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Flood Risk Growth under Global Change – Yangtze Floods in Perspective*

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Abstract Recent floods have become more abundant and more destructive than ever in many regions of the globe. Catastrophic floods observed since 1990 all over the world have led to record-high material damage, with total losses exceeding one billion US dollars in each of over 30 events. The number of great flood disasters in the nine years 1990-1998 was higher than in the three-and-half decades 1950-1985, together. A significant part of these recent losses (including the two highest material damages on record, in 1996 and 1998) have been observed in China.

The immediate question emerges as to the extent to which a sensible rise in flood hazard and vulnerability can be linked to climate variability and change. As the water-holding capacity of the atmosphere grows with temperature, the potential for intensive precipitation also increases. Higher and more intense precipitation has been already observed and this trend is expected to increase in the future, warmer world. This is a sufficient condition for flood hazard to increase. Yet there are also other, non-climatic factors exacerbating flood hazard, such as land-use change (deforestation, urbanization) leading to the reduction of water storage potential and increase of the runoff coefficient. Humans have been driven to occupy unsafe areas, thereby increasing the loss potential. Growing wealth has been accumulated in flood-endangered areas.

There is no doubt that in the future, flood risk is likely to grow in many places, due to a combination of anthropogenic and climatic factors. Vulnerability to floods can be regarded as a function of exposure and adaptive capacity, and all these entities have been increasing in many areas. The vulnerability grows, as exposure increases faster than the adaptive capacity. Yet, it is difficult to disentangle the climatic component of the river flow series from the strong natural variability and direct, man-made, environmental changes. There is a large difference between results obtained for the future conditions by using different scenarios and different models.

Links between climate change and floods have found extensive coverage in the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC). The findings in the IPCC TAR material warn of a considerable increase of the risk of a very wet monsoon season in Asian monsoon region.

This presentation examines the available information on the floods on the Yangtze observed in the

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past-to-present. Further, it will review a sample of available studies on hydrological impacts of future climate scenarios. Results of modeling of future conditions in East Asia will be discussed.

Keywords: Global Change, Yangtze River, Flood risk

Recent floods have become more abundant and more destructive than ever in many regions of the globe. According to the data of the Red Cross for the time period 1971-1995, floods killed, globally in an average year, over 12700 humans affected 60 million people and rendered 3.2 million homeless. Based on data from Berz, one concludes that the number of great flood disasters (understood as such events where international or inter-regional assistance is necessary) has grown considerably worldwide: in the nine years 1990-1998 it was higher than in the three-and-half decades 1950-1985, together. In USA, a statistically significant increase in the total annual flood damage, adjusted for inflation, has been observed in the period 1932 to 1997, with the rate of 2.92% per year.

Since 1990, there have been over 30 floods worldwide in each of which either the material losses exceeded one billion USD or the number of fatalities was greater than one thousand, or both. The storm surge in Bangladesh in April 1991 caused the highest number of fatalities (140 000).

Several destructive floods occurred in 2002. It is estimated that the material flood damage recorded in the European continent in 2002 has been higher than in any single year before. According to Munich Re [1], the alone floods in August of 2002, on the Elbe and the Danube, and on their tributaries, caused damage at the level exceeding 15 billion Euro (therein 9.2 in Germany, and 3 in each of the two countries: Austria and the Czech Republic). During severe storms and floods on 8-9 September 2002, 23 people were killed in the Rhone valley (southern France) and the total material losses went up to 1.2 billion USD. In July and August of 2002, floods and landslides in northeastern and eastern India, Nepal and Bangladesh killed 1200. Two large floods occurred in 2002 in China, in each of which the damage exceeded 1 billion USD.

A significant part of the global flood losses in the last decades have been observed in China. The highest material flood losses, of the order of 30 billion USD, were recorded in China (related to inundations by several rivers) in the summer of 1998, and the second highest global damage, of the order of 26 billion USD occurred in China in 1996. In June 2002, a flood in central and western China caused 3.1 billion USD losses and killed 500, while another one, in August 2002 in central and southern China, caused 1.7 billion USD damage and killed 250.

