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Anthropogenic Climate Change in Asia: Key Challenges

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The energy, agricultural, and water sectors in Asia, a vast continent that comprises more than half of the world's population, are crucially vulnerable to shifts in climate. The acceleration of economic development in Asia over the past few decades, the dependence of its huge agricultural economy on rainfall, and its growing energy demands have thrust climate change and its impacts squarely into important sectors of the Asian society. Further, it is likely that there has been significant anthropogenic warming over the past 50 years averaged over the Asian continent (*Intergovernmental Panel on Climate Change* (*IPCC*) [2007]; see Figure 1a). Asian megacities are already witnessing stresses in food, water, transportation, health, and air quality. The situation could become even worse with projected changes in temperature and rainfall in the 21st century, coupled with the likelihood that climate change will exacerbate extremes.

The Asian climate system (ACS), particularly the aspects linked directly to temperature and rainfall in Asia, is a critical element of the Earth system, with climate change impacts spanning continental to regional scales. As a result, scientists are studying several rapidly escalating climate science challenges important to ACS that also bear relevance to global climate dynamics.

Understanding the Intersection Between ACS and Climate Change

The scientific disciplines spanned by ACS make up a broad spectrum: atmospheric chemistry, dynamics, and physics; climate change; hydrology; cryospheric studies; and oceanography. Through interdisciplinary studies that include observational, numerical modeling, and analysis elements, scientists can better grasp the consequences of human influences upon the climate system, differentiate them from natural and unforced variations, understand shifts in temperature and precipitation patterns, and quantify the climate impacts of greenhouse gas emissions. Such knowledge forms the basis upon which scientists make climate change projections.

ACS is complex, not only as a physical system but also because of the diverse population influenced by it. This necessitates quantification of feedbacks on many levels, including coupling between impact analyses, risk assessments, and communication of findings. The interplay between climate change, economics, and society informs policy planning (Figure 1b). Thus, the scope of issues associated with ACS extends beyond the realm of the traditional physical sciences.

Scientific understanding of ACS can be increased through focusing on five main areas: improving observational systems and capabilities; advancing the causal understanding of observations that document changes in Asian climate; quantifying the agents that drive these climate changes; quantifying the processes that govern the response of the system; and making increasingly reliable projections of the 21st century by sustained improvements in numerical modeling. Anthropogenic forces that influence climate change include increased urbanization and increased emissions of long-lived greenhouse gases and various aerosol species (sulfates, soot, dust, and nitrates) and alteration of land use and land cover. Viewed from the perspective of climate observations, forcing, processes, response, and projections, the following important questions arise for ACS:

