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China's National Assessment Report on Climate Change (II): Climate change impacts and adaptation

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Abstract: Significant and various impacts of climate change have been observed in China, showing both positive and adverse effects, dominantly the latter, in different sectors and regions. It is very likely that future climate change would cause significant adverse impacts on the ecosystems, agriculture, water resources, and coastal zones in China. Adoption of adaptive measures to climate change can alleviate the adverse impact, therefore such measures should be incorporated into the medium-and long-term national economic and social development plans. Because China has done relatively limited research on impact assessment and our understanding of climate change is incomplete, the current impact assessment methodologies used and results obtained contain many uncertainties. To reduce the uncertainties and develop effective and practical climate change adaptive measures in China, it is necessary to emphasize regional case studies on adaptive measures, enlarge the scope of climate change research, and strengthen the assessment of the impacts resulted from extreme weather/climate events.

Key words: climate change in China; climate scenarios, impact assessment, adaptive measures, uncertainties

Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report, global average temperature has increased by (0.6±0.2)℃ during the 20th century [1]. In China, the observed data show that the nation-wide mean surface temperature has markedly increased over the past 100 years and the change ranged between 0.5−0.8℃ [2]. Climate change characterized by warming will impact on various aspects of Chinese social and economic life.

Since the early 1990s, Chinese scientists have studied climate change impacts, vulnerability and adaptation strategies and obtained many good results [3−4]. Based on those study results, a national assessment report on climate change, commissioned by the Ministry of Science and Technology of China, the China Meteorological Administration, and the Chinese Academy of Sciences, was prepared to summarize the current state of knowledge on the impacts of climate change, the country's vulnerability to climate change, possible adaptation strategies, and the related uncertainties.

This paper is a synopsis of section II of the *China's National Assessment Report on Climate Change* which was published in February 2007. We present in the paper the methodologies used for assessing climate change impacts in China, explore climate change impact, adaptation, and vulnerability issues for major sectors of vulnerability, e.g. agriculture, water resources, coastal environment and ecosystems, and for different regions in China, discuss adaptive measures, and identify uncertainties and research areas critical for advancing the understanding of potential consequences of climate change and adaptation options.

1 Methods for climate change impact assessment

The ecosystems that have received relatively little disturbance from human beings can be used as the reference

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pointer to assess the observed impacts of climate change. However, systems like agriculture, water resources and human health are influenced not only by climate change but also by other factors, therefore it is rather difficult to single out the impacts of climate change. Nevertheless, the impacts that have been already observed should be taken as facts when conducting a regional or sector assessment. Despite the difficulty in quantifying climate change impacts, these facts are useful to manifest the impacts of climate change to some extent and offer a basis for assessing potential impacts of climate change in the future.

The future trends of global climate change will be greatly affected by the development paths that human societies will take. Thus, to assess the potential impacts, vulnerability and adaptation associated with climate change, it is necessary to first establish scenarios of socioeconomic development, from which the scenarios of greenhouse gas (GHG) emissions can be derived. Then climate models could just be used to project future climate changes caused by human activities. Two Chinese socioeconomic development modes, one assuming a higher rate and another a lower rate, have been built taking into account the contribution of technology advancement to economy growth and the effect of population growth by the middle of this century.

There are three types of climate change scenarios used by Chinese scientists in the past: incremental increase scenario, equilibrium double CO_2 scenario, and transient GHG emissions scenario. The scenarios used in the study of climate change impact in China are Series IS92 [5] and Series SRES designed by IPCC [6], while the climatic scenarios for the GCM include IPCC's HadCM2, ECHAM4, etc.

Generally, the grid of a GCM is at the level of hundreds of kilometers, its resolution is too low for regional climate change assessment. Therefore, downscaling the grid, i.e. increasing the resolution, becomes necessary. The common ways of downscaling include interpolation, statistical method, and regional climate model (RCM). Interpolation was the main method used in the early years, whereby the GCM results were interpolated to the station level and, with the help of a weather generator, produced daily data needed for assessing potential climate change impacts.

Chinese scientists have researched into ways to improve the resolution of climate scenarios and apply the research outcomes in climate change impact assessment. The China National Climate Center employed the RegCM2 model to simulate the country's regional climate scenarios with doubling of CO_2 concentrations [7]. Since 2002, Chinese scientists has introduced PRECIS, an RCM model from the UK's Hadley Climate Center, into their studies [8], and scaled down HadAM3H to a grid of 50 km × 50 km. Then they established China's SRES climate scenarios and applied them in the assessment of agriculture [9], water resources [4] and natural ecosystems [10]. The statistical method for down- scaling has seldom been used in China.