1 Flood risk on the rise. Why?

Flood risk and vulnerability result from a juxtaposition of two elements: abundance of water inundating areas located normally outside the river bed (hence – normally dry) and presence of damage potential in the inundated area, caused by human encroaching into floodplains with infrastructure. Changes in risk result of changes in the probability of high flows and of changes in the damage potential corresponding to these flows (river stages).

The world has been rapidly changing, so the flood risk and vulnerability have been changing as well. These changes are mostly adverse. An important general driver of global change is the population growth with consequences to food, resource use, settlements, land-use, etc. The reasons for changes in flood risk and vulnerability can generally be attributed to changes in terrestrial, socio-economic, and climatic systems.

Flood risk may have grown as an unwelcome side effect of a range of land-use changes, which induce changes of hydrological systems. Deforestation, urbanization, lands reclamation for agriculture, and reduction of wetlands empoverish the available water storage capacity in the catchment and increase the runoff coefficient. Urbanization has adversely influenced flood hazard in many watersheds by increase in the portion of impervious area (roofs, yards, roads, pavements, parking lots, etc). In result, peaks of runoff responses to intensive precipitation increase and the time-to-peak decreases. Timing of river conveyance may also have been considerably altered by river regulation (channel straightening and shortening, construction of embankments).

Flood risk has grown substantially due to changes in socio-economic systems, such as eeconomic development of flood-prone areas. Myriads of wrong locational decisions have been taken, which lead to establishing settlements in flood-prone areas (floodplains, coast). Floodplains indeed attract development due to their flatness, high soil fertility, proximity to water and availability of construction materials. Demographic growth, shortage of land, and unjustified belief in absolute safety of flood protection schemes, cause the tendency of human encroaching into floodplains, and investing in infrastructure there. Growing wealth has been accumulated in flood-endangered areas. Thereby the flood loss potential increases, while much of natural flood storage volume is lost, ecosystems are devastated, and riparian wetlands destroyed.

About 7% of the area of the conterminous United States is located in the 100-year flood zone and about 10% of population are living there. The latter number approximately corresponds also to the UK conditions. In Japan, half of the total population and about 70% of the total assets are located on floodplains, which cover only about 10% of the total land surface of the country. Yet, the percentage of flood-prone area is much higher in Bangladesh. The 1998 flood inundated two thirds of the country’s area. In less developed countries, informal settlements in floodplains surrounding cities are very common. Such settlements are established by poor people from the countryside, who hope to find employment in towns. Humans have been driven to occupy unsafe areas, thereby increasing the flood loss potential.

The immediate question emerges as to the extent to which a sensible rise in flood hazard and vulnerability can be linked to climate variability and change. Definitely, cclimate change has also contributed to the increase of flood hazard.

According to IPCC①[2], statistically significant increase in global land precipitation over the

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① IPCC stands for the Intergovernmental Panel on Climate Change and TAR for the Third Assessment Report on Climate Change. Professor Zbigniew W. Kundzewicz was involved in the IPCC TAR process in the capacities of: a Co-ordinating Lead Author of Chapter 13 (Europe) of the IPCC Working Group II Report (Impacts, Adaptation and Vulnerability), contributor to the Technical Summary and Summary for Policymakers of the IPCC WG II TAR, and member of the Core Writing Team of the IPCC TAR Synthesis Report. Since the IPCC TAR process, he has been a Co-Anchor of the Cross-Cutting Theme Water, co-author of the tentative outline of the wa-

20th century was noted. It is very likely “that in regions where total precipitation has increased … there have been even more pronounced increases in heavy and extreme precipitation events. The converse is also true.” Moreover, increases in “heavy and extreme precipitation” have also been documented in some regions where the total precipitation has decreased or remained constant. From the point of view of flood generating mechanism, increase of intense precipitation is more important than the growth in the mean. It results from physical laws that the water-holding capacity of the atmosphere grows with temperature. Hence, the potential for intensive precipitation also increases. Higher and more intense precipitation has been already observed and this trend is expected to increase in the future, warmer world. This is a sufficient condition for flood hazard to increase. Yet there are also other, non-climatic factors exacerbating flood hazard, such as land-use change (deforestation, urbanization). Increase of proportion of precipitation falling in large events has already been observed over many areas of the mid- and high latitudes, e.g. in the USA and in the UK [2].