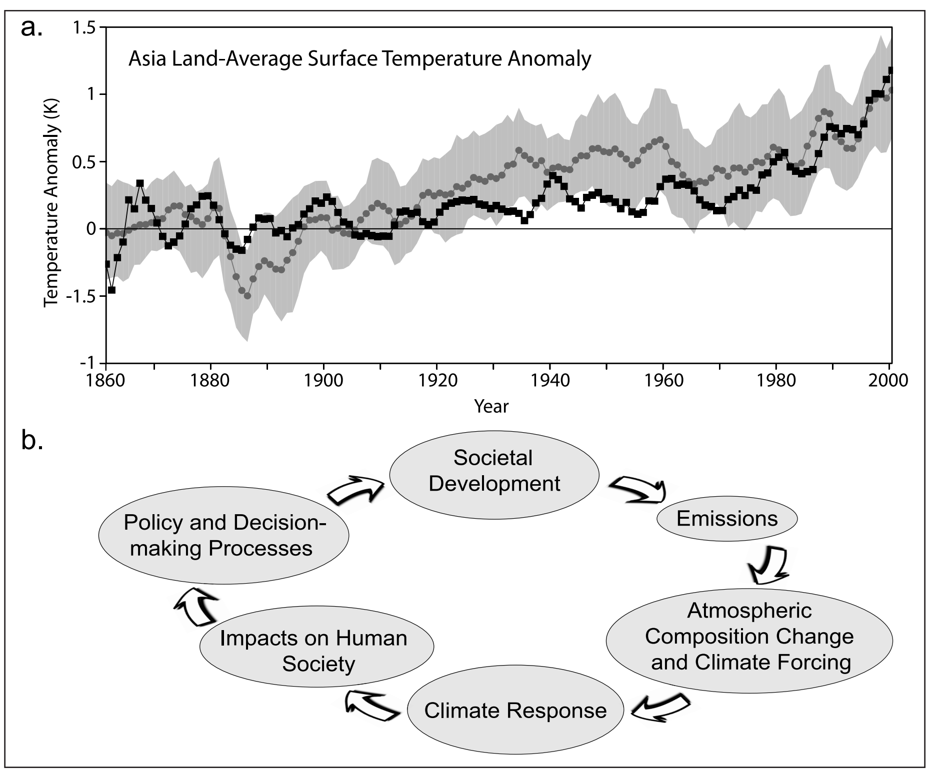

Fig. 1. (a) Climate model simulation results (light gray, ensemble spread; dark gray, model-mean), in response to all forcings, particularly the anthropogenic factors (greenhouse gases, aerosols, land use), can account for the observed (black) increase of the surface warming averaged over the Asian continent in approximately the last half of the twentieth century (based on Knutson et al. *[2006]). (b) A generalized interdisciplinary framework that successfully links societal advancement to climate science and impacts analyses can be used to inform climate adaptation and mitigation strategies.*

By V. Ramaswamy

What is the magnitude of human-influenced emissions of greenhouse gases and aerosols, and land use alterations, and how have they contributed to the observed regional and global forcing of climate change? What are the uncertainties? How have they affected temperature trends in Asia? Are the causes of observed trends understood in terms of the individual components and the processes involved?

Where are the gaps in the current understanding of the interactions between emissions and climate processes in Asia and their effects on the regional heat budget and hydrologic cycle?

What is the observed variability in the Asian monsoons on interannual to interdecadal time scales? What are the spatial variations and trends in rainfall? To what extent are monsoons influenced by human activities?

What are the projected changes in ACS over the next 50 years, including the occurrence of frequent heat waves and excessively high or low precipitation rates?

What is needed to resolve the important science questions, determine the climate impacts, and deliver outcomes in an effective manner so that policy makers can develop appropriate climate adaptation and mitigation strategies?

Answering the above questions requires much further study in a sustained manner. The resulting synthesis will become the basis for impacts analyses that, in turn, will address key questions of societal concern [*Doherty et al.,* 2009].

The Role of Aerosols and Land Use Changes

Model simulations are unambiguous about the role of global anthropogenic emissions on the surface temperature trends in the Asian continent, but major uncertainties in aerosol emissions, and to a lesser extent in land surface changes, seriously limit a precise quantification of their effects relative to those of greenhouse gases.

While the long-lived greenhouse gases are distributed globally, the anthropogenic aerosol concentrations have peaks in the densely populated regions of the Northern Hemisphere, many of which are concentrated in Asia. Aerosols perturb climate directly through scattering and absorption of radiation and indirectly via interactions with and modifying cloud properties. While aerosols do as a whole offset greenhouse gas warming through scattering, different anthropogenic aerosol types play varying roles. For example, sulfates and nitrates tend to primarily scatter radiation, cooling the climate system. Carbonaceous aerosols (composed of black and organic carbon) from fossil fuel, biomass, and biofuel combustion tend to add heat to the surface-atmosphere system [*Ramanathan et al.,* 2005].

