external sources. However, changing land-use patterns in mountain regions, especially changes in agriculture and forestry, should be affecting the nutrient budgets of local streams. Because these streams feed into major river systems supplying water across monsoon Asia, it is expected that focused studies should identify the downstream impacts of land-use changes on water quality.

What will be the impact of expected changes in water availability regimes on agriculture and food security in mountain areas as well as downstream?

As modeling capacity improves, it will be feasible to model future changes in climate in the mountain regions and hence to estimate the future availability of water for agriculture and food security across monsoon Asia. Even with a limited modeling capacity, it is appropriate to carry out sensitivity studies on water availability using credible scenarios of future climate regimes.

2.3.2.2 Ecosystems and Biodiversity

Rationale. A rich assemblage of ecosystems and biodiversity occurs on a single mountain because temperature and rainfall vary with altitude and multiple habitats are formed along the mountain slope. Diversification of species (speciation) has largely been driven by the adaptation to different climate regimes on the mountain slope (Kitayama and Mueller-Dombois, 1995). Humans have traditionally made use of this biodiversity for food, fibre, medicine and other materials. Many mountains in monsoon Asia have long been left untouched by modern economic development because of their inaccessibility and remoteness. However, these mountain systems are now rapidly being affected by global warming and modern economic developments. Three major biodiversity hotspots of the world occur in the mountain region of monsoon Asia, suggesting that the mountains of monsoon Asia have been serving as a cradle for flora and fauna, but are now being rapidly altered by human activity. Ecosystem changes on mountains can occur either as the direct effect of land use, or as the indirect effects of species changes due to climate change. A slight change in temperature or rainfall will translate into a substantial shift of the distribution of plants over a wide altitudinal range. The change of distribution, the loss of flora or the introduction of alien species will change the composition and structure of vegetation, which in turn affects such ecosystem processes as productivity, decomposition, carbon allocation above- and belowground, nitrogen trace-gas emission and soil nutrient supply. The shift in nutrient demand and nutrient supply in soils will change the discharge of nutrients to streams and affect downstream water quality. Changing vegetation also affects the susceptibility of mountains to landslides.

Research Questions

What is the response of ecosystems in monsoon Asia mountains to change and variability of the climate across the arid to maritime monsoon region?

Ecosystems on mountains in monsoon Asia can be classified into the following three major types: tropical ecosystems on humid tropical mountains (Indonesia and Malaysia), temperate and subtropical ecosystems on mountains with strong seasonality of monthly rainfall (Indochina-Himalayas) and temperate and subtropical ecosystems on mountains with strong seasonality of monthly temperature (Japan-Taiwan). Tropical ecosystems may be susceptible to changing rainfall while temperate and subtropical ecosystems may be susceptible to changing seasonality. It is important to document and understand the impacts of climate change and variability on each of these ecosystem types.

Can the most vulnerable ecotones in the monsoon Asia mountains be identified and understood?*

There are critical altitudes that are susceptible to climate change, such as the ecotones defined by cloud limits and temperature inversions, or the dry upland area under air subsidence. Research is needed to document the changes in these ecotones.

Can the impact of local human activities (rather than global climate change) on ecosystems in the monsoon Asia mountains be identified and understood?

Changes in the intensity of human settlement in mountain regions are impacting on natural ecosystems. Further research is needed to document and understand the nature and causes of the changes to the ecosystems. Such research should lead to the development of improved strategies for managing the impacts of land-use change on the natural environment.

Can we identify the consequences of upstream changes in nutrient transport in situ *and downstream ecosystems?*

Changes in land use will lead to changes in the nature and quantity of nutrients flushed into local streams. Because the mountains provide sources for much of the water across monsoon Asia, it is likely that there will be significant downstream impacts on water quality due to land-use changes in the mountains.

2.3.2.3 Agriculture, Forestry and Food Security

Rationale. The mountain regions are characterized as fragile and marginal areas, being difficult to access, with a high rate of population or population intensity growth. Two major farming systems occur over the entire mountainous belt of the monsoon Asia region. In countries like India, Pakistan, Nepal and China, subsistence agriculture is practised while in countries like Japan intensive agriculture is predominant. Owing to generally high variability in microclimate and altitude, the farming systems are complex with multiple cropping patterns. Due to the fragile environment, there is a high interdependency of crop-livestock-forest production systems. Generally this agriculture is considered as a crop and livestock enterprise, which is most threatened by climate change. The mountain crops have low yield due to inherent climatic limitations, traditional varieties and low input levels (Swain *et al.,* 2005). Livestock production is mainly dependent upon the forest, public grazing lands, crop residues and outside sources. There is a high level of imbalance in the supply and demand of fodder. Furthermore, due to poor or limited veterinary services, livestock mortality rates are high. In winter, due to low temperatures and limited available feed, the farmers are forced to move their livestock to lower elevations and livestock lose considerable weight.

In monsoon Asia, more emphasis is generally given to lowland irrigated agriculture than to mountain agricultural systems. Agriculture on steep slopes without proper soil and water conservation has aggravated landslide and soil erosion problems (Nikushoeva and Akhmadov, 2006). In the context of climate change, the frequency, intensity and timing of the major weather elements (rain, snow, temperature and wind) make agricultural practices uncertain. This has resulted in shifts in farming systems and even in occupations. For example, when crop production is threatened by any climatic anomaly (drought or flood), there is a shift towards livestock production, and if there is a fodder shortage or rangelands are degraded, there is a reduction in livestock numbers; these are coping mechanisms. Due to shifts in climate change it is probable that growing-degree days have increased, resulting in wheat replacing fodder crops. Similarly the area under high-value crops like potato and orchids is increasing without consideration of the impact of climate change on these crops over a longer time period. As the communities are heavily dependent upon agriculture, any threat to agriculture also poses a high economic threat. Though food availability from other sources would be possible, it is doubtful whether such a strategy is affordable.

Forestry has been an important activity in the mountain regions of monsoon Asia. It is now threatened both by increased human activity and by climate change, which could lead to changes in fire regimes. Indeed the conservation of upland forests is becoming a major international concern because they are so closely linked to the sustainability of human settlements.

Research Questions

Is there a real shift in cropping patterns and farming systems in the monsoon Asia mountains?

At present there are conflicting hypotheses on the impact of climate change on mountain agricultural systems in different time-frames, and so research is needed to document the historical evolution of farming in the mountainous regions of monsoon Asia. This information will be vital to understand the response of mountain societies to climate and other external changes.

How sustainable are subsistence and intensive agricultural systems in the mountain regions that experience changing climate?

Climate change is imposing stresses on agricultural systems that add to existing stresses due to the development of human settlements in mountain regions. The impact of these climate-related stresses will be different for subsistence farming and intensive farming. For example, a subsistence farmer must survive every year while a commercial activity can sustain losses for a period. Moreover, subsistence farming is essentially a consistent long-term activity, while commercial enterprises are usually able to adapt to changing external factors.

In regions where local vegetation or crop residue have traditionally been used as sources of energy, what could be the impact of climate change on the nature and availability of these resources?

In many mountain regions, local vegetation or crop residue are used as fuel for energy and heating. Some of these natural resources are already under threat due to the expansion of human settlements. It will be important to understand the potential impacts of climate change on the availability of these sources in the future.

2.3.2.4 Energy

Rationale. The mountain regions have energy issues that relate to both sources and sinks. The potential energy of water in mountains provides a ready source of hydro-electric power, especially for areas that are not in the proximity of local mountains. Moreover, there has been a tradition of sustaining small-scale local activities through the burning of local vegetation. Local trees have been systematically felled for the generation of domestic energy and to support cottage industries. As the population of mountain regions has increased, these processes have become unsustainable due to an imbalance between the rates of re-growth and deforestation. Moreover, the changing climate is likely to lead to a local environment that is no longer suitable for former native vegetation. This issue is closely linked to those in the priority area on ecosystems and biodiversity.

Transportation has been a difficult activity in mountain regions, but the introduction of modern technology has facilitated transportation here. This facilitation, however, has associated impacts on land use and energy consumption.

There is an increasing trend towards the generation of hydro-electricity on mountain rivers that have been dammed. If global climate change is leading to changes in the flow regimes of mountain rivers then the impact of these flow changes needs to be assessed. This particular issue is closely linked to issues in the priority area of hydrology and water availability.

Research Questions

> *What is the impact of current hydro-electricity schemes on downstream flows and associated ecological and agricultural systems?*

The implementation of hydro-electricity schemes involves changes to natural stream flow. For simple schemes, such changes may be slight, but major schemes generally involve significant changes in the flow regimes, affecting both the quantity and timing of flows. In order to provide a framework for investigations of the impacts of possible future climate change on downstream flows, it would be appropriate to study the impact of existing infrastructure changes on these flows and their associated ecological and agricultural systems.

> *What could be the impact of possible changes in flow regime under climate change scenarios on the efficiency and effectiveness of existing and planned hydro-electricity schemes?*

Future climate change is expected to affect both the temperature and precipitation of mountain regions. Both these variables influence the hydrological balance of catchments, and hence climate change is expected to affect the performance of hydro-electricity schemes. It would be desirable to carry out studies that improve understanding of the likely performance of hydro-electricity schemes in the future in monsoon Asia. Changes in the performance of such schemes could affect energy supplies to large populations in the mountains and in the surrounding plains.

What is the impact of increased interaction between mountain communities and ecosystems due to improved transportation systems?

The introduction of improved transportation systems in mountain regions leads to at least two distinct impacts. A major impact on human settlements is increased communication between previously isolated communities. The increased communication has been shown to produce both beneficial (e.g. access to new information and technology) and adverse (e.g. loss of local cultures) impacts. It would be useful to document these human impacts on communities in monsoon Asia. The ecological impacts of modern transportation systems arise from the installation of major infrastructure, such as highways, railways and airfields.

2.3.2.5 Natural Disaster Management

Rationale. Glacier retreat and permafrost thaw in high mountains, such as the Himalayas and Tienshan as well as the Tibetan Plateau, have reached an extent and speed that are without historical precedence. This is likely to have substantial impacts on the hydrological dynamics of the region, resulting in greater variability of precipitation and streamflow and in increasing intensity of extreme events affecting both water quantity and quality. Declining dry season discharge from mountain rivers is expected to have major impacts on the economic and ecological services they can support, leading to unforeseen socio-economic consequences for rural and urban development.

Given the geographic distribution of these rivers, this phenomenon has widespread implications. The reduction in glacier resources is becoming an international issue because rivers provide downstream countries with essential water resources to sustain food production, socio-economic development and the environment. The following consequences of climate change could occur:

- More extreme rainfall events in high mountain areas could cause extreme floods.
- Snow-melt onset could cause melt water to occur earlier in spring, leading to low flows in summer and shortage of urban, industrial and irrigation water downstream.
- Glacier retreat and shrinking could form dangerous moraine lakes, which can produce sudden glacier lake outburst floods (GLOFs*).
- Permafrost degradation could cause landslides and debris flow due to the instability of hill slopes.
- Permafrost degradation could decrease the annual minimum flow downstream.
- Reduced water availability and higher temperatures could lead to a greater increase of forest fires in mountain regions.

Research Questions

Can we distinguish the human and climatic factors that trigger natural disasters such as landslides, floods and drought in mountainous regions?

Disasters like landslides and floods have always been hazards in mountainous regions. As human settlement has grown, natural disasters have been exacerbated by land-use changes and the installation of infrastructure for transportation, energy, water and other purposes. At the same time, there has been significant variability in the climate and recently there are clear indications of climate change. In order to properly understand and hence manage these natural disasters, important research is needed to assess the relative roles of human and climate influences.

How can the potentially dangerous glacial lakes in monsoon Asia mountains be monitored to minimize damage associated with GLOFs?

The retreat of mountain glaciers in monsoon Asia is feeding the creation and expansion of glacier lakes (Figure 2.3.4). The increased flows into glacier lakes is leading to an increasing frequency and magnitude of GLOFs, when large volumes of water and debris burst from a lake and cause flooding and damage far downstream (Agrawala *et al.,* 2003). Although such glacier lakes are often in remote and rugged locations, it is vital that techniques are developed to allow them to be monitored for indicators of impending GLOFs.