Where data are available, changes in river flow usually relate well to changes in total precipitation [2]. There are a number of studies reporting that high flows have become more frequent [3]. Many increases of annual maxima and peak-over-threshold (POT) variables have been found in the river flow data in different areas, e.g. in the UK, particularly in Scotland and in southeastern England, and in the USA. However, this does not directly translate into general finding on changes in flood flows everywhere. No globally uniform increasing trend in maximum river flow has been detected due to the complexity of climatic signal and the multitude of additional, non-climatic factors, which in many places can be stronger than the climatic signature.

Box. 1 Key flood-related regional concerns in Asia [4] (after IPCC).

Key flood-related regional concerns in Asia, reported in IPCC TAR

Extreme events have increased in temperate and tropical Asia, including floods ... (*high confidence*)

Decreases in agricultural productivity and aquaculture due to … floods ... would diminish food security in many countries of arid, tropical, and temperate Asia (*medium confidence*)

Increased intensity of rainfall would increase flood risks in temperate and tropical Asia (*high confidence*)

Regional changes in timing of floods have already been observed in many areas, with increasing late autumn and winter floods (caused by rain, not snowmelt) and less jam-related floods and spring snowmelt floods, e.g. in Europe. This has been a robust result. Yet, intensive and long-lasting precipitation episodes happening in summer, especially induced by the Vb cyclone, have led to disastrous recent flooding in Europe. However, one should firmly resist a temptation to attribute the responsibility for occurrence of a particular flood to global changes (e.g. to climate). A particular flood may have manifested the natural variability – virtually any maximum flow rate observed recently has been exceeded some time in the (possibly remote) past. Yet, re-

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ter chapter of the WG II AR4 and of the initial draft scoping note on the technical report on water and climate change.

cent increase in the probability of floods fits well into the general image of the warming globe.

The links between flood-risk growth and climate variability and change have found extensive coverage in the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change [2,4]. In this latter reference, floods have been ubiquitously identified on short lists of key regional concerns. This also refers to temperate and tropical Asia.

2 Future projections

There is no doubt that in the future, flood risk is likely to grow in many places, due to a combination of anthropogenic and climatic factors. Vulnerability to floods can be regarded as a function of exposure and adaptive capacity, and all these entities have been increasing in many areas. In effect, the vulnerability grows, as exposure increases faster than the adaptive capacity.

Carter *et al.* [5] produced diagrams of scenarios for temperature and precipitation change for regions of the globe, including East Asia (defined as the area between the latitudes 20-50° N and the longitudes 100-150° E). Results of Carter *et al.* [5] show (Figs 1a and 1b) that, while for all eight-model results warming for all seasons is projected, most models project wetter conditions. In particular, all models indicate higher spring precipitations (March to May, MAM) and all but one model (CGCM1 from Canada) indicate higher winter (December to February, DJF) precipitation. As far as summer (June to August, JJA) and autumn (September to November, SON) precipitation is concerned, six models indicate wetter conditions, while two (therein CGCM1) indicate mean drying.

Arnell [6] studied change in a proxy for flood risk. He assumed the magnitude of the 10-year return period maximum monthly river runoff as the appropriate index. It results from the global map produced by Arnell[6], that this flood-proxy index will considerably increase for most of the basin of the Yangtze River.