Both sulfate and carbonaceous anthropogenic aerosols have increased in Asia over the twentieth century, and their effects on climate processes offer striking contrasts [*Lau et al.,* 2008; *Menon et al.,* 2002; *Randles and Ramaswamy,* 2008]. Aerosols such as soot not only heat the air but also alter regional atmospheric stability and vertical motions, affecting large-scale circulation and precipitation cycles with significant regional climate effects. Observations suggest that aerosols exist in the form of mixtures, which further complicates researchers' ability to understand their precise climate effects. Further, uncertainties in the temporal evolution of aerosol distributions and their physical properties, especially in the sparsely monitored areas that make up much of Asia, in turn lead to uncertainties in interpreting climate-induced changes in thermal and hydrologic cycles [*Randles and Ramaswamy,* 2008].

Land use changes due to grazing, irrigation, and deforestation are also of concern even if their importance is mostly regionally confined. Land-related influences on climate include changes in surface reflectance properties (albedo), roughness lengths (which affect the boundary-layer airflow), and plant physiology (e.g., leaf area index, plant interactions with the hydrologic cycle).

Compounding uncertainties inherent in evaluating influences on climate change is the lack of adequate documentation and the inconsistencies among data sets concerning aerosols and land use in Asia. These factors seriously limit a thorough knowledge of the drivers of climate change over the twentieth century and into the future.

Precipitation Changes

Unlike the detection-attribution analysis concerning the surface temperature change over the past 50 years, a corresponding robust analysis for precipitation changes in the Asian landmass, or for that matter in all of the continents, has proven difficult. In general, precipitation changes are much more ambiguous and difficult to resolve, both from observational and modeling perspectives, owing to space-time gaps in the observational record, inconsistencies among data sets, instrumentation problems, sampling inadequacies, heterogeneity of the precipitation process and inadequacy of current climate models to resolve these spatial scales, sensitivity to different forcings (e.g., greenhouse gases versus aerosols), and insufficient understanding of intermodel differences.

Additional major deficiencies in the understanding of the changes in the hydrologic cycle and their attribution arise due to poor knowledge of clouds and soil moisture. For example, do the observed changes in Asia's regional temperature and hydrologic cycle indicate an anthropogenic imprint, or are they consequences of natural forcings or oscillations intrinsic to the climate system? Are the influences different in different parts of Asia? Anthropogenic aerosol-cloud interaction is yet another factor that can affect precipitation in Asia [e.g., *Shiu et al.,* 2009], although other factors such as continental warming and changes in cloud dynamics must also be considered.

One encouraging feature in recent investigations is that researchers are going beyond broad space and time averages to examine changes in regional precipitation and extremes in rainfall, factors that are closer to the crux of human anxiety. A related point is that despite problems in quantifying precipitation amounts, shifts in the major precipitation belts may be more discernible. Because of the importance of precipitation (e.g., monsoon rainfall timing and amount) in the populous Asian continent, it becomes crucial to assess the shifts in seasonal and regional rainfall patterns and ascertain the roles of the specific anthropogenic factors.

The Importance of Observations for Projecting and Predicting Changes

Temporally continuous observational data sets derived from systems having extensive spatial coverage would enable sharper model validations and are key to predictive understanding and for refining climate forecasts. Monitoring both long-lived greenhouse gases and short-lived species such as aerosols, especially the spatial distributions of the latter, is essential.

Additional data on urban and rural land practices and land use would also reduce uncertainty in quantifying the net anthropogenic forcing. Improvements are needed in the observational infrastructure, including intensive, internationally coordinated efforts to compile reliable long-term data sets of critical climate variables (e.g., temperature, rainfall, storm frequency and intensity). For example, high-frequency information for eastern Asia and the Tibetan Plateau regions would allow a better grasp of changing atmospheric and hydrologic circulation patterns, thus enabling the verification of local aspects of global and regional climate models. Fortunately, several campaigns are planned to address the basic observational challenges of measuring and monitoring key variables in Asia [*Lau et al.,* 2008].

Data sets come in different varieties, and there needs to be clarity about their heritage and harmonization. Proxy records for changes in Asia's climate extending back to the Maunder Minimum (1645–1715) and beyond would yield insights into climate variability in the preanthropogenic era when only natural (solar and volcanic) forcings prevailed. A proper management strategy of the observed data should involve organized collection, quality checks, archiving, and streamlined dissemination.

