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• **Review** •

From Climate to Global Change: Following the Footprint of Prof. Duzheng YE's Research

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ABSTRACT

To commemorate 100 years since the birth of Professor Duzheng YE, this paper reviews the contribution of Ye and his research team to the development from climate to global change science in the past 30 or so years, including: (1) the role of climate change in global change; (2) the critical time scales and predictability of global change; (3) the sensitive regions of global change—transitional zones of climate and ecosystems; and (4) orderly human activities and adaptation to global change, with a focus on the development of a proactive strategy for adaptation to such change.

Key words: Professor Duzheng YE, climate change, global change, human activity, proactive adaptation

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1. Introduction

Professor Duzheng YE is one of the founders of modern meteorology in China and an internationally distinguished earth scientist. Leaving a legacy of extensive knowledge and profound scholarship, his main contributions can be summarized by a number of important awards he received during his lifetime. Among these awards, the most influential were: The 2005 China National Preeminent Science and Technology Award, which is the highest praise one can receive for contributions to the development of science and technology, and in Prof. YE's case, to earth science from the perspective of atmospheric dynamics, climate theory and global change, as well as Earth system science as a whole. In 2003, Professor YE became the first Chinese recipient of the IMO Prize, in its 48th year. In the award announcement, the WMO indicated YE's "fundamental contributions to both basic and applied science in meteorology", particularly "the initiation of studies on global change and its relationships with sustainable development, orderly human activities and adaptation to its impacts".

In memory of the 100th anniversary of Professor YE, and for all of us who worked with him over the past several decades to celebrate his work, this paper reviews Professor YE's major contributions to the development from climate to global change science, both nationally and internationally, and how his research team followed his footprint in seeking to develop a strategy for proactive and orderly adaptation to global change.

2. Major contributions to the development from climate to global change science

Looking back on the history of international research programs in climate and global change, one can easily identify the footprint of Professor YE. Figure 1 summarizes the progress made in global change research programs under the framework of the ICSU (International Council for Science) and other international scientific organizations since the 1970s. In 1974, the WMO and ICSU organized an international workshop entitled "The physical basis of climate and climate modeling" in Stockholm. The workshop systematically reviewed the history of Earth's climate, the principles of climate formation, the physical/chemical/biological processes of the climate system, climate modeling, and observation. The transition from the classic definition of "climate" into the concept of the "climate system" marked the beginning of modern climate science (WMO and ISCU, 1975). This workshop provided the scientific foundation for the "First World Climate Conference" organized by the WMO in Geneva and, as a result of the conference, the World Climate Research Program (WCRP) was launched in 1979. Professor YE, as a member and officer of the Joint Scientific Committee (JSC/WCRP) during 1982–88, played an important role in the development of the WCRP's international program. Meanwhile, he also led a group of Chinese scientists

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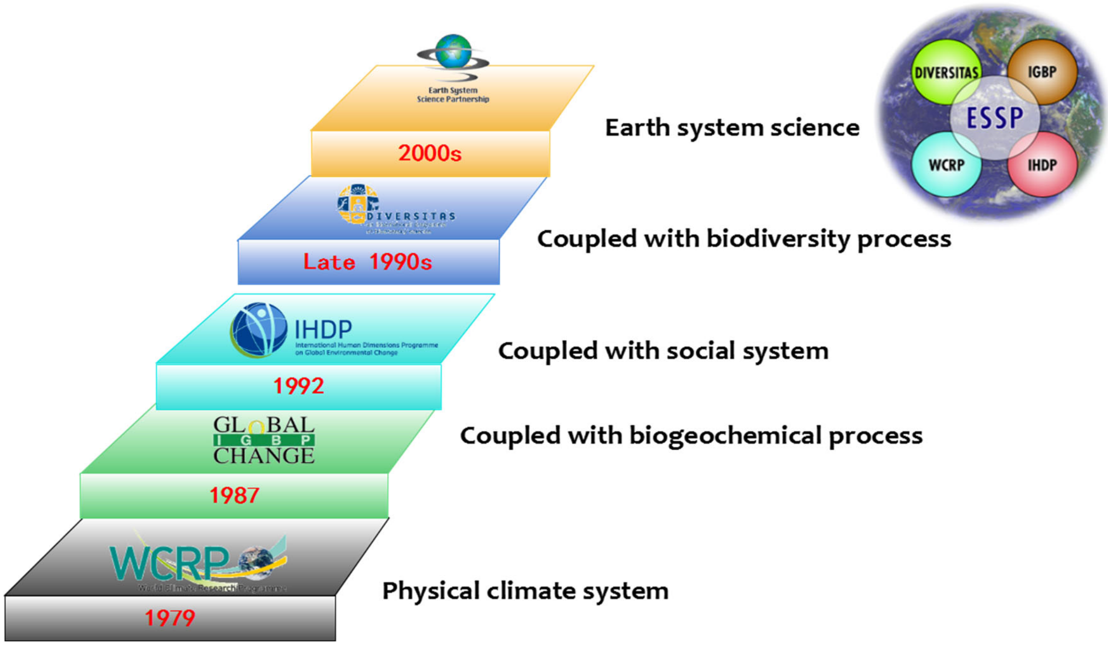

Fig. 1. Road map of the development of international global change research programs since the 1970s.

in establishing the China national committee of WCRP, and served as a chair of the committee during 1985–99. During this period, his research focused on the impact of land surface processes on climate. He, together with his colleagues, simulated the short-term climatic and hydrological effects of snow cover and soil moisture to reveal that such effects can last for several months (Ye et al., 1983, 1984). He emphasized that, similar to those of the ocean, land surface processes also have a "memory" effect on the climate, albeit lasting only for several months rather than the much longer time scales of the ocean.

