CMG Research: Multiscale Nonlinear Domain Decomposition Method for Modeling the Impact of Climate Change on Groundwater Resources

S. Ge, Department of Geological Sciences, University of Colorado
X. Cai, Department of Computer Science, University of Colorado
C. Li, Department of Applied Mathematics, University of Colorado
M. Williams, Department of Geography, University of Colorado

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Continuing climate change poses uncertainties on future water resources. The water cycle encompasses fundamental processes that link various elements of climate and water resources. Holding approximately 30% of Earth's fresh water, groundwater's enormous storing capacity can be an effective buffer in regulating more drastic hydrologic events on the surface, therefore, plays an important but often overlooked role in long-term sustainability of water resources. High altitude mountainous regions are vital source areas for water. Hydrologic processes in high-altitude regions are particularly sensitive to climate change because of the presence of snow, glaciers, and permafrost. Yet, basic questions remain regarding how groundwater is replenished at its source by mountain recharge, the size of groundwater reservoirs, as well as how permafrost influences groundwater. Modeling the groundwater flow processes involving mountain recharge and permafrost faces mathematical challenges due to nonlinearity of the governing equations and multiscale nature of the spatial and temporal domains.

The objective of the research is to develop a more accurate mathematical model and a new robust computational algorithm and high performance software to study the impact of climate change on groundwater resources in mountain watersheds, with a focus on quantifying mountain recharge and permafrost hydrology. The research plan is to first develop a mathematical model that will be capable of handling coupled fluid flow and heat transport in complex geologic systems in multiscale spatial and temporal domains. Second, field hydrogeologic study at two sites will be conducted to gather data for testing the mathematical model. The final stage is to conduct numerical simulations to assess the response of groundwater storage and flow in mountain watersheds to future climate change scenarios.

Intellectual Merit: First, this study will contribute to our scientific knowledge on water cycle processes at multi spatial and temporal scales. In particular, this study will make a unique contribution to strengthening the subsurface element of the water cycle, increasing knowledge on mountain recharge, and integrating little known permafrost hydrology into a water resource study. Second, highly parallel and robust numerical algorithms and software will be developed for the coupled multi-physics system describing the water cycle processes. Third, the proposed mathematical model development will be a substantial contribution to hydrogeologic sciences. Dealing with multiscale fluid flow problems in heterogeneous geologic media has been a long standing challenging. Development of a robust computational algorithm allows efficiently modeling of hydrogeologic systems at such a comprehensive and integrated level that would be difficult to achieve by either mathematicians or geoscientists alone.

Broader Impact: Water resource sustainability and climate change are pressing issues of global and local concern. This study will benefit long term planning of water resources and increase general public's knowledge on the linkage between climate and water resources, by dissimilating results through local media and public lectures. The new computational algorithm implemented by a robust and versatile software will be transferable to other areas of application and available to other researchers. The cross-discipline nature of this project will afford students in mathematics and geosciences a unique opportunity to interact with each other in intellectual and physical settings that differ from those they are used to. This will be achieved by requiring students to take classes outside their home departments, math students to participate in field work, geoscience students to be trained in computational mathematics. Finally a joint math-geosciences seminar will be established to involve all project personnel. By encouraging broad participation, this seminar will foster more and sustained future collaborations between mathematics and geosciences.