Takahashi et al. [7] presented results of integrated modeling of flood risk in China, based on the assumption of the medium population scenario (one billion inhabitants in 2100), employment structure (non-agricultural sector employing 70% of the labor force by 2050 and 80% by 2100), and marginal adaptation costs of adapting to climate change being the same as those for current climate variability. Even if appropriate investments taking climate change in consideration are in place, flood damage to cultivated land was projected to reach the highest level of 1.58 around 2050. However, if no investment in flood protection infrastructure to combat projected climate change is made, the damage may increase to 3.11% by the end of the 21st century.

Recent studies show that plausible climate change scenarios indicate the possibility of increases in both amplitude and frequency of flooding events in the future. In articles on floods recently published in *Nature*, Palmer & Räisänen[8] and Milly *et al.* [9], strengthened our confidence in projected changes in extreme rainfall and flooding.

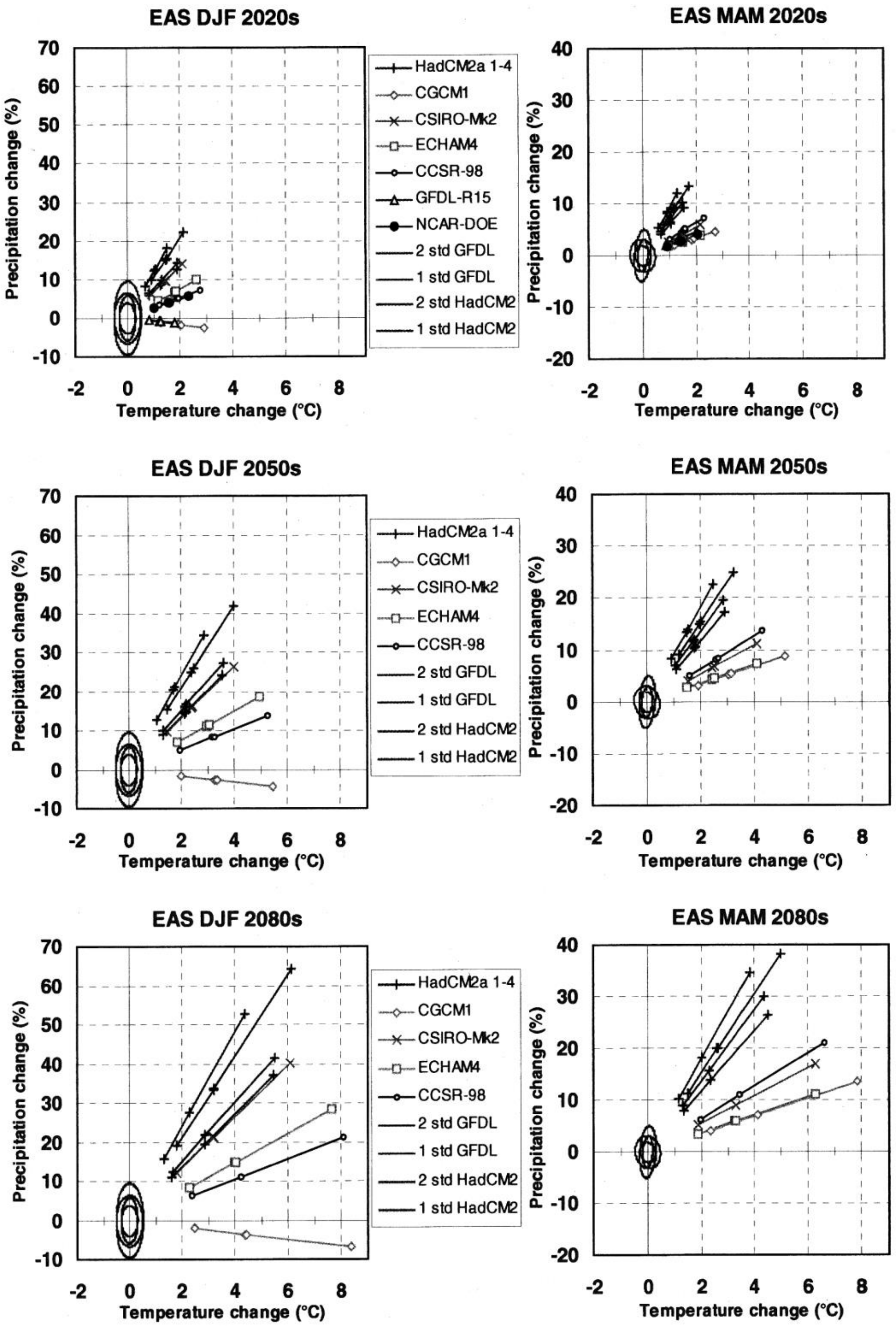

Fig. 1 Projected changes in temperature and precipitation over the region of South Asia for (a) winter (DJF) and spring (MAM)