Another milestone in the development of global change science was the launch of the International Geosphere–Biosphere Program (IGBP) of the ICSU. Tens of thousands of scientists from more than 70 nations participated in this endeavor. As early as in 1984, T. Malone and J. Roederer from ISCU came to visit China and to meet with YE and his colleagues by arrangement of CAST (China Association of Science and Technology). This discussion was the first time that the concept of "global change" was introduced and shared with Chinese scientists. The general idea of an "Earth system" was proposed based on ongoing climate research. Thereafter, YE and his team began to be involved in the planning process of this new program. In May 1984, Fu, a team member, was invited to participate in an authors' meeting in Moscow. In October 1984, a Chinese delegation attended the first Global Change Symposium in Ottawa, Canada, and YE and the author were invited to present a paper at the symposium (Yeh and Fu, 1985). During this symposium, it was agreed upon by the national delegates and participants that a new program was needed to integrate the biogeochemical and physical climate processes, in addition to the ongoing WCRP program. After a four-year feasibility study, the IGBP was formally launched by ISCU in 1988. YE was nominated as a member of the special committee of the IGBP. Later, YE led a group of Chinese scientists in establishing the China National Committee of the IGBP, and carried out a systematic review of related ongoing research in China (Ye et al., 1992). As YE's successor, Fu served as a member of the scientific committee of the IGBP during 1990–96, and GAIM/IGBP during 1998–2002. During this time, YE and his colleagues made significant contributions to the development of the global change research program, not only in China but also at the international level. A global change regional center for temperate East Asia was established in China in 1994, in collaboration with all four global change programs (IGBP, WCRP, IHDP and Diversitas). It was the first center in the START (Global Change System for Analysis, Research and Training) family.

2.1. *Role of climate change in global change*

Since the development of the concept of the "climate system", YE and his team emphasized that climate change can no longer be considered only as the behavior of the atmosphere and ocean. Rather, it should be defined as the behavior of the whole climate system, consisting of the atmosphere, ocean, cryosphere, lithosphere, and biosphere. Under this new concept, climate change is not only the subject of climatology as it used to be, but also of multiple disciplines and of inter-disciplinary science between meteorology, oceanography, geology, glaciology, biology, and so on. In addition, climate change is really a global-scale rather than local-scale phenomenon, albeit it may vary in its finer detail from region to region. Therefore, studying climate change is a scientific problem of an inter-disciplinary nature and global scope: "It is our opinion that climate change and its prediction are qualified to be the central theme of IGBP" (Yeh and Fu, 1985).

On the other hand, it should be pointed out that global change encompasses more than just climate change. Whilst it is indeed the case that large parts of Earth's environmental changes are related to climate change, some changes can be the result of other Earth-related factors, such as volcanic eruptions, earthquakes etc., as well as external (astronomical) factors. Besides, human activities related mainly to societal development or collapse may also cause significant changes to Earth's environment (Yeh and Fu, 1985).

2.2. *Critical time scales and predictability in global change*

As IGBP Report No. 4 described, "a primary goal of the program is to advance our capacity to predict changes in the global environment". This is a scientifically exciting problem, as well as being immensely significant in charting the future of our species. YE and Fu were among the first in the scientific community to discuss the predictability of global change (Ye and Fu, 1989), based on an analysis of the "memory" of the system and two types of forcing factors, internal and external, as well as the adaptation among the components of the Earth system. Specifically, it was pointed out that internal forcing factors can be considered part of the natural course of the Earth system, over relatively long time scales, whereas external forcing factors—derived from human activities such as human-induced land-cover change and anthropogenic emissions of greenhouse gases—may be more important on scales of decades to centuries. The complexity of the predictability problem is manifested in the interaction between anthropogenic processes and natural processes. The reason for focusing on time scales of decades to centuries is to allow enough time for interaction among the components of the Earth system and, particularly, for human and natural processes to interact, which is the key issue in global environmental change. On such time scales, the human driving force is almost equal to, if not greater than, that of nature (Yeh and Fu, 1985; Ye and Fu, 1989; Ye et al., 2001). It was proposed that, faced with the highly nonlinear nature of the Earth system and the complexity of prediction, a good strategy would be to start with several components of the system, and then to address integrated prediction. However, until recently, success in dealing with the whole system was limited by the availability of computational resources, including the speed and storage capacity of super computers. Nowadays, though, this seems no longer a problem, but the complexity of predictability in theory nonetheless remains a key issue to be addressed.

2.3. *Sensitive regions of global change—transitional zones of climate and ecosystems*

Early in the 1980s, YE and his team raised the issue of regionality of global change based on the regional patterns of global climate change (Fu, 1989). It is very likely that there are regions that are more sensitive in response to both natural and anthropogenic forcings. The transitional zones of climate and ecosystems are perhaps one such type of region. These regions are characterized by their instability related to strong gradients of climate and biological variables (Fu, 1985, 1992b; Wen and Fu, 2000). For example, tropical rainforest zones are coupled with intertropical convergence zones in the global atmospheric circulation—transitional zones between the two hemisphere's trade wind systems or between the monsoon and trade wind systems. Both climate change and human-induced deforestation play crucial roles in the changes of tropical rainforests and demonstrate the strength of the interactions between biological processes, geophysical processes and human activities.