Figure 2.3.4. *Glacier lake in Mount Qomolangma in 2005 (by Jingshi Liu).*

2.3.2.6 Air Quality and Human Health

Rationale. In some parts of monsoon Asia, there is increasing urbanization in mountainous regions. A reduction in local air quality is an almost inevitable consequence of urbanization, owing to the concentration of pollutant sources. While human activity provides the basis for poor air quality, it is the meteorology that determines whether there is an air quality problem on any particular day.

Mountainous regions are prone to conditions that can either raise or lower the chance of high air pollution. In suppressed conditions, corresponding to cold stable air trapped near the surface, the air quality can deteriorate markedly as pollutants build up in an essentially stagnant pool of air. These conditions, particularly when wood burning leads to high concentrations of aerosols and carbon monoxide, are very dangerous to human health.

On the other hand, the altitude of mountainous regimes means that there is often a prevailing strong wind which effectively transports local pollution away from the source. As communities in mountain regions tend to be relatively small, the downwind plume usually disperses and does not lead to poor air quality in neighbouring areas.

Research Questions

> *What are the common factors between settlements and air quality in mountain regions across monsoon Asia?*

Air quality in an airshed* is determined basically by the nature and quantity of the sources of pollutants and by the meteorology which interacts with the local orography. Across monsoon Asia, there are large variations in both pollutant sources and meteorology. However, the controlling influences of the orography and the monsoon may provide some limits on the overall nature of air quality in the region. If it is found that there are some common factors controlling air quality in different mountain regions, then it should be possible to develop some common strategies for improving air quality.

> *Given the social and technical constraints on mountain communities, are there feasible strategies to maintain air quality in these areas?*

The sources of air pollutants are determined by the nature of the activities in human settlements. Small subsistence communities often generate pollutants, such as fuelwood smoke, but the population density is too low to lead to significant air quality problems. However, as urbanization increases, the concentration of pollutants can increase to dangerous levels. In early stages of development, communities may not have the resources to undertake strategies that can effectively and efficiently control their air quality. It would be important to determine whether feasible strategies can be developed to control air quality at all stages of urban development in mountain regions.

2.3.3 Implementation Issues

In developing this strategic science plan, it has been important to recognize a number of issues that will affect the implementation of the plan in the mountain zone. The following key issues are now considered: (i) Data availability and relevance, (ii) Modeling, (iii) Regional analyses, (iv) Capacity building, (v) Regional and international links.

Several other issues will also impact on the implementation of the plan. However, the listed issues are seen to be especially relevant to the conduct of research in the mountain zone.

2.3.3.1 Data Availability and Relevance

Owing to the inherent harshness of mountain regions, there is a lack of long-term observation stations at high latitudes in monsoon Asia. This lack of monitoring data even applies to meteorological variables in the region. The absence of data is due partly to the climate but also to the difficulty in measuring frozen precipitation. Basic hydrological data, such as the runoff from glaciers, are also very sparse.

The availability of ecological data varies across monsoon Asia. The finest resolution data are available in Japan, the data in China are at a more coarse resolution, while the data in most other areas are very limited. A frequent hindrance is that ecological data have not been digitized. Furthermore, while useful data sets may be available for a specific period, these data sets may not be routinely updated.

These basic monitoring problems in mountain regions are recognized in the implementation plan of the Global Climate Observing System (GCOS), and some steps are being taken to improve international capacity to take measurements at high altitudes. However, progress of the science objectives of MAIRS will be limited in mountainous regions unless additional long-term monitoring sites are established.

Satellite data are very important for research in mountainous regions, as they provide the only means of obtaining comprehensive spatial coverage especially in rugged terrain. However, satellite data require associated *in situ* data for calibration and validation purposes. In the unique environments of the monsoon Asia mountains, it is necessary to have *in situ* measurements from the region itself, rather than assuming that measurements from other climatic and ecological regimes can be directly applied.

While recognizing the importance of satellite data, it is also necessary to recognize their inherent limitations in mountain regions. The steep gradients (especially in relation to the footprint of most satellite sensors) of the mountains of monsoon Asia can lead to biases in observations due to limitations in horizontal resolution and to the sampling of only one aspect of steep terrain.

2.3.3.2 Modeling

Modeling will be an essential element of MAIRS, as it provides the means to bring together different data in a systematic manner in order to understand the key biogeochemical processes controlling the natural systems of monsoon Asia mountains. Modeling also provides the means for systematic prediction or projection of the future environment.

However, the mountain regions impose particular problems for models. The steep orography means that models must have a high spatial resolution in order to ensure that important mountain features are not smoothed out or misrepresented. Moreover the orography generates physical processes, such as gravity waves and associated turbulence, which are often not treated well in numerical models.

It has already been noted that there is a lack of basic observed data in the mountain regions. This absence of data will further limit the application of models that have been appropriately calibrated and validated for monsoon Asia.

2.3.3.3 Regional Analysis

A key feature of MAIRS will be the focus on regional studies that compare the characteristics of particular features across monsoon Asia. For example, comparative studies of ecotone* shifts, agricultural changes and air quality across the mountain regions will bring new understanding of the relevant processes. Such studies generally fall outside the scope of both national and global programs.

MAIRS will also provide the opportunity for studies that aggregate the impacts of changes occurring across the region. For example, an improved understanding of the hydrological balance across the mountains of monsoon Asia will support better management of the water supply for about half the world's population.

2.3.3.4 Capacity Building

In addition to building the capacity of individuals, it will be important for MAIRS to promote the building of institutional capacity. Activities to enhance the analytical capacity of operational agencies associated with the collection and archiving of long-term data can be effective in encouraging these agencies to share their data and to squeeze most information from them.

Box 2.3.3. About environmental changes in the Mountain Zone.

The mountainous regions of monsoon Asia are significant in extent and in their impact on both local and distant regions. Priority research areas identified for study under MAIRS are: water availability, biodiversity, food security, energy, disasters and human health. The research is expected to involve activities extending from field studies to data analysis and integrated modeling. A multidisciplinary approach will be required to analyse the problems properly.

2.3.3.5 Regional and International Links

As an international program of research, MAIRS will need to draw on and contribute to existing national, regional and international activities. The program will inherently build on and enhance national contributions. However, it is important that MAIRS does not overlap or duplicate the current activities of global and other regional programs. Such problems will be overcome through effective links with relevant activities. For monsoon Asia mountain research, the key programs are:

- The Mountain Research Initiative (MRI) in Switzerland which coordinates research across all mountain re gions.
- The International Centre for Integrated Mountain Development (ICIMOD) in Nepal which promotes the use of satellite data and is developing capacity for archiving regional data.
- GAMBA is a network of mountain ecosystems that monitors ecosystem shifts.
- The Chinese Ecosystem Research Network (CERN) which is a reference network that includes some mountain sites in China.
- DIVERSITAS in Western Pacific and Asia (DIWPA) is a network of biodiversity researchers and standard ized ecosystem monitoring sites, including sites in mountain regions.
- The WCRP Climate Variability and Predictability (CLIVAR) Asian-Australian Monsoon Panel coordinates research on the physics of monsoon system and its interaction with global climate.

- The Coordinated Enhanced Observing Period (CEOP) maintains a reference site network over the Tibetan Plateau and the Himalaya.
- The WCRP Global Energy and Water Cycle Experiment (GEWEX) - Monsoon Asia Hydro-Atmospheric Research and Prediction Initiative (MAHASRI) has a regional study component in Tibet and the Himalaya in collaboration with CEOP.
- The WRCP Climate and Cryosphere (Clic) project will coordinate research on the mountain glaciers and permafrost in the high mountain areas of Asia.

Section 2.4

Semi-arid Zones: Vulnerability of ecosystems due to changing climate and land use

This section contains the Initial Science Plan for MAIRS Semi-arid Zones' research.

2.4.1 Rationale

As a natural process of Earth evolution, the huge arid and semi-arid regions were formed in the Asia continent at the time of rapid uplifting of the Tibetan Plateau approximately 3.6 to 2.6 million years B.P. (An *et al.*, 2001). Figure 2.4.1, based on the Köppen classification of climates shows the geographic location of semi-arid regions over Central Asia as well as some parts of the India subcontinent. By definition, in semi-arid zones, annual potential evapotranspiration exceeds annual precipitation, and the landscapes are characterized by dry climate, low vegetation cover, low nutrition content and low capacity for water conservation. These areas are most vulnerable to environmental change.

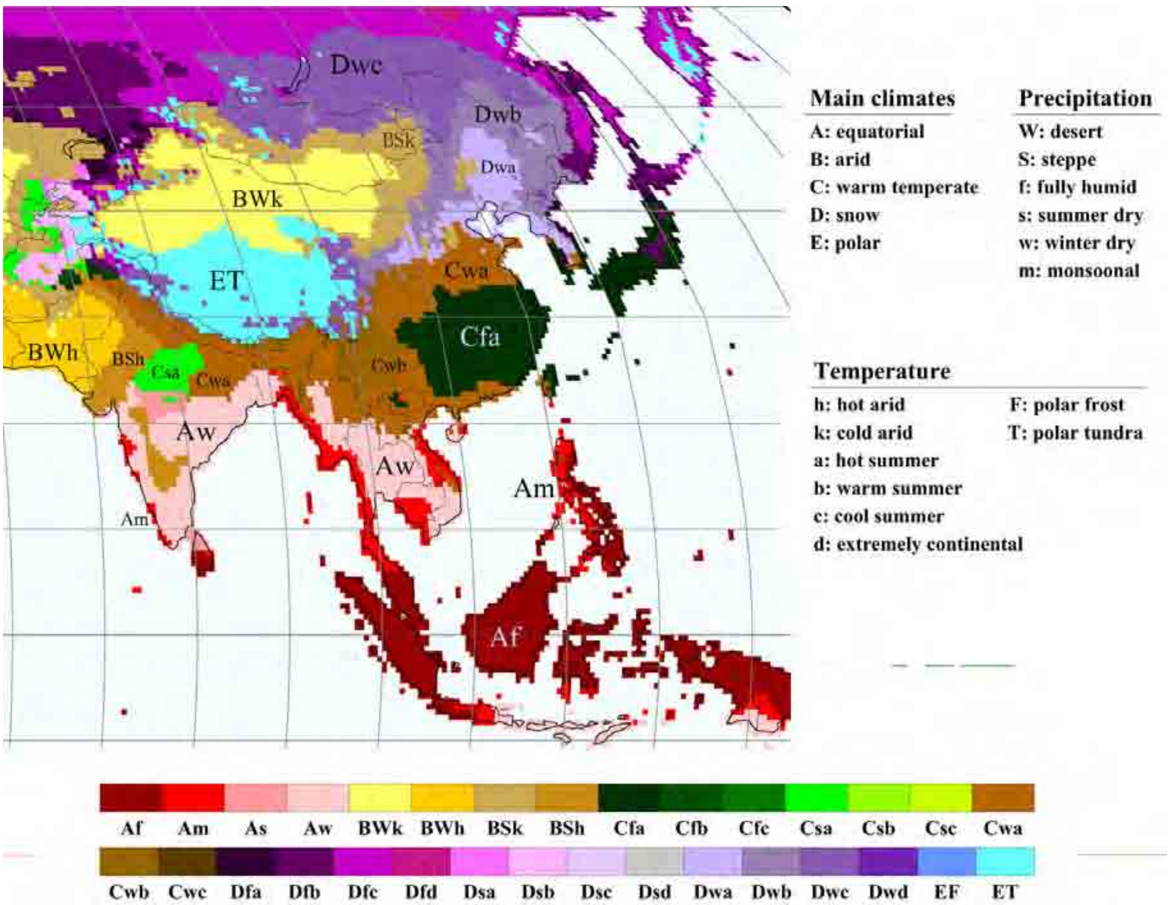

Figure 2.4.1. *Distribution of arid and semi-arid areas in monsoon Asia from world map of Köppen-Geiger climate classification. The areas marked BSh and BSk are semi-arid regions. (From: Kottek et al.,2006).*