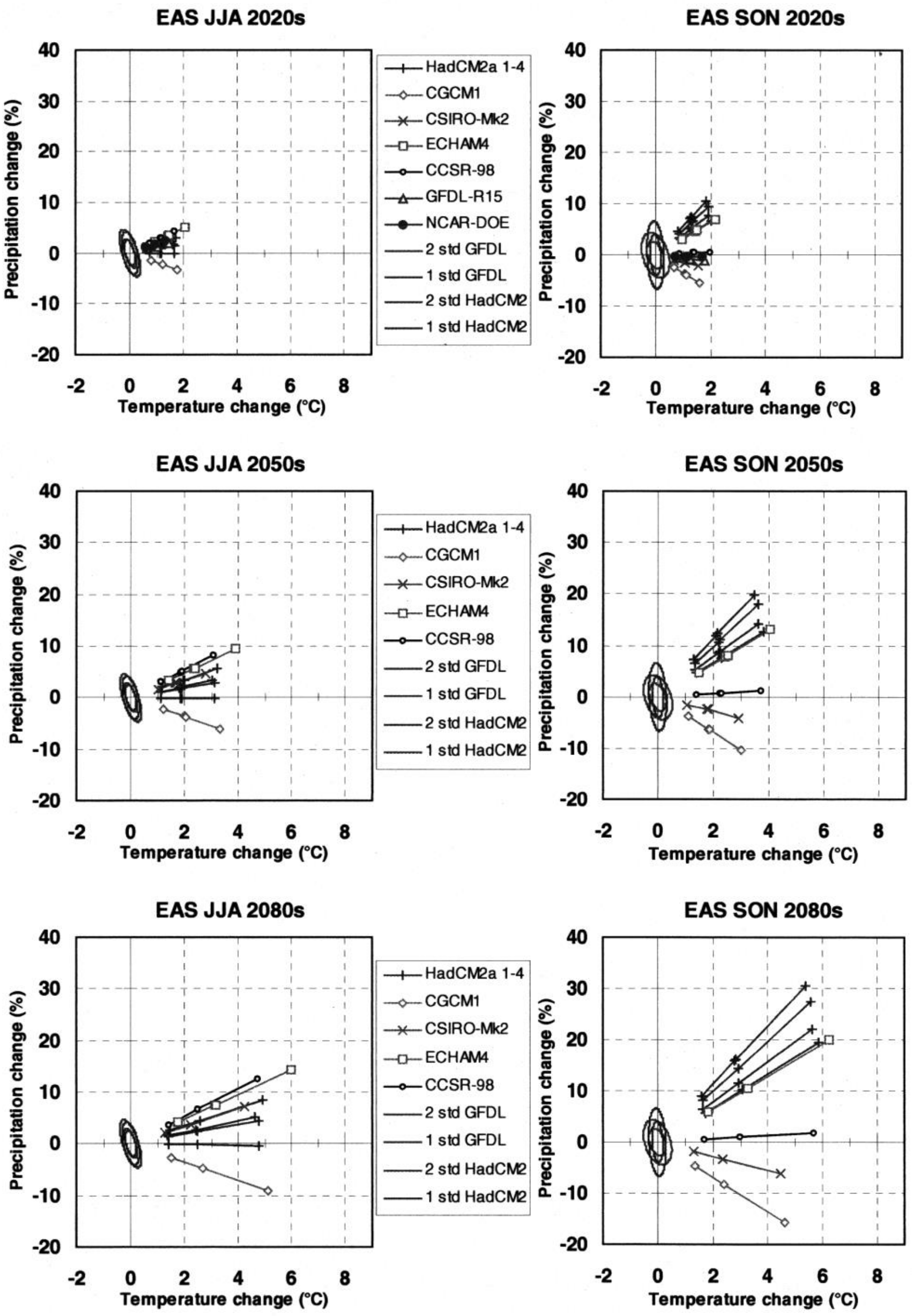

Fig. 1 Projected changes in temperature and precipitation over the region of South Asia for (b) summer (JJA) and autumn (SON); from Carter *et al* [5].

Milly *et al.* [9] demonstrated that for all (but one) large basins (over 200 000 km^2) analyzed, the control 100-year flood is exceeded more frequently as a result of CO_2 quadrupling. In some areas, what is given as a 100-year flood in the control run, is projected to become much more frequent, even occurring as often as every 2 to 5 years (i.e., 20-50–fold increase in frequency). Particularly strong increases are projected in North Asia, but also for East Asia, the increase in frequency is by factor of 5 to 50. According to Milly *et al.* [9], the likelihood that these changes are due to natural climate variability is small.

Palmer & Räisänen [8] analyzed the modeled differences between the control run with 20th century levels of carbon dioxide and an ensemble with transient increase in CO_2 and calculated around the time of CO_2 doubling. They found a considerable increase of the risk of a very wet monsoon season in Asian monsoon region. The modeling results indicate that the probability of total boreal summer precipitation in the Asian monsoon region, exceeding two standard deviations above normal will increase by a factor around 3 over the drainage basin of the Yangtze river.

3 Gaps in knowledge and need for research

Tab. 1 List of variables related to floods, where changes may have occurred

Variables and notions related to climate and atmospheric systems
Total precipitation
Intense precipitation events
Wind intensity
Seasonal distribution and climate variability (e. g., ENSO)
Sea level