2 Climate change impact assessment on vulnerable sectors and regions

2.1 *Observed impacts*

Since the 1950s, the rates of sea level rise along China's coastal line have been at 1.4−3.2 mm per year; marine ice condition on the surface of Bohai Sea and Yellow Sea has decreased; glacier areas in Northwest China have decreased by 21% since the Little Ice Age; the permafrost in Tibet has gotten thinner by up to 4−5 m; the water levels of some high plateau inland lakes have risen; and grassland production in Sichuan, Qinghai, and southern Gansu Provinces have decreased. Since the 1980s, spring phenophases have advanced 2−4 d. In recent years, coral bleaching occurred in the coastal of Hainan and Guangxi Provinces.

Drought-stricken areas have widened in northern China and flooding has gotten more serious in southern China. Since the 1980s, agricultural production has become more unstable. In some places, droughts and heat waves have become more severe. Crop damage from spring frost has increased due to mild winters that lead to earlier onset of budding and flowering in winter wheat, trees and fruits, making them more vulnerable to cold. However, climate warming over the past two decades has caused winter wheat plantation in Northeast China moved northward and extended westward. Certain varieties of maize that have a relatively long growth period and high yield have been grown more widely, resulting in productivity increase. Since the 1950s, the runoffs to six large rivers in China have all been observed experiencing a decreasing trend, with the largest decrease occurred along the Haihe River. Some rivers in northern China faced intermittent flow. While large flooding events occurred along the Yangtze, Pearl, Songhua, Huaihe, and Yellow Rivers as well as the Taihu Lake in the 1990s resulting in increasingly heavy losses. Climate change and sea level rise have already affected China's coastal areas, where the economic losses from storm surges, flooding, heavy rains, drought and other serious climatic events were most significant. The Yellow River Delta, Yangtze River Delta and Pearl River Delta are more vulnerable to storm surge, coastal flooding, shoreline erosion, and losses of wetlands than other coastal places. Since the 1960s, forest area of Mount Qilian has decreased by 16.5%, its forest belt has moved up by 400 m, and forest coverage decreased by 10%. In Sichuan Province, grass production and quality have decreased. The areas of wetland in southwest China, the Sanjiang (Three-River) Plain and the wetland of Qinghai Province have also shrunk and their functions declined. Since the 1950s, the fluctuation cycle of mountain disasters in the Southwest China has shortened, and the frequency of disaster events and the losses they caused have increased. Climate change has raised the possibility of disease incidence and transmission, greatly influencing the distribution and the potential danger of vector-borne infectious diseases. After a flood disaster, the incidents of infectious diarrhea diseases, such as cholera, dysentery, typhoid and paratyphoid, often increased. In the past 40 years, although the Qinghai-Xizang Plateau experienced a warming trend, the coverage of dry grassland has actually increased due to increased rainfalls.

2.2 *Projection of future impacts*

According to China's national development plans, by 2050, per capita Gross Domestic Product (GDP) would hit US$10000, the total population rise to 1.54−1.58 billion, and the total consumption of primary energy reach 3.9−4.9 Gt of coal equivalent. This projection is very close to the IPCC SRES B2 scenario (mid-low emissions scenario), the pathway for regional sustainable development. Under the B2 scenario, RCMs project that the average temperature for whole China would increase by 1.2℃, 2.2℃, 3.2℃, and precipitation increase by 4%, 7%, and 10% by the 2020s, 2050s, 2080s, respectively. These changes, however, would not likely alter the situation of water resources distribution in China characterized by abundance in the southern part and scarcity in the northern part.

2.2.1 *Impacts on agriculture*

Climate change would decrease the stability of agricultural production causing larger variations in crop productivity. The most recent studies show that climate change will greatly influence China's agricultural output. By 2030, the overall crop productivity in China could decrease by 5%−10% if no action is taken. By the second half of the 21st century, climate change could cause yield reduction in rice, maize and wheat up to 37%. In the next 20−50 years, agricultural production may be seriously affected, compromising long-term food security in China.

Water demand for irrigation would grow in most regions of China due to increased evaporation, and in some regions, decreased precipitation as the climate gets warmer. Coupled with intensified water stress, this situation will significantly affect the costs of food production and investments demanded. The carrying capacity of grasslands and the number and distribution of grazing animals will undergo large changes as well.

2.2.2 *Impacts on forests and other ecosystems*

Climate change would not have a significant impact on the geographical pattern of net primary production of forests in China. However, through 2030, the productivity of forests is projected to increase by 1%−10%, with the southeastern region realizing less increases and the northwestern region more. The structure and composition of forests in Northeast China would experience great changes, with defoliate and broadleaf trees becoming dominant species.

In semi-arid areas, desertification would gain more momentum. The upper limit of mountain grassland could move up by 380−600 m, while the areas would decrease in size. However, the productivity of the grassland could increase by 13%−23%.