These areas are also known as the major source of dust aerosols, which not only directly cause serious damage to human health, agriculture and economics, but also to other regions through long distance transport of huge amounts of dust particles across the Pacific Ocean and even North America. The dust aerosols also have significant influence on the regional and global climate through their radiative forcing. When deposited in the ocean, aeolian mineral dust is important to many biogeochemical cycles, including the growth of phytoplankton, which influence the carbon cycle in the ocean. Figure 2.4.2 shows the dust distribution and the long distance transport of the dust aerosols of April 1998 from simulation and the TOMS aerosol index (Wu and Fu, 2004). Researchers have also proposed an interaction process between dust aerosols and the hydrological cycle (Ramanathan *et al*., 2005). The variation of climate and water cycle in this area is highly correlated with the strong variability of the Asia monsoon system. This leads to the high frequency of extreme events and climatic disasters in this region. Both observation and numerical modeling have shown that an aridity trend is occurring and will occur most significantly in semi-arid regions under global warming (Fu *et al.*, 2002; Dai, 2003; Ma *et al.*, 2003). Figure 2.4.3 presents the global drying trend in the last 30 years, as indicated by PDSI from 1972 to

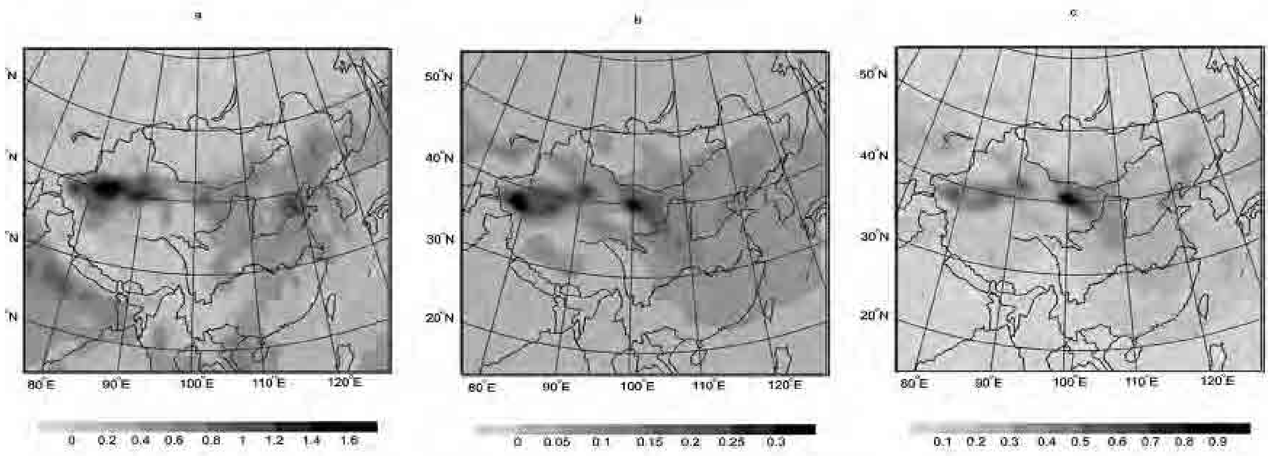

Figure 2.4.2. *Dust distribution of April 1998 from simulation and the TOMS aerosol index (from Wu and Fu, 2005): (a) Aerosol index of TOMS; (b) Simulated column burden of dust (g m^{-2}); (c) Simulated optical depth of dust.*

However, the semi-arid region also has the most significant change of land cover via human development. Human-induced land cover changes in this region have generated, inter alia, further land degradation, the expansion of land under desertification, loss of groundwater reservoirs and increased dust storm frequency. The large-scale human destruction of natural vegetation also influences the intensity of the summer monsoon and reduces moisture transfer to the continent; this exacerbates aridity over the semi-arid regions (Fu and Yuan, 1999, Fu, 2003).

It should be pointed out that current climate models have shown the highest bias error of simulated precipitation in summer over arid and semi-arid Asia. Figure 2.4.4 presents the bias of simulated annual total precipitation to observation (%) (10-year average). The ensemble of all models (upper right hand corner) shows that the highest bias of total precipitation in the arid and semi-arid area of Central Asia can reach as high as 200% or more. The rest of the figures represent variability among different models (from the inter-comparison of the regional climate model project for Asia, Fu et al., 2004). This is perhaps due to scant knowledge of land surface dynamics, especially hydrological processes over arid and semi-arid regions in the land surface model. Currently most hydrological modules in the land surface model have been developed and calibrated for use in humid areas.

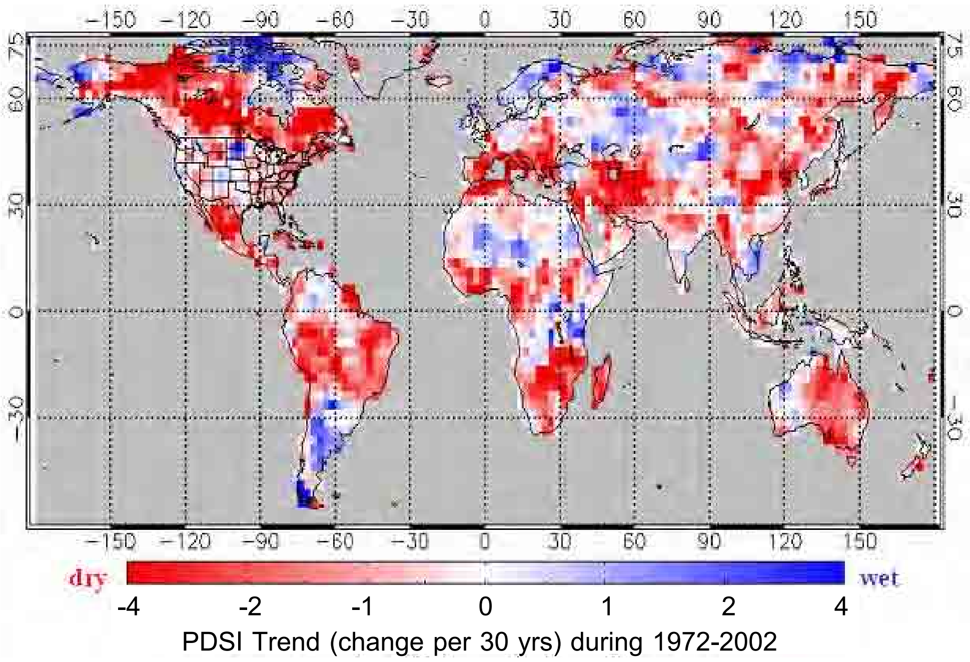

Figure 2.4.3. *The global drying trend over last 30 years shown as the Palmer Drought Severity Index (PDSI). The areas in red show "drier" and in blue show "wetter" conditions (From Dai et al., 2003)*

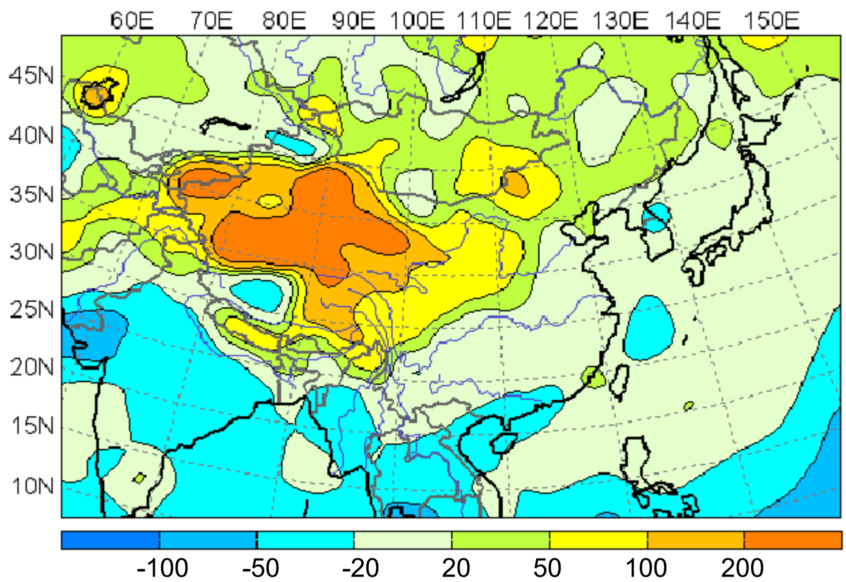

Figure 2.4.4. *Bias of simulated annual total precipitation from ensemble of 6 regional models to observation to observation (%, 10 year average). It shows that the bias of total precipitation in arid and semi-arid regions of central Asia can exceed 200%. (from: from inter-comparison of the regional climate model project for Asia, Fu et al., 2004).*

2.4.2 Research Questions

The goal of research in semi-arid monsoon Asia is to improve significantly the understanding of the interactions within the atmosphere-biosphere-hydrosphere system under the forcing of monsoon variation, global warming and human development (land use mainly). This may assist in projection of future climate and water cycle changes for assessment of their impacts on water resources, ecosystems and the socio-economic development of semi-arid regions in Asia and for the development of adaptation strategies.

The overarching science question for the Semi-arid Zone is:

How will semi-arid zones change over the next two to three decades with respect to water availability, air quality, food production, provision of ecosystem goods and service and climate extremes and hazards?

As a practical strategy, the key research questions that need to be addressed are:

What is the integrated picture of the historical evolution of the semi-arid human environmental system over-the last 3,000 years, including climate, atmospheric composition (dust aerosols), water resources, eco-sytems, land use/cover, population and economics? What determined the extent and condition of semi-arid Asia in recent historical time? Do socio-economic and political factors matter?

How does global warming affect the regional climate, water cycle, aridity trend, desertification processes and provision of ecological goods and services over semi-arid Asia?

How do human-induced land cover changes affect the regional climate, water conservation and nutrient-content of the soil, land degradation, the structure and function of terrestrial ecosystems and the frequency of dust storms?

What are the processes involved in land-atmosphere interactions and how will they change?

What will be the global consequence of changing the long distance transport of dust aerosols, such as the carbon cycle in oceans?

What are the social and economic consequences of the further deterioration of semi-arid environmental systems, such as concerns related to human health, food and water security and economic development?

How does human society adapt to such changes in vulnerability in order to achieve sustainable development of the region?

2.4.3 Priority Research Areas

To address these questions, three priority areas for research have been identified: Interactions among global warming, monsoon variablitiy and aridity trends, Atmosphere, land and ecosystem interaction under changing land-use patterns, Dust aerosols, the hydrological cycle and regional climate (Box 2.4.1).

Box 2.4.1. Priority areas for research in the Semi Arid Zone:

- Interactions among global warming, monsoon variability and aridity trends and water resource management.
- Atmosphere, land and ecosystem interaction under changing land-use patterns and ecosystem services.
- Dust aerosols, the hydrological cycle and regional climate and environmental conservation.

2.4.3.1 Global Warming, Monsoon Variability, Aridity Trends and Water Resource Management

Regional response to global warming and monsoon variability in semi-arid monsoon Asia, such as changing rainfall patterns, surface evapotranspiration and frequency and intensity of climate extremes in the past and currently as well as scenarios for the next two to three decades need to be documented or simulated. Assessment of their impacts on water resources in the region need to be made by developing a new numerical model framework with better description of hydrological processes in semi-arid regions. Strategies to adapt to changing water resources due to further aridity, or vice versa, need to be developed and research results transferred effectively to decision-makers or stakeholders.