Another such region is the semi-arid region in northern China—a transitional zone between the inland arid region of Northwest China and the humid monsoon region of Southeast China. This region is very sensitive to both climate change and land-use/land-cover change. In the last century, the most significant aridity trend occurred over this region, as well as other semi-arid regions of the world (Fu et al., 2002; Ma and Fu, 2003). A recent study also highlighted more significant warming across all the semi-arid regions of central Eurasia, as compared with that over other parts of the world (Ji et al., 2014).

2.4. *Proposal on the concept of "orderly human activities"*

Looking back to the history of human kind, it's not difficult to find the evidence that human activity is one of the major drivers of the deterioration of the life-supporting environment. However, only recently people began to realize that the human species has the recognition and capability to lessen the negative effects on the life-supporting environment. Such an understanding led us to raising the concept of "orderly human activities", which can be defined as the kind of activities that ensure the life-supporting environment as a whole, and as far as possible in a localized sense, continues without notable degeneration or even becomes increasingly better in the foreseeable future, whilst at the same time maintains natural resources to meet the requirements of social and economic development. Therefore, orderly human activities take "sustainable development" as the goal and criterion to distinguish all broad-scale human activities as "orderly" or "disorderly". A research scheme of orderly human activity in the life-supporting environment was proposed (Ye et al., 2001). The research focus was the mechanisms that regulate life-supporting environmental changes, the development of Earth system models to integrate human activities in adaptation to the changes of the system, and the development of practical approaches to adaptation for attaining overall benefits on short- and long-term time scales, as well as local, regional and global spatial scales. Figure 2 is a diagrammatic representation of the orderly human activities in the life-supporting environment. It illustrates the central research themes, main research approaches, and practices, to demonstrate what these so-called "orderly human activities" look like.

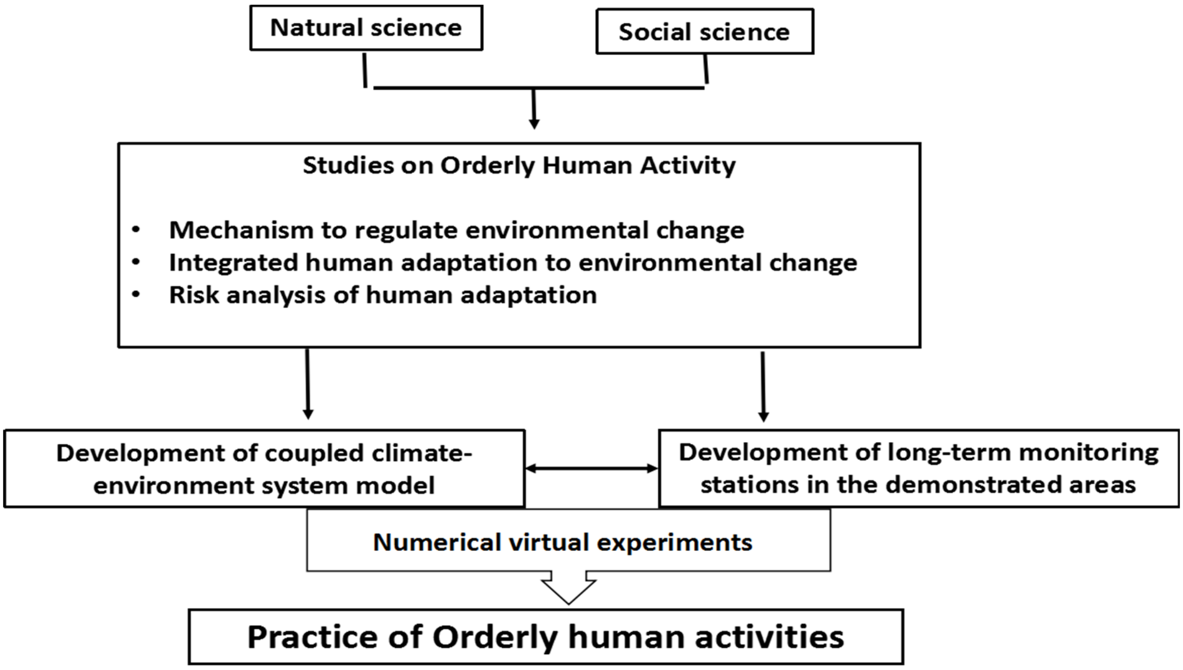

Fig. 2. Orderly human activity in the life-supporting environment.

3. Development of a strategy for proactive orderly adaptation to global change

Following the footprint of Professor YE's research, his research team has focused mainly on the study of human adaptation to global change in the last several years.

3.1. *Key issues in the new phase of global change research*

In the past few decades, the study of the Earth system has achieved significant progress, to the point where it has now reached a time of transition. Specifically, for the past two decades, our priority has been to understand the functioning of the Earth system and the impact of human actions on that system. Over the next decade, however, the global scientific community must assess the risks humanity is facing from global change and find ways to mitigate, in an effective manner, the dangerous changes taking place and cope with the change that we cannot manage. To meet such a challenge, the 2011 ICSU General Assembly approved the establishment of Future Earth—Research for Global Sustainability as a 10-year interdisciplinary program. This is a collaborative program with an alliance of partners as follows: the ICSU (International Council for Science), ISSC (International Social Science Council), Belmont Forum (funders of GEC research), UNEP (United Nations Environment Program), UNU (United Nations University), UNESCO (United Nations Education, Science and Culture Organization), and WMO (World Meteorological Organization).