Variables and notions related to terrestrial systems (hydrological systems and ecosystems)
River discharge and stage (amplitude, frequency statistics, seasonality)
Water storage capacity (e. g., decrease caused by land-use change, e. g. deforestation, urbanization, elimination of flood plains and wetlands)
Runoff coefficient and infiltration capacity, portion of impervious area (e. g., changes caused by urbanization)
Impacts on ecosystems
Variables and notions related to economic and social systems
Anthropogenic pressure (population growth, urbanization, deforestation, channelization, and human occupation of non-safe areas, especially squatter settlements)
Adaptive capacity
Vulnerability
Measures of flood losses (number of fatalities; number of evacuees; total material damage; insured losses; losses in cultural heritage; further specification of losses, e. g., destroyed infrastructure, buildings, industrial plants, railways, bridges, roads, dikes, etc.; inundated area; therein agricultural land, crop loss)
Risk perception

Even if, globally, there are many time series of long records of river flows, the data on different aspects of floods are scarce. In order to understand changes in different aspects of flood, it would be worthwhile to study the behaviour of the long series of the characteristics assembled in

Table 1[3] (based on Kundzewicz & Schellnhuber[5], , where changes may have occurred. Unfortunately, very few long time series are available, and they relate to a small subset of listed variables only.

Assessments of number of flood fatalities are notoriously unreliable. For instance, the assessments of the number of fatalities in the floods on the Yangtze in July and August 1931, according to different sources, differ as 1 to 25, as shown in Tab. 2.