2.4.3.2 Land Use, Atmosphere-Biosphere Interactions and Ecosystem Services

Changing land-use and land cover patterns in semi-arid Asia in the past and currently and scenarios for the next two to three decades need to be documented via various methods, including use of remote sensing information and simulation by land-use/cover models. Land-atmospheric energy, water and CO_2 fluxes, water and energy balances of land surfaces and the structure and dynamics of atmospheric boundaries need to be analysed on the basis of continued enhancement measurements over different types of land cover in semi-arid monsoon Asia. New land surface models or parameterization schemes of land surface processes for semi-arid regions need to be developed and coupled with climate models for further studying of their impact on regional climate. The impacts of changing land use and land cover as well as climate on the structure and function of ecosystems in these regions needs be evaluated through study of ecological components at observation stations and through the use of ecosystem models.

2.4.3.3 Land Degradation, Dust Aerosols and Environmental Conservation

Land degradation over semi-arid Asia due to climate change and non-sustainable land use in the past can be reconstructed from land survey data and remotely sensed information. The records of dust storms over the region over longer historical time scales can be reconstructed by various proxy data. Meteorological data on the frequency and intensity of dust storms are available for the past 40 years for most semi-arid regions. Satellite data in the last decade provided information to study more numerically and visually the behaviour of dust storms and the radiative characteristics of dust aerosols. Field measurement of aerosols at the stations will provide more information on dust aerosols and their physics.

The direct and indirect effects of dust aerosols on radiation and cloud physics need to be studied by site measurements at the stations as well as by aircraft measurements. These data will provide the information needed to research the impact of aerosols on climate and the atmospheric component of the hydrological cycle.

The impacts of aerosols on ecosystems and human health also need to be evaluated. Policy recommendations for environmental conservation need to be developed based on such knowledge.

2.4.4 Issues for Implementation

Implementation of the research in semi-arid Asia requires the development of tools including integrated observation and data systems, models for integrated analysis and modeling and field studies.

2.4.4.1 Integrated Observation System

Observations based on field sites and satellite monitoring will provide the basic information for understanding the driving forces and the process of land-use change, aridity, dust events and practical and potential human control.

2.4.4.2 Field-site Observation

The measurement at field sites must focus on:

- The flux exchanges between land and atmosphere. Sensors on towers, automatic meteorological stations and other instruments will support the observations of wind speed, temperature, humidity and radiation to derive the flux exchanges of momentum, heat, water vapour and CO_2 over representative ecosystems (O_3, NO_x, VOC).
- Biological components to understand the variations of ecosystems include biodiversity, above and underground productivity, vegetation height, fraction, leaf area index, photosynthesis, water vapour potential, soil organic matter, litter decomposition and chemical element cycling.
- Atmospheric aerosol and atmospheric radiation and optical depth.
- Human activities including land use, urban development, etc.

Figure 2.4.5 shows two measurement stations as reference sites in semi-arid areas.

Figure 2.4.5. *Measurement stations with towers in Lanzhou in Northwest China over the Loess Plateau and Tongyu in Northeast China*

2.4.4.3 Satellite Monitoring

With the data from new generation sensors — MODIS onboard Terra of NASA EOS and VEGETATION on board SPOT — and other sources of operational stationary and polar-orbit satellites, regional characteristics of the atmosphere and land, their changes, regional and global impacts will be monitored. Moreover, calibrated with the aforementioned ground truthing, satellite data will provide regional and globalscale quantitative understanding with respect to:

- Regional land characteristics, such as aridity, biomass, water balance, etc.
- Land cover and land-use changes in association with land degradation and degraded land recovery under natural and anthropogenic forcing.
- Dust transport tracking and dust aerosol distribution.

2.4.4.4 Integrated Data and Information System

The MAIRS efforts for monsoon Asia semi-arid regions require at least categories of data:

- Statistical data on human development.
- Observation records of the monsoon system and changes.
- Observation records of the water system and changes.
- Observation records of atmospheric composition and changes based on the aforementioned observations.
- The reconstruction of historical data on the evolution of the human–environmental system in semi-arid Asia through proxy data from studies of loess, tree rings, lake deposition and historical literature will provide information on patterns of land cover changes, frequency and intensity of droughts, dust storms, etc. in semi-arid Asia at different time scales.

A data management and information system is needed for data archiving, access, processing, data exchange and dissemination, to assure data sharing, utility and usability.

2.4.4.5 Models for Integrated Study

The global model outputs may be used to drive the regional environmental system model to understand the physical, chemical and biological interactions in semi-arid regions, including dust aerosol generation and transfer, the climate effects of dust aerosols and land-use changes due to human activities. A Regional Earth System Model for monsoon Asia needs to be developed and should include all components of the monsoon system. For more detail see Box 2.4.2.

Box 2.4.2. A brief introduction to the modules in Regional Earth System Model.

Socio-economic module. The socio-economic development module provides the anthropogenic forcing of monsoon system and the consequences of the society and the economy developments under changing monsoon climate system. The climate and the socio-economic module are coupled through anthropogenic GHG emissions (emission module) and land use practice changes (land use module).

Land use module. The land use module assesses the biophysical suitability of a land block and potential contribution of biomass, regulates the competition for land resources and generates the spatial patterns of land use/cover along with the landscape changing based on biophysical and socio-economic factors.

Emission module. In emission module, the emissions of greenhouse gases and aerosols such as sulfate aerosol and black carbon and dust aerosols into the atmosphere from industrialization, urbanization and intensive land use are estimated, which are regulated by socio-economic developments of the region through the socio-economic module.

Atmosphere module. Atmosphere module is the core of Regional Earth System Model. It is used to calculate the properties of the standard atmosphere. The basic climate variables such as air density, pressure, temperature, wind speed and water vapor at certain latitude are generated and passed to other modules.

Radiation module. The radiation module contains parameterizations for solar and long-wave radiation as well as the radiative effects of clouds, greenhouse gases, and aerosols.

Biosphere module. Biosphere module is to simulate the biophysical and biogeochemical surface fluxes and, by coupling with atmosphere module, to explore the dynamic behavior of the Earth system, including the feedbacks between atmosphere, vegetation through energy, water, momentum, and carbon cycles. It will be incorporated to investigate variation of natural Earth system as well as the land cover change due to anthropogenic perturbations such as anthropogenic greenhouse gas emissions.

Land-surface module. The land-surface module will be designed to describe the two-way interactions between climate and ecosystem, including both physical transports among soil-vegetation-air and dynamic processes of physiology and ecology.

Chemistry module. With large-scale industrialization and urbanization, the atmospheric loads of green house gases and aerosols are increasing due to industrial emission and carbon fuel burning. The chemical process therefore is involved in the Regional Earth System Model. In this module, by regulating the transportation, deposition and chemical reactions processes, the concentrations and distributions of atmospheric trace-gases and aerosols with radiative effects are calculated. The chemical model also should enable Regional Earth System Model to take the direct/indirect effects of aerosols into account.

Hydrological module. Considering the critical role the hydrological process playing in land surface process in semi-arid regions of monsoon Asia, a hydrology module is designed to give descriptions of the regional cycle of hydrological variables such as ground water, snow depth and runoff. Coupled with atmosphere and biosphere modules, it will reflect the influences of natural monsoon climate variations including those of temperature and precipitation and water resource management.

Impact and assessment module. Facing a changing climate and its inevitable impacts on environment and social/economic developments, adaptation is necessary for human being as well as the society. To study and assess the impacts of climate changes and to transfer scientific results to decision maker's, an Integrated Assessment Models will be included in Regional Earth System Model as an impact and assessment module. It will focus on the assessment of impacts of regional development and the examination of the vulnerability of the region and the development of responses measures.

2.4.5. Regional and International Links

Aridity Trends in Northern China and Human Adaptation, a project supported by the Ministry of Science and Technology. Phase I has been implemented for five years (1999-2004) and is going to enter its second phase from 2006 to 2010; two CEOP reference sites from China were set up in the region and observations have been carried out since 2001.

CEOP Semi-arid Region Study, a new component of CEOP Phase II (2005-2010). This focuses on observation, analysis and modeling of the water and energy cycle of semi-arid regions, including semi-arid Asia, and their role in the climate system. This might help better prediction of water resource status and management in semi-arid regions. More CEOP reference sites in semi-arid Asia are available.

Adaptation and Mitigation Strategies (ADAM), a project funded by the European Commission for 2006 to 2009. This focuses on the development of new strategies for adapting to climate change, including regional case studies in China and India, in particular, adaptation to aridity trends in Inner Mongolia (Northern China).

The WCRP Global Energy and Water Cycle Experiment (GEWEX) - Monsoon Asian Hydro-Atmospheric Research and Prediction Initiative (MAHASRI) project has a regional study component in the semi-arid region of North East Asia in collaboration with CEOP.

Asia Flux Net, a network of stations measuring water, energy and CO_2 fluxes over the land surface of Asia.

GEOSS. This Global Earth Observation System of Systems under development aims to achieve comprehensive, coordinated and sustained world observations for the benefit of humankind. The MAIRS observation program will contribute to and benefit from GEOSS in all its aspects.

RMIP for Asia. This is a joint effort of ten research groups of regional climate modeling researchers working for an inter-comparison study of a regional climate model for the monsoon Asia region.

Section 2.5

Urban Zones: Changes in Resource Use and Emissions as a Result of Rapid Urbanization

This section contains the Initial Science Plan for MAIRS Urban Zones' research.

2.5.1 Introduction

Urbanization in monsoon Asia is occurring at very rapid rates. How it unfolds will have major implications for local, regional and global sustainability, especially with respect to air and water resources (Lebel 2005, Sanchez-Rodriguez *et al.* 2005). The monsoon climate provides a profound context against which agricultural areas, patterns of trade, emergence of human settlements and cultural practices and institutions have evolved over centuries. There are indications that human activities, especially those associated with economic development that is dependent on urbanñindustrial transformation, are for the first time having a detectable impact on the large-scale monsoon system.

Crucial questions, therefore, are:

How and to what degree is urbanization altering the vulnerability of societies to potential changes in the Asian monsoon?

Is the Asian monsoon system resilient to urbanization related transformations of land, water and air in urban and other zones?

What impacts might such changes have on human health and wellbeing? What contribution does urbanization make to these changes?

Conventionally, urbanization is defined in demographic terms. Urbanization results from population growth, migration adding population to existing urban areas and human settlements reaching a certain threshold size or density after which they are formally recognized as urban by their national governments. But, change in density is only one aspect of urbanization. As the nexus of multiple production-consumption systems urbanizing regions function to meet and stimulate people's needs and wants, for example, with respect to mobility, shelter, diet, work and play (Lebel *et al.* 2006a). Urbanizing regions have roles with respect to other places, for example, as centres of manufacturing, political power, commerce or innovation. Spatial organization, or urban form, has several dimensions apart from density and size. As a result of these other considerations what is considered "urban" is a negotiated and dynamic label. One consequence is that the projection of a geographic shadow of MAIRS urbanization theme onto an "urban zone" does not have a single well-defined definition, but rather many, depending on purposes of analysis. Figure 2.1.1. depicts the size of cities as a proxy of urbanization.

Nevertheless, there are some key patterns and linkages with other more physically defined "zones" that can be highlighted. For example, the most extensive and most rapid urbanization is taking place in the coastal zone with implications both for this region and hinterland source regions from which those populations are often being drawn. Combined with very rapid declines in fertility rate, the demographic landscape of monsoon

Asia is undergoing a thorough re-organization with areas of significant ageing and prospects of population decline and others with further growth and increases in density.

Box 2.5.1. On urbanization.

Urbanization is only one component, and one lens, through which to look at the remarkable social development and environmental transformations of Asia in the past few decades and into the future. But it is potentially a very important one for policy in this region because the process of change is still unfolding and might be redirected along more benign and safe pathways, and changes may have particularly high leverage. There are also significant opportunities for the rest of the world to learn lessons about non-motorized transport, high density settlements and other aspects of urban form, function and transformation from the monsoon Asia region.

Three priority research areas for MAIRS are proposed: Energy, emissions and urban air quality, Urbanization, flood regimes and disaster management, Urbanization and water security (Box 2.5.2).

Box 2.5.2. Priority areas for research in the Urban Zone.