Recently, a statement from the "Our Common Future under Climate Change International Scientific Conference", 7–10 July 2015, Paris, France, once again indicated that "Climate change is a defining challenge of the 21st century. Its causes are deeply embedded in the ways we produce and use energy, grow food, manage landscapes and consume more than we need. Its effects have the potential to impact every region of the Earth, every ecosystem, and many aspects of the human endeavor. Its solutions require a bold commitment to our common future. We in the scientific community are thoroughly committed to understanding all dimensions of the challenge, aligning the research agenda with options for solutions, informing the public, and supporting the policy process."

Based on the Future Earth Research Plan and other related documents, the key issues in this new phase will be: (i) What significant climate and environmental changes are likely to happen in the future due to both natural and anthropogenic forcing? (ii) What will be the vision of future development of human society? (iii) How can human well-being adapt to the future change of the Earth system? It is obvious that the final goal of the Future Earth program should be to reach global sustainability through orderly and proactive adaptation to global change.

3.2. *Concept of proactive adaptation*

Earth's climate has been changing ever since it came into existence. As the global climate changes, Earth's plants and animals adapt by continuously evolving, according to Charles Darwin's theory of natural selection (Darwin, 2005). All species are faced with more pressure for "survival" as global environmental change becomes exacerbated. In plants, global warming has led to earlier budding and blooming and narrowed leaves, for instance; and in animals, a major change has been in the timing of migratory activities. This is a manifestation of plants' and animals' adaptation to climate change. However, such adaptation has not taken place through conscious choice. Similar to other species on Earth, humans have also survived and evolved through adapting to climate change. To this end, the history of humankind is a history of human adaptation to climate changes, but mainly in a passive sense. Essentially, passive adaptation involves action taking place when changes occur—and such adaptation actions are taken based on our current understanding of the relationship between climate variables and ecological/social/economic parameters.

In the above context, it follows that, with knowledge not only of the past and present, but also in terms of likely future changes, a great challenge emerges for adaptation to move from a passive to a proactive stance. In other words, rather than just to react to the change which has already happened, one could proactively adapt by developing strategies based on projections of future climate changes, knowledge of the consequences of future climate changes to ecosystems, societies and economic systems, assessment of the capacity of human society to adapt to climate changes, and risk analysis (through virtual experiments) of the consequences of proposed adaptation actions. Within this paradigm of proactive adaptation, forecasting capability is the scientific foundation, numerical simulations or potential test beds are the technical backbone, and socioeconomic power is the material foundation. There is no match in human history for the current depth of our understanding of climate change and its impacts on global ecosystems and socioeconomic growth, the level of scientific and technological development, as well as economic power. With that, turning passive to proactive adaptation is now technically plausible. Therefore, proactive adaptation should be the future direction for sustainable development of human society, as illustrated in Fig. 3.

3.3. *Focus on temporal and spatial scales*

Regional and decadal scales should be the focus of adaptation studies, because people do not live in a global-mean environment—they live under regional climate and environmental conditions. Decadal prediction and adaptation are not only of increasing scientific interest, but also potentially benefit society. Regional adaptation is important from an Earth system science perspective. Regions are not closed systems, and thus the linkages between regions and the Earth system are crucial: regions may function as choke or switch points, and small changes in a critical region may lead to significant changes to the Earth system. Regions may manifest significantly different Earth dynamics; changes in regional biophysical, biogeochemical and anthropogenic components may produce considerably different consequences for the Earth system at the global scale. On the other hand, studying decadal and regional adaptation may contribute directly to the science of sustainability. For example, many investments in infrastructure and development are planned for decadal time scales and at the regional level. Knowing how climate will change regionally over those periods may help in making cost–benefit analyses of new investments and plans.

3.4. *Proposed major research program for proactive adaptation*

To develop the proactive research program, three major components are proposed:

• Development of an observation system in regions sensitive to global change;

• Development of approaches to create future changes of climate in selected regions: i.e. regional corrections of Earth system model outputs of future changes;

• Approaches to develop adaptation action plans: risk analysis through virtual numerical simulation on the consequences of proposed adaptation actions.

3.5. *Example of a human adaptation study: Research on the aridity trend and human adaptation in northern China— a transitional zone of climate and ecosystems*

As indicated in the award announcement of the 48th IMO Prize, Professor YE's "fundamental contributions to both ba-

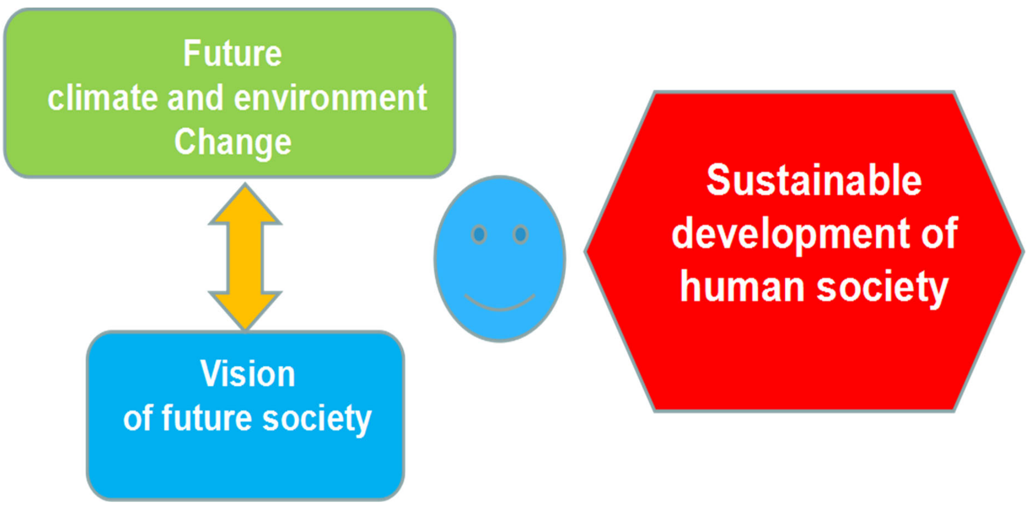

Fig. 3. Schematic diagram of proactive human adaptation to global environmental change.