Regional warm and dry weather would lead to reduced wetland resources, loss of biodiversity, increased number of endangered species, and the conversion of large areas of swamp to meadow land in the Sanjiang Plain of China. Sea level rise would cause reduction in wetland area, degradation of wetland, and submergence/erosion of tidal flat land in the Yangtze River Delta.

In the coming 50 years, the spatial distribution of the permafrost in the Tibetan Plateau would undergo a rather significant transformation: 80%−90% degradation of permafrost islands, deepened seasonal thawing of permafrost, and the formation of thawing interlayer and deeply buried permafrost. The areas of surface permafrost could reduce by 10%−15% and the nether limit of permafrost on sunny slopes could rise by 150−250 m.

Future climate change would accelerate the shrinking of inland lakes. The mountain and highland lakes that rely on inland glaciers for recharge, such as the lakes on Tibetan Plateau and Pamir Plateau, could initially enlarge as a result of glacier melting, but eventually shrink as the glaciers are reduced over time.

2.2.3 *Impacts on water resources*

Climate warming could decrease river runoff in northern China and increase in southern China. The annual average evaporation would increase in each watershed, with the Yellow River Basin and inland river basins possibly experiencing about 15% increase. Therefore, the probability of droughts and floods would increase, exacerbating the instability of water resources distribution and the gap between water demand and supply.

The volume of glaciers would change as the climate changes. By 2050, the total area of China's western glaciers is projected to decrease by 27.2%. Over the same period, glacier thawing would increase water discharge, peaking the amount during 2030–2050 with annual increases of 20%–30%.

2.2.4 *Impacts on coastal environment*

The response of China's coastal regions to climate change and sea level rise would be different from that of Europe and America. Storm surges, droughts and other extreme climate events are the main coastal disasters. Currently, the Yellow River Delta, the Yangtze River Delta and the Pearl River Delta are the most vulnerable coastal regions in China.

By 2030, the sea levels along Chinese coastal areas could rise by 0.01–0.16 m, increasing the possibility of flooding and intensified storm surges. The disasters could increase coastal erosion, degrade coastal ecosystems such as wetlands, mangroves and coral reefs, and exacerbate saltwater intrusion.

2.2.5 *Impacts on other sectors*

Climate change could increase the frequency of heat waves and their intensity, resulting in higher mortality and morbidity of serious diseases. It would endanger human health by increasing the occurrence of diseases and the transmission of infectious diseases. Climate change would increase the degree and range of cardiovascular diseases, malaria, dengue fever and heatstroke.

Climate change may cause the melting of mountain snow and the rising of sea levels, so that mountain, coastal and island landscapes would change, affecting nature conservation areas and national forest parks characterized with excellent environmental quality and biodiversity. Climate change could thus affect tourism and the safety of tourists.

Climate change would further challenge power supplies in China because of people's increasing reliance on air conditioners. The Qinghai-Tibet Railway and other large projects could also be adversely affected by the thaw of permafrost, and/or rainfall changes.

2.2.6 *Impacts on different regions*

Temperature increase would benefit agricultural production in Northeast China, but some specific ecosystems (such as wetland and permafrost) will deteriorate or disappear as a result of climate warming and human activities. The structure of forest ecosystems will change as well. In North China, climate may continue to become obviously warmer and drier. As water demand would increase significantly, water shortage would get worse. However, warmer winters will promote the development of protected agriculture in the region. In Northwest China, while precipitation may increase, the region would remain water stressed. Some simulations indicate that water shortage in this region could reach about 20 billion m^3 per year in 2010–2030. The range of desertification will extend to the regions with overlapping agriculture and livestock raising and along the edge of oasis after 2050.

In East China, the frequency of exceptional flood would increase, it is not likely to happen once in a century. In the central part of China, temperature increase will not be obvious, but droughts and floods would come in turn more frequently. The yield of double-harvest rice, especially of the late-season rice in Central China would decrease due to climate change.

In Southwest China, the strength, scale, scope and frequency of land disasters are expected to increase over time resulting in more severe losses. The South China region is susceptible to sea level rise, estimated to be between 0.60–0.74 m by 2100. This would adversely affect low-lying and damp areas in the Pearl River Delta more than other places. The border lines of mangrove areas would move northward and the scope of coral bleaching would expand.

3 Adaptation measures to climate change

Developing rational adaptation measures and enhancing the adaptation capacity will play an important role in minimizing the adverse impacts of climate change and promoting sustainable development in China. The pertinent adaptation measures for main sectors should include:

Agriculture: a) strengthening agricultural infrastructure; b) breeding stress-resistant crop varieties; c) developing new agricultural technologies including biotechnology; d) promoting large scale plantation of superior crop varieties in suitable areas; e) adopting special techniques to increase and stabilize crop yields in order to enhance the agriculture sector's resistance to disasters.