Tab. 2 Assessment of the number of flood fatalities in the Yangtze floods in July and August 1931, according to different sources

Number of fatalities	Source
400 thousand	National Flood Control and Drought Resistance General Directorate Office & Ministry of Water Resources of China [10]
1400 thousand	Munich Re [11]
3700 thousand	Burton [12]
145 thousand	Data given in several Chinese presentations at the present Workshop

It would be of much interest to decipher the reason for these significant differences. It may be that higher estimates are distorted by double counting, or evidencing more fatalities than strictly number of flood victims (e.g., all deaths in a given region, touched by flooding). Resolving this discrepancy could help us put the Yangtze floods in perspective.

Quantification of flood statistics is subject to high uncertainty. It is difficult to disentangle the climatic component from the strong natural variability and direct, man-made, environmental changes. There is a large difference between results obtained by using different scenarios and different models. It is a robust statement that, in general, today’s climate models are not good at producing local climate extremes due to, *inter alia*, inadequate (coarse) resolution. However, there is a hope that, with improving resolution, future models will be able to grasp details of extreme events in a more accurate and reliable way.

Studying changes, which influence flood hazard and flood risk is a challenging area for research. Among changes in question are:

(1) Changes in intense precipitation;
(2) Changes in cyclone track;
(3) Changes in land use;
(4) Changes in exposure and vulnerability.

4 Conclusions

There is no doubt that flood risk has grown in many places and is likely to grow further in the future, due to a combination of anthropogenic and climatic factors. Intense precipitation grows in the warming globe, even in the areas where a decrease of mean precipitation has been observed.

However, reliable quantification of flood statistics is very difficult to obtain for the past-to-present and is virtually impossible to obtain for the future. The whole area of flood risk analysis is underdeveloped, both in terms of data and models. As far as floods on the river Yangtze are concerned, there is a multitude of generating mechanisms – monsoon rainfalls, which differ in intensity, duration, areal extent and timing. Yet, there are several changes in climatic, terrestrial, and socio-economic systems, which augur an increase of the flood risk in the Yangtze basin.

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全球变暖导致洪水风险增加——长江洪水前景分析

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摘 要

近期在很多地方洪水越来越频繁且破坏性更大.20 世纪 90 年代以来全球大洪水造成社会经济财产巨大损失，30 次大洪水每次总损失额均超过 10×10^8 美元.1990-1998 年的 9a 时间的大洪水爆发的次数比 1950-1985 年期间 35a 大洪水次数还要多.近年来中国大陆也遭受了若干重大洪水灾害(包括 1996 和 1998 年两次大的财产损失）.

与气候变率和变化相关的洪水灾害和易爆发程度的显著增加，这是当前最紧迫的问题.随着气温升高大气中持水量也增加，因此大规模强度的降水的可能性也增大.已观测到高而集中的大降水事件而且这种趋势在未来气候变暖条件下可能增加，大降水事件的增加是洪灾增加的必然条件.当然也有一些其它的非气象因素加剧洪灾的发生，比如土地利用变化（森林砍伐、城市化）导致土壤持水能力下降，径流系数增加；此外，人类占据了洪泛区，可能导致洪水损失增大.另外物质财富在洪泛区的积聚也导致了洪灾损失增加.

毫无疑问，由于人类活动和气候的共同作用，未来洪水风险在很多地方可能增加.洪水易爆发程度被认为是暴露系数和调节能力的函数，而且在许多地方所有这些变量都可能增加.而随着暴露系数比人类调节能力增加快，因此洪水易爆发程度增大.然而，要完全从径流变化中区分气候因素导致的强烈自然变率还是直接的人为环境变化是很困难的.由于使用不同的假定情景和不同的气候模型，得到的未来环境的预测结果差异也很大.

IPCC 第三次评估报告中广泛讨论了气候变化与洪水之间的关系.IPCC 第三次评估报告警告说，在东亚季风区非常湿润的季风季节出现的可能性非常大，进而会导致相应地区洪水风险增加.

本文总结了迄今为此可收集到的有关长江洪水的资料.利用一些案例来分析研究未来假定情景下气候对水文的影响,并对东亚地区的模拟结果进行了讨论.

关键词 全球变暖 长江 洪水风险

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