sic and applied science to meteorology", particularly "the initiation of studies on global change and its relationships with sustainable development, orderly human activities and adaptation to its impacts", during his life time, have paid special attention to the environmental issues faced in China. The aridity trend in northern China is one of these issues.

Because of the long history of human civilization and the particularity of the landscape, the aridity trend over northern China features interwoven short- and long-term effects, as well as global and regional effects. The situation is most serious over the semi-arid region—the transitional zone of climate and ecosystems (Fig. 4). There is an integrated behavior of the climate system and interaction with human activities, and should therefore be studied as a cross-disciplinary issue. To address the problem, a 10-year research project entitled "On the Aridity Trend of Northern China and Human Adaptation", during 1999–2010, was carried out, under the support of the Ministry of Science and Technology of China.

3.5.1. *Research framework of the project*

The project was designed with six tasks:

Task 1 was to document the history of climate and environmental changes in northern China, from geological, to centennial, to decadal scales, based on high-resolution proxy data as well as modern meteorological and hydrological observation data.

Task 2 was to examine the global patterns of aridity trends and time regimes in transition in the past 60 years in association with the aridity trend of northern China.

Task 3 was to study the atmospheric dynamics and air–sea interactions in relation to the aridity trend, from both an observational and modeling perspective.

Task 4 was to study the impacts of anthropogenic factors, such as increased concentrations of dust aerosols and changing land-surface processes, mainly due to human-induced land-cover changes, on the aridity trend.

Task 5 was to study the ecosystem and hydrological processes in the semi-arid region and assess the impacts of the aridity trend on socioeconomic development in the region.

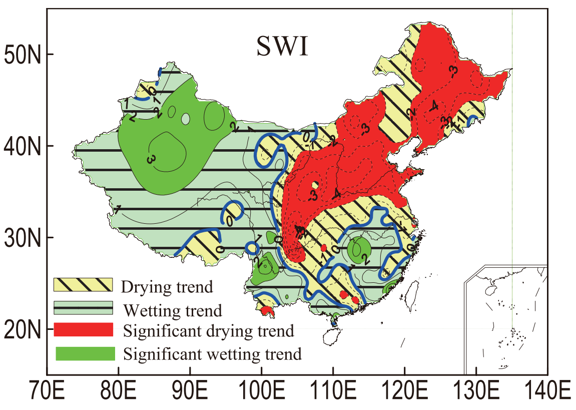

Fig. 4. Trend in the aridity index in China, 1951–2007 [Revised and reprinted from (Fu and Ma, 2008)]. SWI is the surface wet index.

Task 6 was to study human adaptation to the aridity trend in northern China.

The most significant progress in the implementation of this project was the development of field observation sites in the semi-arid region, and a regional integrated environment model system (RIEMS) and observation–data–model fusion system (ODMFS) for studying aridity in northern China. The detail of RIEMS and ODMFS are introduced in Figs. 5 and 6.

3.5.2. *Main results of the project*

The research results of the project are presented in detail in the book *Aridity Trend of Northern China* (Fu and Mao, 2017). However, the key findings can be summarized more briefly as follows:

(1) The climate over northern China is characterized by wet–dry oscillations on multiple time scales. The aridity trend in the last half-century is part of a composite picture of those oscillations.

Documented changes of aridity over northern China on geological time scales, from the dust records of the Chinese Loess Plateau, in the last 3.5 Ma or so, indicate that there has been an overall increase in aridity over northern China, with dramatic enhancements in aridity at about 2.6 and 0.7 Ma. This tectonic time scale change in aridity is roughly consistent with the evolution and development of ice sheets in the North Polar Region. On the orbital time scale, the arid regions of northern China greatly expanded during the glacial periods, as compared with the interglacial periods. During the last glaciation, millennial-scale climatic events (D-O cycle and Heinrich events) can be detected in most high-resolution loess records, which are well documented in Greenland ice cores. It is believed that the variability of aridity over northern China on that time scale is associated with the climate change in the North Polar Region.

The dry–wet oscillation on decadal to centennial time scales during the Holocene has been documented using high-resolution proxy data, including historical documentary records, lake sediments, pollen records, cave records, tree rings, ice cores, and speleothems. All proxy data have generally shown an aridity trend over northern China during the last two millennia, especially in the last 100 years. During the second half of the 20th century, the aridity trend was demonstrated by the increased frequency of light rain and extreme arid events. In addition, the most significant aridity trend was observed in a semi-arid region.

(2) Large scale atmosphere–ocean interaction of the climate system is believed to be one of the main driving forces for the development of the aridity trend in northern China in the last several decades.