- Energy, emissions and urban air quality
- Urbanization, flood regimes and disaster management
- Urbanization and water security

Issues of air quality and emissions' management, flood management and water security are also important to people and ecosystems in rural areas. A study of urbanization, therefore, cannot be just about "cities and towns" but must look at processes of change and their impacts, which can occur elsewhere through production-consumption system linkages (Lebel, 2004).

2.5.2 Priority Research Area

2.5.2.1 Energy, Emissions and Urban Air Quality

Rationale. Urbanization is a major driver, and outcome, of economic and social development. Development has depended, and will continue to depend for some time in the future, on fossil fuel energy sources. The life styles of people in urban areas are crucial to patterns of energy demand for mobility, comfort and the production of consumer goods. In rapidly urbanizing regions in the developing parts of Asia, deteriorating air quality is a common phenomenon with serious consequences for public health and the environment. Apart from locally significant pollutants, aerosols, trace gases and greenhouse gas emissions may have important impacts regionally and globally. Emissions of aerosols can change the atmospheric heat balance, the size and weight of cloud particles. What influence these have on the intensity of monsoon circulation, onset timing, number of rainy days and extreme events is still not well understood. Nor is it clear to what extent do urban form or the pathways of transformation through which regions urbanize have consequences for emissions and pollution problems above and beyond those effects directly attributable to economic growth. Urbanization may be part of the solution rather than the problem in decoupling emission growth from social development (Mitra and Sharma 2002, Lebel *et al.* 2006a).

Industrial sources of pollution are linked to urban environments throughout Asia as many of them have developed with the expansion of labour-intensive manufacturing and agro-industries. The way people's aspirations and needs for mobility are served in urban areas is a major factor driving changes in transport sector emissions and because of density and congestion affects on urban air quality (Lebel *et al.* 2006a). The rapid rise in private motor vehicle use, in particular, represents a huge challenge to efforts at improving urban air quality (Barter, 2000).

Figure 2.5.1. *The demand for mobility is high (Picture by L.Lebel)*

Activities in urban areas are central to the design and operation of energy systems (Dhakal, 2004). Urban areas are the nexus of multiple production and consumption systems (Lebel *et al.* 2006a). Urban form, function and roles can have major implications for energy and emission intensities (Mitra and Sharma, 2002). A switch to a service-based economy, for example, can result in polluting industries just being relocated elsewhere (Bai, 2002).

Switches to renewable energy sources, improved energy production, storage and distribution technologies and more efficient use by urban residents, firms and government agencies are therefore also critical to decoupling growth in emissions from social development (Nakicenovic, 1997). Technological leapfrogging has occurred and remains a very important component of urban-industrial transformation opportunities (Rock, 2002, Rock and Angel, 2005).

Urban sources of air pollution (including aerosols, ozone and ozone precursors) contribute to climate forcing. To what extent these cause changes in the monsoon system is not known (Figure 2.5.1). This needs special study.

What we do know is that aerosol composition and acid precipitation change seasonally and in South Asia there is a switchover from black carbon to dust particles during the summer monsoon. The changes in aerosol composition are dependent on many factors, are complex and need special study of changing emission patterns. It is expected that urbanization processes are an underlying cause of some of these changes with both positive and negative impacts on emissions relative to non-urban land uses and human settlement patterns.

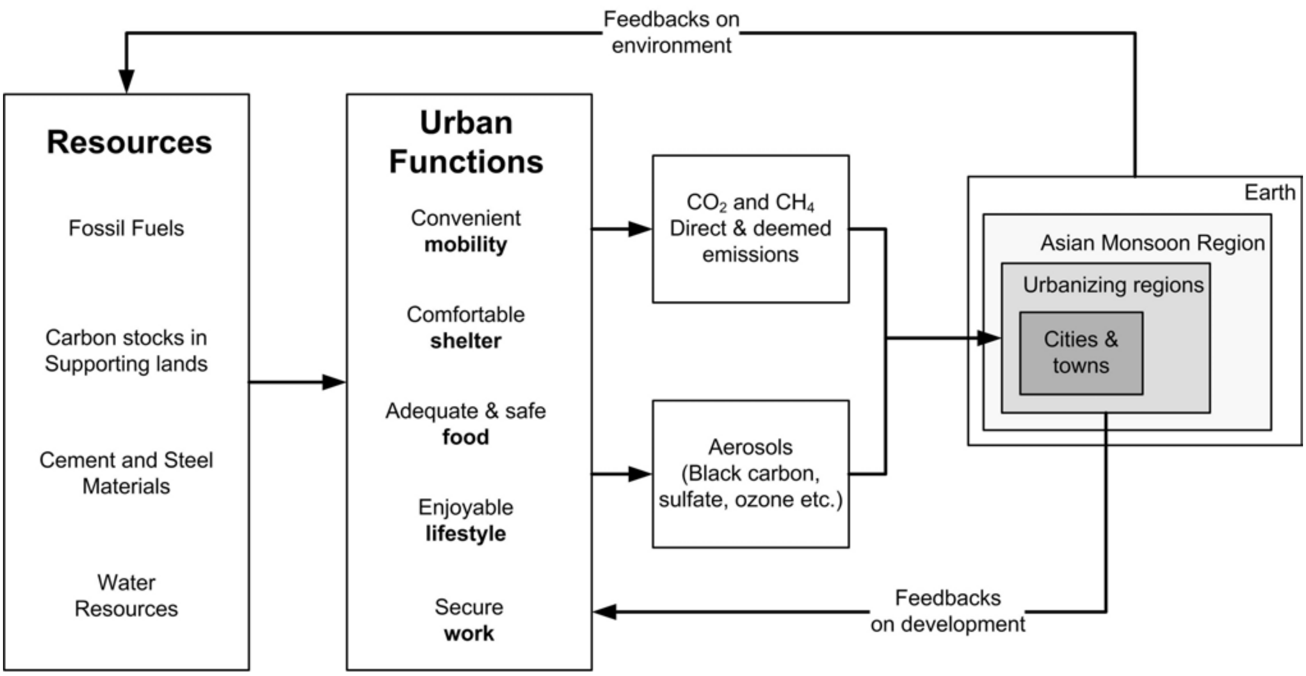

Figure 2.5.2. *Conceptual framework for the Urban Zones.*

Researchable questions. Key questions for MAIRS include:

How does the process of urban transformation and urban locations contribute to emissions and sinks in the monsoon Asia region?

What are the key emission sources in urban areas? To what extent are problems of urban air quality attributable to local emission sources? How do patterns of consumption impact on deemed emissions from urban activities?

What are the impacts of urban emissions on the climate system, health, ecosystems and agriculture?

To what extent and how does urban form, function and location (climate, topography) influence the intensity and composition of emissions?

How have urban policies, planning and management impacted on direct and deemed emissions resulting from activities in urban areas?

2.5.3 Urbanization, Flood Regimes and Disaster Management

Rationale. In many parts of monsoon Asia the major cities have grown in the deltas literally building on the foundations of a rice-growing civilization. The landscape has been managed for floods for centuries. Communities whose livelihoods depend on the productive functions of "normal" seasonal flood cycles have learned to live with floods and have embraced their arrival with songs and dances (Manuta and Lebel, 2005). Institutions and cultural practices around the "management" of floods are among the most persistent, sometimes surviving for centuries.

Over the last few decades industrialization and the accompanying processes of urbanization have led to a very different land-use patterns, economic structure and livelihood bases. Political organization has also changed. Floods are much more threatening events to urban areas.

Flood disasters are now the most frequent and devastating natural disaster in monsoon Asia. Their impacts have grown in spite of our improved ability to monitor and describe them in part because the expansion of urban areas into flood plains and wetlands places additional people and infrastructure at risk. Land-use changes, in particular, to flood plains and riparian ecosystems, and also runoff characteristics of watersheds have implications for the onset, distribution, speed and quality of flood waters.

As a result societies usually spend increasing amounts to protect and rebuild damaged flood protection structures (Takeuchi, 2001). Societies respond in various ways, including investing in flood-protection measures, land-use regulations, early warning systems and so on (Lebel *et al.,* 2006b). Structural interventions to protect valuable urban-based assets, like city business districts, may shift risks of flood disasters onto other people and places. The actions of governments and communities during and immediately after major floods can also be critical for exacerbating or limiting disasters, especially with respect to health and the livelihood security of vulnerable groups. Inadequate assistance and inappropriate interventions can recreate the conditions for the next flood disaster.

Changes to the Asian monsoon system, by altering flood regimes, may compound the existing challenges of managing floods in urbanizing regions by altering flood regimes. There are several possible pathways. First, increasing sea levels exacerbate risks of flooding of cities in coastal zone deltas (Dutta and Babel, 2005, Dutta *et al.,* 2005). Second, the increasing frequency of extreme precipitation events is important apropos landslide risks and the risks for settlements in upland areas or sudden the river bank floods in lower flood plains. Third, climate change impacts on melting glaciers in the uppermost reaches or reduced precipitation in inland continental areas. Concurrent changes in land and water use may exacerbate or reduce the effects of changes in climate on disaster risks.

Flood issues are important in both rural and urban settings. It is for the benefit of cities, however, that most intervention measures are taken to modify flood regimes. For this reason a priority focus in MAIRS on floods and urbanization is appropriate.

Researchable questions. Key questions for MAIRS include:

What changes to flood regimes in urbanizing regions are occurring as a result of interactions between *climate, land and water uses in monsoon Asia?*

How have these changes in flood regimes altered the vulnerability of different social groups in urban and surrounding rural areas? What are the main impacts of changing flood regimes on health and livelihoods?

How have urban societies responded to major flood events and changes in flood regimes in the past?

What are the main actions that can be taken in the next few decades to reduce urban vulnerabilities to changes in flood regimes in the monsoon Asia?

2.5.4 Urbanization and Water Security

As important an issue as floods are seasonal or longer-term scarcity of water is also affected by global environmental changes (Global Water System Project 2005). The MAIRS program needs to address issues of both overabundance and scarcity of water.

Rationale. Water security is emerging as an increasingly important and vital issue for the monsoon Asia region. As the region's population and economic growth continues to surge, the demand for water is increasing substantially, without a concomitant increase in water resources. Many Asian countries are beginning to experience moderate to severe water shortages, brought on by the simultaneous effects of agricultural growth, industrialization and urbanization. Among other issues, urbanization is expected to shift water out of agriculture to supply drinking water for growing cities (Kramer, 1999). In China, growing industrialization and urbanization are requiring increased amounts of water, the same water that would have gone to agriculture. Roughly half of China's cultivated land is irrigated; as demand for water rises, the country will need to deploy water-saving and waste-treatment technology (Postel, 1998). The economic consequences of water shortages in China are significant: Water shortages in cities cause the loss of an estimated US$11.2 billion in industrial output each year. India is experiencing similar shortages; as far back as 1998, the government warned that per capita availability of freshwater in India was declining due to rapid population growth and industrialization.

In recent years evidence indicates that water security is becoming increasingly affected by climate change. Several countries in the region have experienced severe droughts. In the future, climate change impacts on water resources may increase water stress in the region. Climate change challenges existing water resource management practices by adding uncertainty. The historic basis for designing and operating infrastructure no longer holds with climate change because it cannot be assumed that the future hydrological regime will be the same as that of the past.

Industrial and domestic sources of pollution are linked to water quality deterioration in most Asian countries. In Asia, roughly 90 to 95% of all domestic sewage and 75% of all industrial waste is discharged into surface waters without any treatment (Anonymous, 1998). All of India's 14 major rivers are polluted, primarily because they are used to dispose 50 million m^3 of untreated sewage into India's coastal waters every year. New Delhi alone is responsible for dumping more than 200,000 m^3 of raw sewage and 20,000 m^3 of industrial waste into the Yamuna River that passes through the city on its way to the Ganges. The same trend can be seen in many Southeast Asian countries. In Malaysia and Thailand, pollutants in these nations' rivers — such as pathogens, heavy metals and various poisons from industry and agriculture — regularly exceed government standards by 30 to 100 times.