Flood and drought control: a) strengthening hydrological infrastructure to enhance the capacity of flood and drought control, water supply, and emergency response; b) incorporating the potential impacts of climate change on water resources as limiting factors in construction projects.

Forestry: a) continuing reforestation efforts; b) enhancing the abilities of tree species to adapt to environmental changes; c) strengthening nature reserves management; d) preventing and controlling forest fires, forest diseases and insects.

Grassland management and animal husbandry: a) determining grazing capacity of pastures in terms of climate change; b) halting over-grazing and avoiding prairie degradation; c) stopping and reversing the trend of desertification to enhance the resistance of livestock production to climate change.

Coast protection: a) raising the design standards of facilities for tide prevention; b) enforcing tide prevention facilities in the coastal areas;

Climate prediction and forecast: a) improving the forecast of climate hazards; b) establishing prediction, monitoring and control systems in order to enlarge the coverage of epidemic supervision area.

Regional adaptation measurements may include the following. In Northeast China, climate warming provides advantageous conditions to move winter wheat cultivation areas northward and enlarge rice paddies as suitable. In North China, adaptation could involve establishing water saving systems, preventing and managing desertification, and promoting regional social and economic sustainable development. In Northwest China, administrators should focus on reasonable allocation of water resources, development of water saving agriculture, protection and improvement of ecosystems and the environment, and enhancement of adaptive capacity in agriculture in dry-land areas. In Central China, capacities should be built for controlling and mitigating droughts, floods and other disasters, for strengthening water retention and drainage, and for monitoring and preventing of schistosomiasis. In Southwest China, adaptation to climate change involves strengthening prediction and early-warning systems for landslides and mud-rock flow, speeding up and improving water and soil conservation, and protecting the prairies in Tibet. In the coastal areas of East China and South China, the protection level of storm-tide stopping levees should be raised due to sea level rise, and the abilities to monitor and to issuse early warnings for typhoon and storm surge strengthened. Since adaptation measurements can help alleviate negative impacts of climate change, it is important to progressively incorporate them into national medium and long term development plans and strategies.

It is necessary to develop a monitoring system to examine the impacts of climate change and to establish a science and technology system to research into adaptive strategies. Building multi-disciplinary research and management teams in China at advanced international levels is critical for enhancing the analytical and decision-making abilities to respond and adapt to climate change.

4 Uncertainties in climate change impact assessment and their improvement

There are many uncertainties in the current impact assessment methodologies and results due to limited scientific research conducted in China on climate change. Because many models take climatic and non-climatic scenarios (including socio-economic assumptions) as input parameters when assessing climate change related impacts, vulnerability and adaptation, a high level of uncertainty originates from the assumptions of scenarios. Main uncertainties come from the two aspects, that is the imperfection of climate models and the uncertainty of future GHG emissions, which can be reduced only if we are able to accurately project non-climatic scenarios of socio-economic, environmental and land use changes, and technology advancement in the next several decades to one century.

The uncertainties of impact assessment models come from four main sources: 1) limited understanding of climate change impacts on various ecosystems and the interaction among them; 2) not all factors considered in the impact assessment models; 3) the impacts of climate change on trade, employment, and socio-economic development are seldom considered in impact assessment models; and 4) insufficient consideration to the effects of adaptation measures on lessening the vulnerability to climate change.

An effective way of reducing the uncertainties is to construct climate change scenarios under various GHGs emission scenarios. To counter the "scientific uncertainty", various models and climate change scenarios should be employed in the impact assessment.

To reduce the uncertainties, it is also necessary to improve the understanding of the response mechanisms of ecosystems to climate change, through collecting the data of long-term changes in plant/animal communities and species, investigating different ecosystems in different areas, better controlling confounded factors during the experiments, and distinguishing the effects of climatic factors from non-climatic ones.

We should strive to develop integrated models for impact assessment and improve the projection of non-climatic factors. More consideration should be given to technology advancement, policies, major construction projects, and adaptive measures in the impact assessments, so as to improve the accuracy of the assessments for different sectors/areas, especially for agriculture and human health. While assessing the impacts of climate change under different scenarios, the interaction and intervention among various disciplines should be emphasized.

Given China's vast territory and diverse climatic conditions, regional case studies are necessary for the assessment of climate change impacts and adaptation needs. Existing impact assessment efforts in China have mainly concentrated on agriculture, water resources, ecosystems, and coastal environments. Not many studies have looked at the potential impacts of climate change on human health, transportation, eco-tourism, major civil projects, residential buildings, and marine ecosystems. Since climate change would very likely do its damage through extreme weather/climate events, studying the occurrence of extreme climate events and their consequences is essential and should be enhanced.

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