Intensification of meridional SST gradients over the tropical Indian Ocean–western Pacific warm pool region is one of the key modulators of the global subtropical decadal aridity trend, and one that has strengthened in recent decades. Consequently, the Hadley circulation has been weakening in boreal summer and intensifying in boreal winter. As a result, descending motion anomalies have intensified and rain-

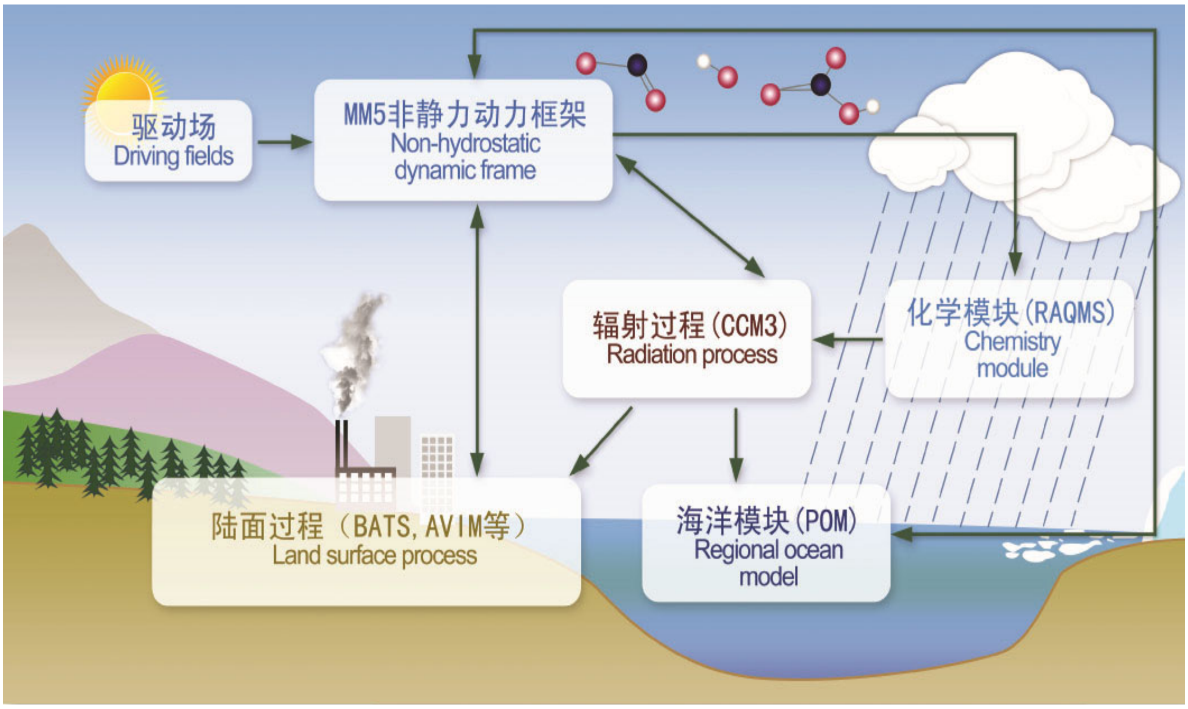

Fig. 5. Schematic diagram of the Regional Integrated Environment Model System (RIEMS) [revised and reprinted from (Wang et al., 2015)].

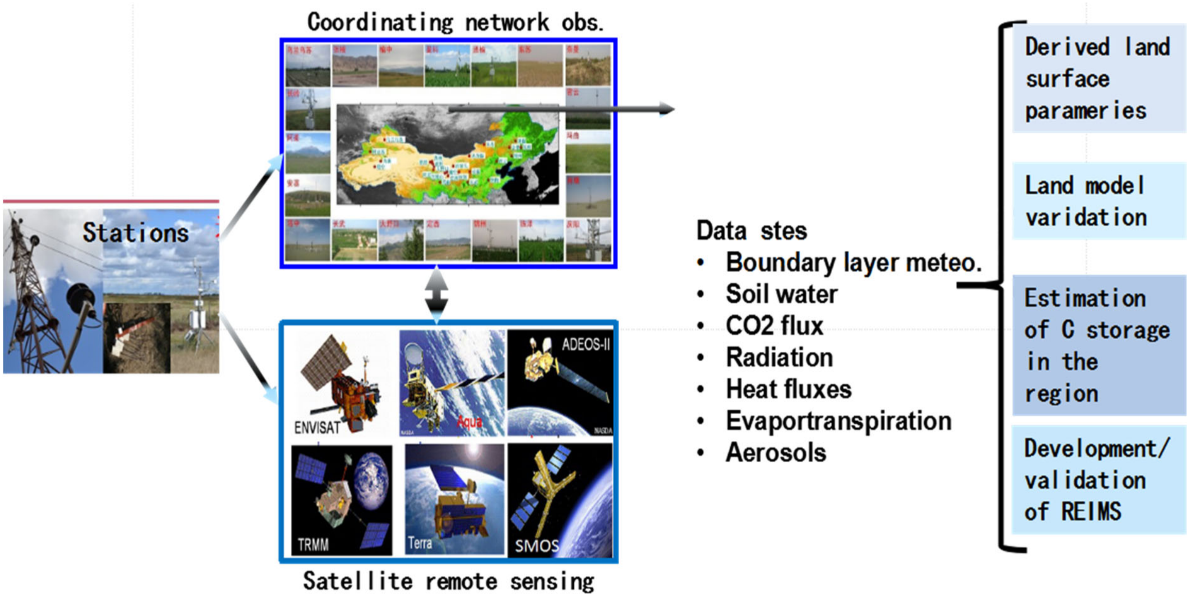

Fig. 6. An observation–data–model fusion system for studying aridity in northern China.

fall has reduced in the subtropics in both boreal summer and winter. The aridity trend in northern China appears to be a part of this story.