Figure 2.5.3. *Recycling is still very limited (source: internret)*

Water in urban areas is also wasted. In many urban cities in Asia, water is lost due to leaks in municipal water networks which could be as high as 50% (Bequette, 1998).

Another concern in the region is growing competition over shared water resources. Singapore, for example, is highly dependent on (and vulnerable to) Malaysia for its water supplies. Many nations, such as those in the Mekong Delta region, share water resources and depend on mutual cooperation for continued fresh water supplies. Meanwhile, plans for massive cross-border transbasin water diversions are posing another set of social conflicts and risks to ecosystems. In South Asia, conflicts over freshwater has strained relations between India and Bangladesh, as well as India and Pakistan. In the future, diminishing and degraded freshwater resources could lead to internal instability in many nations, and possibly even spark interstate conflict.

Water security is an important issue in both rural and urban settings, but it is in cities that the changes in consumption needs are greatest. It is in cities that most intervention measures are made with changes to allocation policies; this alters water security in both urban and non-urban areas. For this reason a priority focus in MAIRS on how urbanization affects water security in the context of changes to the Asian monsoon is appropriate.

Researchable Questions

Which urban water sources (surface and groundwater) are most vulnerable to changes in the monsoon?

To what extent is urbanization influencing water demands and water allocation in different sectors?

What are the impacts of increased urbanization on water quality, especially, those aspects important for health and ecosystem functions?

How are groundwater in coastal regions and sea-water intrusions being affected by climate change and urbanization?

How will the rapid urbanization affect current regional water-sharing policies? How are conflicts over shortages resolved in transboundary water resources?

What institutional capacity do different societies have to cope with changes in supply and demand?

What role can technology play in urban environments in improving water-use efficiency and quality control?

2.5.5 Implementation Issues

Design. A two-level design is desirable. First, large-scale regional studies covering multiple cities and towns in urbanizing regions are needed to test ideas about urbanization impacts on emission budgets, flood regime changes and water security issues. Second, more detailed and focused, multi-site, multi-centre, comparative studies around particular human settlements or clusters need to aim at understanding specific social processes and emission or resource-use issues.

Large Regions. Two larger-scale regional studies appear to have high potential. Within the region there are several locations undergoing rapid urbanization for which there are substantial monitoring networks already in place as well as histories of emission inventory research. These would be ideal locations for more integrated comparative studies. Initial candidate areas include the Yangtze River Delta Region (Shanghai) and the Indo-Gangetic Plain (Delhi). In both regions a dense network of observing systems is available. For the Yangtze River Delta, these are the China EPA network plus research networks. For the Indo-Gangetic Plain there are similar networks and research sites. In addition, there are Atmospheric Brown Cloud observatory stations. Remote sensing opportunities are available from satellites and aircraft.

The Yangtze River Delta Region (YRDR) covers 99,000 km^2, or 1% of the Chinese land area, and is home to around 90 million people. YRDR is one of the most economically developed, densely populated areas in China. YRDR plays an important role in China's economy, 21% of the China's GDP came from the YRDR in 2002. The YRDR holds half of the 100 richest counties in China. Air pollution is a serious environmental problem. For example, it has resulted in reductions in annual cumulative number of hours of sunshine of 300 hour over the past 50 years. Temperatures in YRDR cities have risen relative to surrounding areas, as have the number of days with heavy rain.

The Indo-Gangetic Plain spans northern and eastern India, Pakistan, Nepal and Bangladesh. The fertile alluvial soils fanned out by the Ganges and Indus rivers have been a major area for cultivation and civilization over millennia. Over the past several decades agricultural land and water resources have come under increasing pressure for alternative uses related to urban industrial development (Aggarwal *et al.* 2004, Lepers *et al.* 2005). This intensification complicates strategies to adapt to and cope with the likely impacts of climate change in the region. Moreover, emissions associated with rural and urban activities have grown tremendously with prospects of local and larger-scale implications for atmospheric quality and climate (Mitra and Sharma 2002, Aggrawal *et al.* 2004).

In both regions dense network of observing systems are currently available. For Yangtze river Delta, these are China EPA network plus research networks. For Indo-Gangetic plain similarly we have CPCB networks and research sites. In addition, there are ABC observatory stations. In addition, remote sensing opportunities are available from satellites and aircrafts.

Work under priority subtheme 1 is particular suited to these two large regions, but there are advantages to also addressing water-related work here as well.

Multi-centre Comparative Studies. Multi-centre studies should, wherever possible, build upon locations with good research foundations, especially where there is good historical information. An effort should also be made to expand the set beyond the "well-studied", often largest city areas, along dimensions like providing insights into different urbanization contexts, urban roles or forms.

Policy Relevance. Each of the three areas of proposed work under the urbanization theme would provide good opportunities for the involvement of practitioners and policy-makers in study designs and dialogues around findings of primary research. The main impact should be a better understanding of the opportunities and limits of urbanization as an entry-point to managing air quality, flood disaster risks and water security.

Capacity Building. The MAIRS program overall should make an effort to securing the involvement of least developed countries in particular Cambodia, Bangladesh and Lao PDR. Vulnerability in these countries to changes in the monsoon may be particularly high. Research in these countries, in particular, should be open to opportunities that urbanization could have for reducing vulnerabilities.

2.5.6 Program Linkages

The MAIRS program will need to liaise closely with several existing projects in the international global change (science) programs that have programmatic overlap and high potential for the development of studies of mutual interest. The IHDP's new core project on Urbanization (Sanchez-Rodriguez *et al.* 2005) addresses both vulnerability and contributions to global environmental change issues and would be useful for all three priority areas.

The Global Carbon Project (2003) activities on urbanization, regional development and carbon management are highly relevant to the first priority area. The Urban Transformation and Urbanization Research Network (U-TURN) has brought collaborators together in South and Southeast Asia (www.sea-user.org/uweb.php?pg=17) to look at the social side of carbon and air quality management. Other research groups have done studies of large cities in China, Japan and Korea (Bai and Imura 2000, Bai 2002, Dhakal, 2004). MAIRS could make a major contribution by bringing these networks together.

Work on flood disaster management in the MAIRS region has largely taken place at the interface of several projects, including GECHS and IDGEC in IHDP, and various climate-related projects coordinated by START. Much of this work has had a significant urban focus. The Institutions Flood Asia network (www.sea-user.org/uweb.php?pg=18) has successfully completed collaborative studies cutting across South, Southeast and Northeast Asia networks and could be a good starting point for additional work on this theme (Nikitina 2005, Lebel *et al.* 2006c).

Work on the impacts of urbanization on water security fits closely with the agendas of the Global Water Systems Project (2005) and the IHDP-GECHS program. Relative to the other two subthemes this topic has been comparatively neglected within the global environmental change programs, with much more action and progress outside them.

In all three subthematic areas there are significant bodies of research and synthesis being carried out by national and international organizations which would be of benefit to MAIRS.

CHAPTER 3

IMPLEMENTATION OF INTEGRATED STUDIES

This chapter characterizes the most important approaches and modus operandi for integrated regional studies.

3.1 Introduction

A number of issues related to the implementation of integrated research studies needed to be considered in the development of this strategic science plan. For example, it is important to account for the opportunities and challenges associated with the conduct of research across the Asian region, as well as for the potential benefits of effective interaction with the broader research community and with policy-makers. The following key issues are now considered:

(i) Data availability and relevance,
(ii) Modeling,
(iii) Regional studies,
(iv) Capacity building,
(v) Regional and international links,
(vi) Contributions to sustainable development.

Each of these issues will affect the manner in which the science plan is implemented and may even affect the specific aims of specific research projects.

3.2 Data Availability and Relevance

Integrated research studies in monsoon Asia will require data from a variety of sources. However, differences in geography and development mean that the availability of the required data varies significantly across the region. Basic meteorological and hydrological data are generally available, but the rugged terrain of some areas can limit these data. Moreover, it is apparent that some countries still restrict access to their meteorological data. Other data types, such as ecological data, are not collected routinely and so their existence is linked to the interests of the research community associated with each region. Thus, these data tend to be collected intermittently and, while they are readily available in some more developed countries, there may be very few such data in other countries.

An important aspect of MAIRS projects will be to conduct an initial inventory of the availability of data required to carry out each project. Even where relevant data are available, it is likely that they will not be in digitized form and so efforts will be required to digitize and archive data to support analysis for MAIRS projects. It will be important to ensure that scientists from the country of origin of data are involved in the analysis of such data. This approach provides a strong incentive for countries to cooperate in joint projects.

It is also expected that new data will need to be collected to support MAIRS projects. Such data will usually be collected in specific field campaigns linked to the objectives of projects. Alternatively, opportunities will be sought where MAIRS can initiate sustained activities that will lead to the establishment of long-term homogeneous observations that can be used for climate change studies. An example of sustained measurement sites would be the creation or consolidation of reference networks where high-quality data would be collected across a range of disciplines, to support integrated studies.

It is expected that MAIRS will develop a formal data policy, which will promote open access to data used in MAIRS studies and which will be consistent with ICSU's data policy. Such a policy will need to be sensitive to differences in culture in different countries, but it will also need to ensure that data collected in MAIRS projects are available to the research community across monsoon Asia. Current trends in information technology support the development of distributed data systems which will allow each participating group to maintain its own data but afford ready access to all data.

Because MAIRS has a focus on integrated studies, it is expected that a range of data types will be collected, archived, shared and analysed. The size of monsoon Asia means that satellite data will be especially important for providing information on the environment across large regions of varying terrain. The satellite data will generally be linked to specific *in situ* data for calibration and validation purposes. While the handling and analysis of large data sets can be difficult for smaller research groups, the MAIRS policy will be to promote access and analysis capacity in all groups associated with each project.

3.3 Modeling

Modeling will be an essential aspect of MAIRS integrated studies, as it is the means for combining data and information from a range of sources to simulate processes in a consistent manner. Modeling also provides the means for dynamic prediction of future states of the environment in monsoon Asia. The development and evaluation of models will depend upon access to relevant observations across the region, and so modeling will be an integral component of any field project in MAIRS. Some work will be required to ensure that field data are readily accessible and are in a suitable form for assimilation into or comparison with numerical models.

Across monsoon Asia, countries are keen to develop capacity in modeling and MAIRS should contribute to the development of this capacity in at least two ways. First MAIRS will provide a link between the regional modeling activities and those carried out through the global programs of WCRP and IGBP. Secondly MAIRS will promote collaboration in modeling across organizations in monsoon Asia. A possible strategy for supporting modeling across the region could be the establishment of a regional modeling network or working group, which would provide a forum for the exchange of knowledge and code, as well as for the design and implementation of collaborative studies to advance modeling in all participating organizations. The group would have formal links with the modeling activities of the global research programs, so that duplication would be minimized and there would be mutual benefits from exchange of knowledge.

It is likely that MAIRS studies will involve analysis of the potential impacts of future climate change, and such studies can benefit from the application of regional scenarios of future changes. The MAIRS modeling network could provide a forum for optimizing the preparation and dissemination of such scenarios. It would be desirable for a suite of regional scenarios to be prepared, consistent with global scenarios being developed through the IPCC process and which consistently add detail relevant to monsoon Asia.

3.4 Integrated Regional Studies

The focus of MAIRS is on integrated research studies across monsoon Asia; these will have substantial benefits and some associated challenges for all participating countries. The regions of interest will be determined by the natural environment rather than political boundaries, and so the studies will take into account the full scope of interactions in each region. These interactions may be associated with physical connections, such as the transport of pollutants across a major airshed, or with connections between different elements of the environment, such as the recharge of groundwater by precipitation, or with societal impacts, such as the effect of the use of groundwater for agriculture in a catchment area. The studies will need to be multidisciplinary, involving teams of scientists from across institutions and countries in the region.

