Regional and decadal analysis of climate change induced extreme hydro-meteorological stresses informs adaptation and mitigation policies

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Climate change projections corresponding to the IPCC SRES A1FI scenario obtained from the integrated CCSM3 earth systems model were analyzed at regional and decadal scales to develop projections of extreme hydro-meteorological stresses. The extreme stresses considered in this study include major decadal or regional changes in temperatures or precipitation patterns, regional co-occurrence of increased temperature and reduced precipitation, reduction in soil moisture and stream flows, as well as increase in the intensity, duration or frequency of extreme events like heat waves, severe droughts, rainfall extremes, significant storms and possible floods. The analyses consider population projections from the A1FI scenario and produce anticipatory insights which are expected to be relevant for impacts on water resources, natural hazards, critical infrastructures, agriculture and nutritional resources, energy usage and regional tensions. While precise projections were developed for the entire globe, the focus was on detailed analyses of specific regions which represent either the top emitters of greenhouse gases or are among the most vulnerable to climate change impacts. The analysis was developed for the entire 21st century; however, the focus was on an adaptation scenario based on the state of the world in 2050 and a mitigation scenario based on the state of the world in 2100. The study led to both confirmation and refinement of existing knowledge and development of new insights. The methodologies used for the analysis were drawn from the geographic information sciences, extreme value theory, and geospatial-temporal data mining.

One part of our analyses considered grid-based decadal monthly averages. Thus, for each CCSM3 model output grid, we considered the average value for an entire month like January or July for each decade (e.g., "current" decade from 2000 to 2009, or "2050" decade from 2045-2055, or "2100" decade from 2090-2099) and then calculated the difference of the future decadal averages compared to the current decadal average. The globally average temperature for January increased by 2.29 degrees Celsius with a standard deviation of 2.2 in 2050 and by 5.7 degrees with a standard deviation of 5.9 in 2100. The corresponding numbers for July were 2 degrees average and 1 degree standard deviation in 2050 and 4 degrees average and 2 degree standard deviation in 2100. In the northern hemisphere, the mean summer (July) and winter (January) temperatures for the study regions (e.g., US, Europe, China and India) showed significant increase. In China, the average temperatures in the Tibetan plateau appears to rise above freezing, which may have serious implications in terms of de-glaciation and drastic longer-term reductions in the headwaters of the rivers that eventually cause the mega-deltas of the Indian sub-continent and eastern China. The average wetness of the land decreases by about 4 cm in July in East China and about 7 cm in eastern China. These may lead to extreme stresses on water and food resources and agriculture in the populated and cultivated regions of eastern China. Winter temperatures in most of the European Union appear to grow milder. However, extreme stresses in Europe, especially in the south, are likely from increased summer temperatures of 8 to 9 degrees Celsius in the heart of the European Union, specifically Austria, Balkans and Italian Alps, and about 6 to 7 degrees in Spain and most of France and Germany, in the 2100s. These levels of temperature increase imply tropical or sub-tropical summers in large parts of Europe as well as an intensification of heat waves, which agree with prior projections (Meehl and Tebaldi, 2004: Science, 305, 5686). The entire European Union appears to become drier on the average, with reduced summer precipitation, reduced soil moisture in the summer and reduced annual stream flows. The significant heating combined with drying may lead to additional stresses on water, vegetation and agriculture. In addition to hazards related to heat waves, significant stress on the energy sector due to air-conditioner use is likely. In the western United States (nearly a third to a half of the continental US), summer (July) temperatures are expected to rise by 4 to 5 degree Celsius in July on the average by 2050 and 6 to 8 degrees by 2100. The average summer precipitation reduces significantly in the western United States in roughly the same region where the increase in temperature occurs. The annual summer stream flow and the soil moistures reduce significantly in the summer across the continental US. Extreme water-related stress is expected in the Western United States, which confirms recent insights (Barnett et al., 2008: Science, 319, 5866). In the Indian sub-continent, winter (January) temperatures increase much more significantly than summer (July). However, the more extreme stresses will likely be caused by the significant warming in the north and northwest parts of India as well as in the Himalayas and the Tibetan plateau. Enhanced snowmelt may cause additional stream flow initially but de-glaciation would likely reduce runoff significantly in the long run. The monsoon rainfall amount in July shows an average increase in the eastern part of South India, Bay of Bengal and east central portions but a significant decrease in the Arabian Sea on the north-western part of the southern Deccan peninsula. Extreme storms increase in several parts of India. Overall, the insights appear to corroborate and/or complement the insights obtained from observations by previous researchers, specifically, decrease in total monsoon rainfall but increase in extremes (Goswami et al., 2006: Science, 314, 5804).

The regional and decadal changes in climate will be mostly felt on the regional water resources as well as water-related infrastructures. In addition, agriculture and food sectors will be impacted, as well as energy consumption and management. Natural hazards will cause strains on humanitarian relief infrastructures while water-related regional tensions will likely increase. Adaptation and mitigation decisions need to consider the impacts of regional climate change on projected population and demographic distributions as well as future technological and economic change which may significantly impact vulnerabilities and resilience. The guidance developed from these analyses was used in a climate change wargame organized by the Center for a New American Security (CNAS) in July 2008.

References

1. Barnett, T.P. Et Al (2008): *Human-Induced Changes in the Hydrology of the Western United States.* **Science**, 319 (5866): 1080-1083, 22 February.
2. Goswami, B.N. Et Al (2006): *Increasing Trend of Extreme Rain Events over India in a Warming Environment.* **Science**, 314 (5804): 1442-1445, 1 December.
3. Meehl, G.A, and C. Tebaldi (2004): *More Intense, More Frequent, and Longer Lasting Heat Waves in the 21st Century.* **Science**, 305 (5686): 994-997, 13 August.

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