Observational analyses suggest that the Hadley cell has expanded by 2°–5° of latitude in the past three decades. Such a widening of the Hadley cell has important implications for shifts in precipitation patterns that lead to expansion of dry land worldwide, including the aridity trend in northern China. This expansion can also be captured in the simulated climate change in response to increased concentrations of greenhouse gases, albeit at a much slower rate. To understand the mechanisms driving the expansion of the Hadley cell, and the discrepancy between GCM-simulated and observed expansion, presents new challenges.

(3) Evidence suggests that anthropogenic factors, such as increased concentrations of dust aerosols and changing

land-surface processes, mainly due to human-induced land-cover change, may also have contributed to the aridity trend in arid/semi-arid regions of northern China.

Transported and local anthropogenic dust aerosols can significantly reduce cloud droplet size, optical depth, and liquid water path. Dust aerosols may warm the cloud, enhance evaporation of cloud droplets, and further reduce cloud water path via the so-called semi-direct effect. Such semi-direct effects have played an important role in cloud evolution and exacerbated drought conditions over the arid/semi-arid areas of northwestern China.

Observational evidence and modeling studies suggest that the intensification of the regional aridity trend is directly related to human-induced land-use/land-cover changes. A local feedback process of the aridity trend over degraded grassland under a warming climate has developed as follows: high temperature leads to increased evapotranspiration and sensible heat flux and then to reduced soil moisture and less latent heat flux; Such change of land surface process would further have feedback effect on atmosphere: low humidity and less precipitation. Such changes of atmosphere will affect further the land surface processes and result in dry soil, low NDVI and and less latent heat flux. Finally the aridity trend in the region will further be enhanced. Such a feedback mechanism may also interact with large-scale atmosphere–ocean interaction on decadal and multi-decadal scales. However, there is no quantitative estimation of such effects, because results are very likely data- and model-dependent.

(4) Hydrological processes are complex and variable in semi-arid regions of northern China. Climate change and human activities substantially influence runoff in northern China, with significant regionality. For instance, the annual runoff within the Laohahe Basin, a representative semi-arid region in northern China, has had a significant decreasing trend, with an abrupt change in 1979. The effects of climate change and human activities on runoff from 1980 through 2008 have been simulated using three types of hydrological models. The simulations suggest that human activities are the dominant factor, contributing 89%–93% of the total reduction in runoff, while climate change has contributed 7%–11%.

(5) The aridity trend in the arid and semi-arid regions of northern China has had direct impacts on natural and agricultural ecosystems, as well as the aquatic system, and indirect impacts on agricultural production and people's livelihoods, ultimately affecting economic and social development. Measures need to be taken to mitigate their negative effects. Under the influence of the aridity trend, high temperatures will reduce the positive effect of elevated CO_2 concentrations on biomass, while drought stress will decrease the accumulation of carbohydrates and alleviate/eliminate photosynthetic down-regulation. Based on field experiments and numerical simulations, the adaptabilities of plants to drought stress will be enhanced by the combined effects of elevated CO_2 and high temperatures. The vegetation distribution will also change, due to the altered water and heat conditions. Since the 1990s, the crop area affected by severe aridity has constituted more than 60% of the total crop-disaster area in China. It is estimated that the national economic loss due to aridity disaster has reached approximately 1.1% of Gross Domestic Product.

(6) The following adaptive strategies are recommended: distinguish regional advantages; adjust the agricultural structure; increase the proportion of forest and animal husbandry; control agricultural irrigation areas; promote water-conserving irrigation and reduce water-use of each unit; implement a water ticket system; and improve the capacity of water conservation and the rainwater resource (Tyson et al., 2001; Fu et al., 2002).

4. Outlook: Transition of MAIRS into a component of Future Earth

In 2002, under the strong support of Professor Duzheng YE, Fu proposed the development of an international research program entitled "Monsoon Asia Integrated Regional Study (MAIRS)" to the Chinese Academy of Sciences, which was then submitted to START in 2003. It was finally accepted by ESSP (Earth System Science Partnership) at the Beijing Conference on Global Environment Change, November 2006. The conference statement declared: "Recognizing there are issues special to regions, the Beijing Conference initiated the Monsoon Asia Integrated Regional Study to examine the threats posed to populations and ecosystems in Monsoon Asia". This is the first regional element of ESSP and the first international program led by China in the field of global change, with participants from almost all Asian monsoon countries, as well as the United States, Australia and EU member countries.

The initial scientific plan of MAIRS (Fu et al., 2006) described the challenge of the region, as well as the main research issues and plan for implementation. The scientific plan pointed out that almost all aspects of societal and economic activities in monsoon Asia are critically dependent on its climate and the variability of the climate. On the other hand, there are indications that human activities—especially those associated with economic development—may be having a detectable impact on the large-scale monsoon system. Our understanding of the implications of these major environmental changes has progressed substantially in the last decade, and there is now a real potential to address larger Earth-system questions. Figure 7 is a conceptual framework of MAIRS (Fu et al., 2006).