Perhaps most important, easy facilitation and public access of information to a host of concerned parties in Asia, from scientists to risk managers and policy analysts, ought to be ensured. Very crucially, the unfettered and open exchange of data to climate researchers and planners should be a paramount consideration, particularly across national boundaries. This would ensure that the full scope of global change problems as relevant to Asia can be addressed and that solutions obtained can be used by all for effective adaptation and mitigation strategies.

Testing Models

Quantitative testing of models should be intensified using the growing array of climate observations in Asia. These include systematic identification of biases in the essential climate variables; verifications of key physical processes; comparisons of relevant climate variables, in particular the occurrence of extremes (e.g., duration of drought, heavy rainfall episodes); and construction of scientifically based and practically usable confidence levels.

One useful recent development is the multimodel ensemble concept, but it is not yet clear how far this will advance the quality of ACS precipitation features. The influences of topography and convective processes on precipitation remain major gaps in climate modeling. Downscaling methods for climate variables in the context of regional change are appealing, but whether these will yield reasonable estimates for ACS remains to be established. Recently formulated high-resolution global models could also become important tools in the regional context. Reliable models for climate links to agriculture (e.g., irrigation, changes in vegetated surfaces, etc.) would also improve the full scope of climate projections and predictions.

Connecting to Other Disciplines

Looking beyond the physical sciences, substantial gaps exist in the connection between climate science models and models of biology and socioeconomics. There is a scarcity of research efforts that address how models in these vastly different areas can inform or interface with each other, either through providing appropriate input and output parameters or through study of the sensitivity arising from the models' interdependencies.

Making connections beyond the sciences with other disciplines often is one of the weakest links in relating climate science to societal concerns. To help with this, a generalized interdisciplinary framework can be envisioned that successfully links societal advancement to science (see Figure 1b).

This loop yields insights into key human and environmental factors that need to be monitored such that society can be guided toward timely and effective climate mitigation and adaptation strategies. The study of feedbacks in this loop would address the sensitivity of the climate-society linkage to various parameters and would in turn advance the information base on tipping points, vulnerabilities, and thresholds that threaten to cause abrupt and possibly irreversible changes in ACS.

It is important to set milestones that enable a meaningful evaluation of the progress made in communicating science to the general public and in supplying inputs to policy makers for decision support. The metrics constructed must be realistic and should involve relevant communities and agencies. While better organization and coordination of research are undoubtedly needed for a coherent outcome, there is a concurrent need to be policy relevant while avoiding policy prescriptions. Asia and the world want simple yet credible scientific information delivered promptly and with clarity. A range of sectors such as fresh water, agriculture and food, transportation, air quality and health, and energy, along with national and regional planners in Asia and worldwide, are increasingly asking for knowledge to deal with the risks of climate change even if the scientific uncertainties remain large. It becomes the responsibility of the climate science community to convey with clarity the uncertainties and confidence levels without sacrificing scientific rigor. Thus, data and products that are readily usable and carry statements about the uncertainties in each variable (e.g., temperature, rainfall) must be provided.

A Complex System

Climate change will likely add to the stresses already existent in the other socioeconomic aspects of the human populations in Asia. These exacerbated stresses will be felt around the world through climate system linkages and through economic and geopolitical links.

As with climate change in the rest of the world, at stake are the cultural and social structures in the region—for example, projected limited water resources and associated public health concerns will influence life expectancies and living standards.

With cautious optimism, through holistic approaches to climate science and its societal influences and impacts, new knowledge will provide increasingly reliable inputs and thus continually improve decision support and policy planning. Scientific information on ACS has to be articulated clearly to meet the specific needs of the diverse public and private enterprises, policy makers, on-ground decision makers (e.g., regional planners), and other key players in Asia. How climate science outcomes, human population growth and adaptation, economic and technological developments, and policy decisions intersect and interact will shape how Asia copes with climate change in the 21st century.

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