Box 3.1. The regional studies of MAIRS will be integrated in several ways across:

- National boundaries, recognizing the natural geographical extent of a problem.
- Research disciplines, recognizing that most problems will involve interactions across the physical, chemical, biological and even societal aspects of the climate system.
- Community sectors, recognizing that it is desirable for the scientific community to work with the operational and policy communities to enhance the societal impact of their work.
- Research methods, recognizing that most problems will require field studies and the analysis of data, as well as theoretical and modeling studies.
- Data types, recognizing that data will need to be accessed from a range of sources, including *in situ* research studies, satellite programs and routine monitoring agencies.

A significant benefit of the regional studies will be the analysis of transboundary problems that are usually not considered by individual nations. Moreover, because of their regional nature, they are not the formal responsibility of the global research programs. The focus on complete regions will also lead to the analysis of downstream impacts associated with both transport problems (such as the transport of pollutants in air and water) and resource availability (such as the reduction in stream flow due to the extraction of water from long rivers for agriculture and urban use).

While integrated studies will be very informative and useful, their implementation will pose a number of challenges. It will be vital to develop a team approach involving scientists from a range of relevant disciplines and from all areas and countries in the specified region. It will also be necessary to ensure that cultural and political sensitivities are recognized in designing and implementing each project. These issues are likely to be especially important in the collection and archiving of data and in the dissemination of the results of regional analyses.

3.5 Capacity Building

With its focus on integrated regional studies, MAIRS should provide many opportunities for capacity building across monsoon Asia. The current scientific capacities vary greatly across the region. An objective of MAIRS is to promote the enhancement of research skills particularly in the institutions and regions where current capacities are limited. This objective will be partly met through the development of collaborative studies across the region, so that scientists from different institutions work closely together. The skills of individual scientists could also be enhanced through exchange programs where scientists can spend a reasonable time working in laboratories in different countries in monsoon Asia.

Global environmental change in the Earth System is a relatively new area of study, and many universities do not offer either undergraduate or graduate courses in Earth System Science (ESS). However, the relevance of ESS to societal needs is becoming increasingly clearer, as demonstrated by the range of priority research areas identified in the MAIRS science plan. It would therefore be appropriate for MAIRS to promote the establishment of both undergraduate and graduate studies in ESS in universities across monsoon Asia.

The establishment of processes for the collection, archiving and dissemination of data and information should assist capacity building in MAIRS. Joint field projects will enhance the skills of all people involved in each project, and the subsequent archiving of the field data through mechanisms with open access to the MAIRS community will further promote capacity enhancement. Current trends in computing and communications technology suggest that field and other MAIRS data could be effectively archived and accessed in distributed systems, which will ensure that all participating centres develop the relevant data handling capacity.

All countries are interested in developing capacity in modeling. As models become more complex, large-scale teams are needed to develop and support such systems. This development suggests that MAIRS, while promoting the skills of individual scientists and institutions, may also need to promote a collaborative modeling effort across the region. Independent of any model development activities, MAIRS will seek to enhance access to state-of-the-art models across monsoon Asia and to enhance the capacity of groups to apply these models to regional problems.

Box 3.2 Contributions to sustainable development.

While recognizing that MAIRS is focused on scientific research and that sustainable development depends upon complex interactions between science, technology and politics, it is expected that the results of MAIRS studies will contribute to activities in countries across monsoon Asia aimed at sustainable development. These contributions will be achieved through communication activities that are carefully targeted at relevant communities. It will be especially important for MAIRS communication activities to have a regional focus and to be sensitive to cultural and political differences across the region. As a science program, MAIRS communications will involve the dissemination of the scientific results of its projects to a range of sectors in monsoon Asia. The extent and scope of the communication activities will be determined by a balance of resources and research priorities in MAIRS. A key determinant of the nature of communication activities will be the perceived needs of different sectors.

3.6 Regional and International Links

The establishment of MAIRS will complement the activities of global research programs in two ways. First it will add regional detail to the essentially large-scale studies of the global programs. In developing MAIRS projects, scientists will draw on the results of the global programs. However, they will also identify issues at the regional level that have global implications, and so there will be a variety of interactions with the global programs.

To promote these interactions, it will be important for MAIRS to have links with relevant working groups in the global programs. A number of these links have already been identified in Chapter 2. It is also expected that the MAIRS Project Office will work closely with the program offices of the global programs.

Box 3.3. A communications strategy.

In order to ensure that MAIRS is recognized across relevant research and sectoral communities, an effective communications strategy will be developed. The strategy will be carefully targeted to optimize the outcome. The strategy will also allow for the range of cultural and economic differences across monsoon Asia.

3.7 Conclusions and Actions

The detailed implementation of MAIRS will be developed by the research community once the Initial Science Plan is completed, disseminated and considered. However, it is clear that certain issues need to be considered at an early stage. With the focus on integrated regional studies, it is necessary to start developing the mechanisms to establish the multidisciplinary and multinational groups to plan and carry out the required research. Such projects will generally be dependent upon funding from a range of agencies and countries, and so appropriate coordination processes will need to be developed.

The collection, archiving of and access to data will be a fundamental aspect of MAIRS, and so strategies and policies for these activities should be considered at an early stage. These strategies will need to account for differences amongst different disciplines and different countries.

A key integrating aspect of MAIRS is modeling, and so strategies need to be developed to promote optimal use of resources across the region that promotes the enhancement of access to and application of models. The modeling activities will need to be linked with relevant activities in global research programs, and also with existing regional activities.

The MAIRS research projects will involve field projects, analysis studies and modeling. Such activities are carried out in the subprograms of the global research programs, and MAIRS needs to establish effective links with the appropriate working groups of the global programs.

CHAPTER 4

ORGANIZATION AND STRUCTURE

This chapter presents the current organizational structure for the MAIRS program. It will evolve as the number of involved persons and organizations expands, linkages become more concrete and research approaches become more specific.

4.1 Introduction

MAIRS is a new international research program to address the coupled human and natural processes of environmental change in the monsoon Asia region. MAIRS was implemented by START at the request of the ESSP and the GEC programs. The MAIRS program is guided by a Scientific Steering Committee (SSC) and supported by an International Program Office (IPO) to reach its objectives effectively and efficiently.

The core of the MAIRS program consists of a working group, with projects, for each of the four scientific themes, and the SSC and the IPO. Research projects and working groups are the primary producers of research results and MAIRS will collaborate with many partners. The SSC reports to START; the IPO reports to the SSC and to its sponsors.

Box 4.1. The Vision of MAIRS

To significatntly advance understanding of the interactions between the human-natural components of the overall environment in the monsoon Asian region and implications for the global Earth System, in order to support the strategies for sustainable development.

To achieve its vision, the objectives of MAIRS are:

- To better understand how human activities in the monsoon Asia region interact with atmospheric, ter restrial and marine components of the environment, in particular with respect to irreversible thresholds and to major shifts in risks and vulnerabilities.
- To contribute to the provision of a sound scientific basis for sustainable regional development.
- To develop predictive capacity for estimating changes in global-regional linkages in the Earth System and to recognize the future consequences of such changes.

4.2 Projects

The building blocks of the MAIRS program are research projects and the scientists working in them — our partners. Some of these projects will be initiated by the theme working groups while other projects have been or will be developed separately as listed for the themes in Chapter 2. "MAIRS projects" are characterized as follows:

- They correspond with a part of the Initial Science Plan.
- They promote "integration".
- They involve partners in at least two of the three subregions from the region.

- Their partners agree to common data policies and ICSU-defined transparency.
- Their partners agree to share results with others and to dialogue with clients.

The MAIRS SSC will determine whether proposed projects meet the above criteria.

MAIRS will initiate and promote projects that deal specifically with improving understanding of (i) the resilience of the Asian monsoon system to human transformations of land, water and air, and (ii) vulnerabilities of societies within the region to changes in the Asian monsoon system. Collaboration with and building on ESSP and GEC projects, as well as other relevant activities, will be promoted, provided this will not reduce the focus on MAIRS objectives. Collaboration brings in more and specific expertise and knowledge about research issues, accelerating research and increasing efficiency, and it disseminates research results to a wider community, thereby increasing relevance.

4.3 Working Groups

There are working groups for each of the research themes and for specific cross-cutting tasks.

The theme working groups consist of projects and other thematic activities and comprise the persons active in research, capacity building and/or advocacy for that theme. The role of the working groups is to focus our resources on the top priorities of MAIRS, and to lead and foster scientific progress in the theme through planning, synthesis, conferences and workshops. Projects from ESSP and GEC programs, as well as other Earth System research activities, can participate in theme working groups.

The role of a task group is to lead and execute cross-cutting tasks and to integrate them with the efforts of other projects and organizations. Task groups are needed for resource mobilization, for data policies and management, for harmonization of modeling approaches, as well as for capacity building in Asian Earth System science.

Each working group is led by a member of the SSC. The IPO will provide support to the leaders and to the working groups.

4.4 Governance

Governance of the MAIRS program with respect to science and cooperation is the responsibility of the SSC. The SSC leads and guides the consortium with respect to planning, development and implementation. Its primary functions are to:

- Lead, guide and oversee development, planning, implementation and scientific integrity.
- Ensure use of integrative approaches and methods.
- Promote programmatic linkages and collaboration with international and regional programs and agencies concerned with global environmental change.
- Assure relevance through a dialogue with client groups.
- Encourage governments and funding agencies to support research that contributes to MAIRS objectives.

The SSC consists of up to 15 leading international scientists and experts from different disciplines, with emphasis on experts from countries in the monsoon Asia region. (The names of the current members are listed on the back page). The first SSC members and the chairperson were appointed by the SSC of START after consultation with the ESSP and GEC programs. Three vice-chairpersons were elected among its members.

4.5 Facilitation

Activities of the SSC and working groups are facilitated by an International Program Office (IPO).The IPO is a small unit to support and advance the MAIRS consortium on a day-to-day basis. It functions under the guidance of the SSC. It is located at the Institute for Atmospheric Physics of the Chinese Academy of Sciences in Beijing, PR China. The office was formally established in January 2006 and has facilitated the development of this Initial Science Plan for MAIRS. The IPO is sponsored by the Chinese Academy of Sciences and the Chinese Ministry of Science and Technology. It can fund small synthesis projects and support activities, but does not fund research projects.

4.6 Beneficiaries, Clients and Donors

The ultimate beneficiaries of research by MAIRS are (i) poor people in rural and in urban areas in Asia for whom adaptation to consequences of environmental change will be facilitated, and (ii) affluent consumers in the region for whom options for and constraints to sustainable regional development will be pointed out.

Figure 4.1. *Adaptation to and mitigation of environmental change. Upper left: Land use change shown by new farm ponds and diversification of crops (by P.Tipraqsa). Upper right: promotion of maximum resource use efficiency through micro-irrigation and fertigation of sugarcane (by T.M. Thiagarajan). Lower left: Solar energy (picture from internet). Lower right: large scale reforestation (picture from internet).*

The MAIRS program does not pass its results directly to these very large (hundreds of millions of people) and very diverse (socially, culturally, economically) groups of beneficiaries. Impacts will be achieved through "clients*": organizations that can reach and influence the target groups. The clients* include (i) policy-makers and managers in national and local governments and their think-tanks, (ii) national, regional and international organizations that fund Earth System research, (iii) policy-makers and managers in private sector enterprises, as well as in investment banks that promote their development and (iv) journalists and NGOs for mass communication media in the monsoon Asia region.

To reach its objectives MAIRS will sustain and expand its engagement with national and international donors.

4.7 Products

The MAIRS program expects to generate the following products:

- The projects and working groups will produce scientific results and insights. Results published in appropriate channels increase understanding and knowledge, and contribute to building a sound scientific basis for regional development.
- Individual and institutional capacity will be built in Earth System science in monsoon Asia.
- The IPO will support research, communication and synthesis, through:
    - a website and a newsletter — both to serve the science community with science information and ongoing events, as well as facilitated electronic discussions;
    - a publication channel for working papers and reports of scientific research;
    - databases on human resources in the region (scientists, projects, clients).