There is now real potential to address the broad question of whether the Asian monsoon system is resilient to this human transformation of land, water and air. 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 certain vulnerabilities. So, the second overarching question is: are societies in the region becoming more, or less, vulnerable to changes in the Asian monsoon? Environmental change in the Asian monsoon region is not independent of global changes,

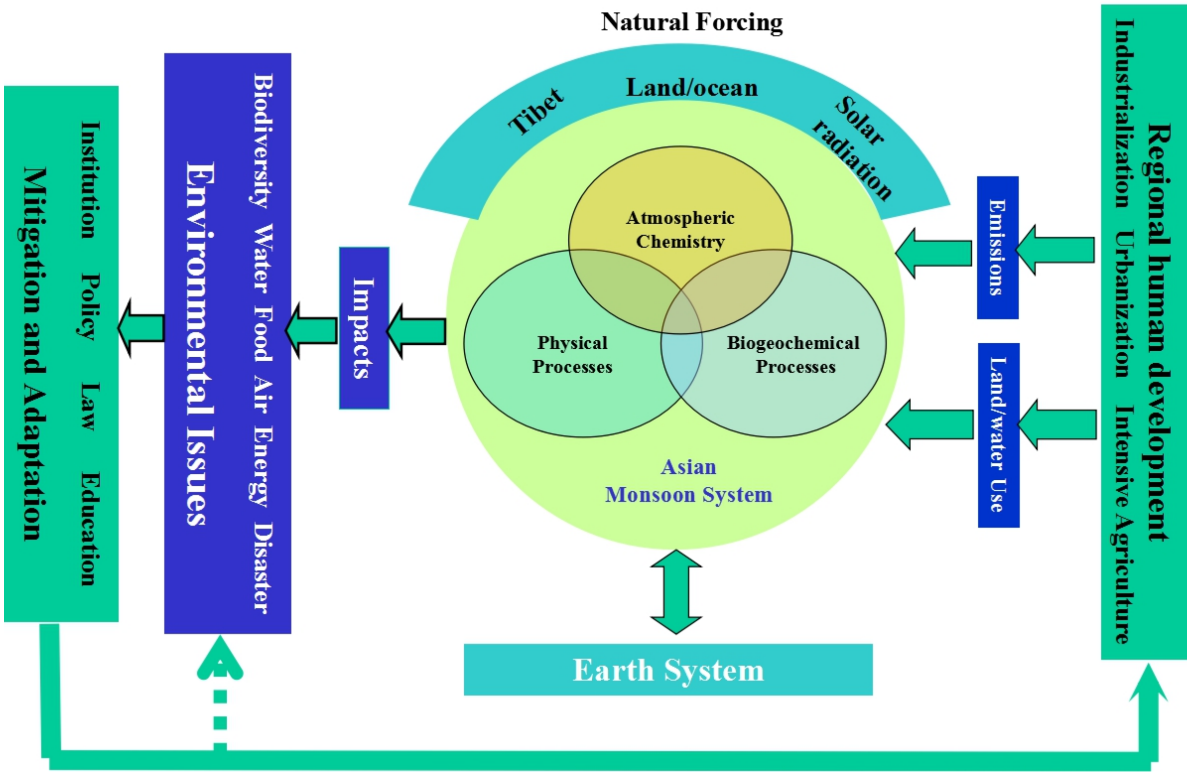

Fig. 7. Conceptual framework of MAIRS (Monsoon Asia Integrated Regional Study) [Reprinted from (Fu et al., 2006)]

and vice versa. There is still little knowledge on how and by how much the regional and global environmental systems are conjoined. The third key question is, therefore: what are the likely consequences of changes in monsoon Asia on the global climate system?

To start answering these questions, we distinguish four research themes. Each theme addresses key integrated issues in a vulnerable geographic zone. They are:

a. Rapid transformation of land and marine resources in coastal zones;

b. Multiple stresses on ecosystems and biophysical resources in high mountain zones;

c. Vulnerability of ecosystems in semi-arid zones due to changing climate and land use;

d. Changes in resource use and emissions due to rapid urbanization in urban zones;

Clearly, meeting these challenges requires consideration of:

• The major demographic, socioeconomic, and institutional drivers for change, including scenarios of change related to urbanization and industrialization, energy production and biomass burning, land-use/cover change and water resources harvesting, including dam construction;

• The effects on regional and atmospheric composition/pollution, regional water cycle and coastal systems, and local ecosystem structure and function;

• The impacts on biogeochemical cycles and the physical climate system, including its variability at different scales; and

• The impacts of global and other feedback effects on the regional biospheric life support system, including food systems, water resources and health.

Significant progress has been made in the past 10 years or more in collaboration with a number of international programs and countries of the region. Looking back on the initial scientific plan and the ongoing activities and progress, one finds a high degree of overlap between MAIRS and Future Earth at the regional level. However, the future of MAIRS as a component of Future Earth needs to involve working more closely with stakeholders to build the knowledge base underpinning future sustainable societies and ecosystems and to promote the rapid implementation of strategies for the sustainability of monsoon Asia. Here are some thoughts in terms of the direction that the scientific agenda of MAIRS as a component of Fututre Earth program should be taken into account:

• Dynamics of the integrated Asian monsoon system;

• Regional component of an Earth system model for monsoon Asia;

• Network of integrated observation platforms in critical regions of monsoon Asia;

• Forecasting of the multi-decadal changes of monsoon climate and their consequences in ecosystem/social/economic systems;

• Development of the vision for the future society of monsoon Asia;

• Proactive and orderly adaptation to monsoon climate change;

• Policy and institutional development of adaptation.

We live in a special period of the history of our planet. We are now in a position to have the intelligence and imagination to understand the whole picture of Earth's climate changes and its impacts on global ecosystems and the social/economic development of human society. We are in a position to have the scientific, technological and economic capacity to adapt to global change. Earth is in our hands.

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