4.8 Partners

MAIRS will have many partners in research activities and other forms of collaboration. Important groups are:

- START Regional Centres. These centres for research on environmental change were created in South Asia, Southeast Asia and temperate East Asia a decade ago. The centres are well integrated in subregional structures. They will provide stepping stones to a fully fledged MAIRS consortium. Their directors are members of the MAIRS SSC.
- The ESSP and the GEC programs. Their core projects and joint projects provide opportunities for joint action and are scientific sounding boards for new understanding. Actual linkages are specified in Chapter 2.
- Projects that are developed by other organizations and regional networks. Examples are specified in Chapter 2.

CHAPTER 5

NEXT STEPS

This chapter presents activities that MAIRS will undertake in the near future.

Several activities by MAIRS are anticipated in the next few years. They relate to developing actual projects, activating the organizational structures, development of resources for the research and preparing capacity building and science communication. Most of these activities will occur in parallel.

Development of actual projects. The development of scientific projects is the major function of MAIRS and will be led by the SSC and the theme working groups with the support of the IPO. It is expected that some projects will be developed in collaboration with existing programs, while others will be established by MAIRS alone. Collaborative projects will involve the establishment of MAIRS-related activities that intersect with the interests of a partner program. Where other existing programs do not have activities on MAIRS issues, new projects will be established with relevant science communities across monsoon Asia. It will be important for MAIRS to be clearly focused on outcomes. Suitable projects for fast-track development will be promoted by the SSC in the early stages of MAIRS. In this way, MAIRS will develop a balanced portfolio of projects that will deliver useful outputs and outcomes over the lifetime of the program. Project development and implementation need science inputs, such as from state-of-the-art conferences, extensive interaction with ESSP and GEC partners, as well as, to the degree feasible, inputs from clients* of our research. Consultation with many Asian and other scientists is needed since a participatory process is at least as important as its outcomes. A particular challenge is to encourage the involvement of countries whose scientific capacity in the field of global environmental changes and Earth System science is still small.

Activating the structures. The organizational structures need to be fully implemented. This has internal and external aspects. The *internal aspect* is that theme working groups will be set up and activated. A major activity of each working group will be to hold a conference with participants from across monsoon Asia to: (i) bring together scientists and information to establish (and publish) the state of the art in the theme and (ii) to plan new research activities, information exchange and cooperation. Where feasible, we will organize such conferences with other organizations. Data are a key issue for MAIRS so we envisage organizing a workshop to identify the sources of public data that can be made available rapidly for MAIRS projects. Likewise, modeling is a key methodology in MAIRS where harmonization of existing approaches is needed at an early stage. The *external aspect* refers to relations with other Earth System scientists and their organizations. The extent of the role of MAIRS in the ESSP and the International Earth System Science Community is not yet set and needs further development.

Capacity building. Reaching MAIRS objectives and its Vision will be accelerated by boosting the number of Earth System scientists in the monsoon Asia region and by strengthening their individual and institutional capacities for integrated research. MAIRS intends to cooperate with START and its regional centres to seek partners to develop university curricula on Earth System Science with a special focus on the monsoon Asia region. Among the courses will be environmental law and economics and disciplines to effectively link science with policy-making. Distance learning will be explored for students from all MAIRS countries to "enable scientists from all countries to participate in emerging scientific areas" (ICSU, 2005).

Resource mobilization. Of particular importance for a new program like MAIRS is the mobilization of human and financial resources, i.e. collaboration with partners with respect to scientists' time, access to facilities and data and the financial support of donors. MAIRS does not plan to become a donor for research funding, but it will cooperate and provide guidance to national and international organizations for global environmental research. Likewise, MAIRS will not employ staff members for research, but it will facilitate and support scientists from other organizations to join in working groups. Therefore, MAIRS will promote its Initial Science Plan among potential science partners as well as among stakeholders and donors.

Regional integration. The integrative nature of MAIRS is already implied in the critical questions about environmental change mentioned in the introduction to the research themes and in the executive summary. However, research projects, typically cannot address simultaneously all questions in the entire monsoon Asia region. For reasons of research efficiency, we proposed four research themes that each cover a large part, but not all, of the science field. The integrated study for entire monsoon Asia region across four critical zones will be undertaken as the second level of the integrated study.

CHAPTER 6

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6.2 Acronyms and Abbreviations

ADAM	Adaptation and Mitigation Strategies
ADB	Asian Development Bank
APN	Asia-Pacific Network for Global Change Research
AMMP	Asian and Australian Monsoon Panel
B.P.	Before Present
CDAS	Categorical Data Analysis System
CEOP	Coordinated Enhanced Observing Period
CERN	Chinese Ecosystem Research Network
CGIAR	Consultative Group on International Agricultural Research
Clic	Climate and Cryosphere
CLIVAR	WCRP Climate Variability and Predictability Research Programme
CMAP	Climate Modeling, Analysis and Prediction
CPCB	Central Pollution Control Board
DIVERSITAS	An Integrated Programme of Biodiversity Science
DIVPA	DIVERSITAS in Western Pacific and Asia
ENSO	El Niño Southern Oscillation
EPA	Environment Protection Agency
ESS	Earth System Science
ESSP	Earth System Science Program (before 2007: ESS-Partnership)
FAO	Food and Agriculture Organization of the United Nations
GCOS	Global Climate Observation System
GCP	Global Carbon Project
GEC	Global Environment Centre Foundation
GECAFS	Global Environmental Change and Food Systems
GECHS	Global Environmental Change and Human Security
GEOSS	Global Earth Observation System of Systems
GEWEX	Global Energy and Water Cycle Experiment
GPCP	Global Precipitation Climatology Project
GSFC	NASA Goddard Space Flight Center
GWSP	Global Water System Project
IAI	Inter-American Institute for Global Change Research
ICSU	International Council for Science Unions
IDGEC	Institutional Dimensions of Global Environmental Change
IGAC	International Global Atmospheric Chemistry
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimensions Program
iLEAPS	Integrated Land Ecosystem-Atmosphere Processes Study

IMBER	IGBP Integrated Marine Biogeochemistry and Ecosystem Research
IPCC	Intergovernmental Panel on Climate Change (UN)
IPO	International Project or International Program Office
LOICZ	Land Ocean Interactions in the Coastal Zones
MAIRS	Monsoon Asia Integrated Regional Study
MAHASRI	Monsoon Asian Hydro-Atmosphere Scientific Research and prediction Initiative
MODIS	Moderate Resolution Imaging Spectroradiometer
MRI	Mountain Research Initiative
NASA	National Aeronautic and Space Administration (USA)
NCAR	National Center for Atmospheric Research (USA)
NCEP	National Center for Environment Prediction (USA)
PSDI	Palmer Drought Severity Index
REIMS	Regional Environmental Integrated Modeling System
RMIP	Regional Model Inter-comparison Project
SARCS	Southeast Asia Regional Committee for START
SASCOM	START South Asia Regional Committee
SCOPE	Scientific Committee on Problem of the Environment
SOLAS	Surface Ocean Lower Atmosphere Study
SSC	Scientific Steering Committee
START	System for Analysis, Research and Training
TOMS	Total Ozone Mapping Spectrometer
TEACOM	START Temperate East Asia Regional Committee
UNEP	United Nations Environment Programme
UN-ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
U-TURN	Urban Transformation and Urbanization Research Network
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
YRDR	Yangtze River Delta Region

6.3 Glossary

Airshed: is a geographical region, determined by orography and meteorological conditions, in which air quality conditions are affected by a common set of pollution sources.

Clients: Persons and organizations that interact with MAIRS to learn about its results and to propose its research priorities; clients are the intermediaries between MAIRS and the ultimate beneficiaries of the research.

Cryosphere: The portion of the world's climate system which consists of snow and ice deposits including ice sheets, ice caps, glaciers, seasonal or permanent snow cover, lake and river ice, permafrost and frozen ground.

Earth System Science: Earth System Science undertakes to understand how the Earth is changing and the consequences for life on Earth with a focus on enabling prediction and mitigation of undesirable consequences. This requires an identification and description of how the Earth System is changing, the ability to identify and measure the primary forcings* on the Earth System from both natural and human activities, knowledge of how the Earth System responds to changes in these forcings, identification of the consequences of these changes for human civilization and finally, the ability to accurately predict future changes with sufficient advanced notice to mitigate the predicted effects. (From: http://education.gsfc.nasa.gov/esssproject/ess_definition.html)

Earth System dynamics: The interactions and feedback between the component parts of the Earth System. These exhibit multiscale temporal and spatial variability. Understanding of the Earth System's natural dynamics has advanced greatly in recent years, and now provides a sound basis for evaluating the effects and consequences of human-driven change. (From: www.essp.org).

Ecosystem services: The benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth. (From: http://www.greenfacts.org/links/site-boxes/ma.htm)

Ecotone: A transitional zone between two communities containing the characteristic species of each.

Environment: The complex set of physical, geographic, biological, social, cultural and political conditions that surround an individual or organism and that ultimately determine its form and nature of its survival (UNESCO, 2005). "Environment" and "Natural Resources" are sometimes used synonymously.

Forcing of climate change:

anthropogenic forcing: human activities that cause the climate system to change, e.g. through greenhouse gases.

natural forcing: natural processes that cause the climate system to change, e.g. the ENSO.

GLOF: Glacier retreat and shrinking can form moraine lakes with unstable outflow, which can produce sudden and major glacier lake outburst floods.

Lifestyle: Consumption pattern of natural resources, both directly and indirectly. It is strongly related to income and technology.

Monsoon Asia region: The contiguous region of Asia, including East, Southeast and South Asia. It comprises all Asian countries where the seasonally varying monsoon circulation is clearly felt, and the surrounding fresh- and saltwater bodies. The region includes Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia, China including Taiwan, India, Indonesia, Japan, N. Korea, S. Korea, Laos, Malaysia, Mongolia. Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand and Vietnam. The MAIRS logo shows their combined territory.

Natural resources: Materials that occur in nature and are essential or useful to humans, such as water, air, land, forests, fish, wildlife, topsoil and minerals. (Future harvest Institutions, 2006.) "Natural resources" and "Environment" are sometimes used synonymously.

Scenario: A plausible description of how the future may develop, based on a coherent and internally consistent set of assumptions about key relationships and driving forces (e.g. rate of technology changes, prices). Note that scenarios are neither predictions nor forecasts. (IPCC, 2006).

Transformation (social transformation)*:* the major changes that societies undergo with respect to their activities, livelihoods and use of natural resources.

Zones in MAIRS

The total geographic area with particular biophysical and socio-economic characteristics. Each of the four zones is not contiguous and together they do not cover the total surface area.

Coastal Zone: The land along the coastline up to 100 km inland, and below the sea surface down to 200 m depth.

Mountain Zone: All land over 1,000 m in elevation.

Semi-arid Zone: Land where the average annual precipitation is less than the annual potential evapotranspiration.

Urban Zones: Urbanization results from population growth and migration. Once settlements reach a certain threshold size or density they are formally recognized as urban by their national governments. But change in density is only one aspect of urbanization. As the nexus of multiple production-consumption systems urbanizing regions function to meet and stimulate people's needs and wants such as for mobility, shelter, diet, work and play. Urbanizing regions have roles with respect to other places, for example, as centres of manufacturing, political power, commerce or innovation. Spatial organization, or urban form, has several dimensions apart from density and size. As a result of these other considerations what is considered "urban" is a negotiated and dynamic label.

The vision of MAIRS is "To significantly advance understanding of the interactions between the human‑natural components of the overall environment in the monsoon Asian region and implications for the global Earth System, in order to support the strategies for sustainable development".

MAIRS objectives are:

- To better understand how human activities in the monsoon Asia region interact with atmospheric, terrestrial and marine components of the environment, in particular with respect to irreversible thresholds and to major shifts in risks and vulnerabilities.
- To contribute to the provision of a sound scientific basis for sustainable regional development.
- To develop predictive capacity for estimating changes in global-regional linkages in the Earth System and to recognize the future consequences of such changes.

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