Research Experience and Future Directions

Climate is a complex system that involves interactions among atmosphere, ocean, ice, land and human activities. It is also complicated with internal variability ranging from synoptic scales to millennium scales and climate change due to anthropogenic forcing. Although our understanding of climate and climate change is continuously improved with progresses in the observing network and climate model development, uncertainties remain in the weather and climate prediction. Climate models can misrepresent diurnal cycle, seasonality or spatial distribution of rainfall or disagree on climate projections over some regions. This is partially due to our limited understanding of the physical mechanisms underlying the hydrological cycle, as well as the high computational cost to resolve weather/climate processes and regional environment (e.g. topography). Several research challenges are actively studied with recent availability of high-resolution observations and increase in computational power. What circulation features support regional rainfall and its variability? What is the added value of convective-permitting models for representing diurnal cycle and deep convection? What environmental factors are important for the development of extreme events? How will the magnitude and frequency of extreme events change with global warming?

These research questions are not only important in climate and atmospheric science, but also have great social significance. Rainfall variability has implications for regional agriculture, water resources and land-use planning, especially for countries that suffer from food/water scarcity, catastrophic floods and lack of infrastructure. Improving the fundamental understanding of rainfall systems benefits weather and climate prediction and, further, local planning and decision-making. It helps to understand and communicate the regional impacts of extreme events as well as the potential impacts of climate change. My main research goals are directed by these needs, and are focused on the interactions between environmental factors and regional rainfall.

Past and Current Research:

Most regions in East Africa have an arid or semi-arid climate, with much of the rainfall delivered during March – May and October – December (known as the long-rains and the short-rains seasons). Local communities suffer from severe food insecurity and heavily depend on rainfall for agriculture and water resources, which makes them vulnerable to climate variation and change. However, coupled general climate models underestimate the long rains and overestimate the short rains, which undermines confidence in their climate projections. Further investigation of physical processes is needed to improve the simulation of East African rainfall. I examined the role of Walker circulations in influencing East African rainfall, which is one of several potentially relevant environmental factors. Specifically, I identified three Walker circulations near East Africa using the Ψ -vector method, namely, the East African, the Congo Basin, and the Indian Ocean Walker Circulations. I explored their influence on the interannual variability of East African rainfall in multiple reanalyses and observational precipitation datasets. With an anomalously strong/weak Indian Ocean Walker Circulation, less/more rainfall occurs over East Africa in the short-rains seasons. Such relationships do not emerge consistently across the datasets for the long-rains seasons or for the other two Walker circulations. The rainfall variations were found associated with anomalous midlevel moisture divergence that is primarily due to anomalies of wind divergence instead of atmospheric moisture. The anomalous horizontal advection of moist static energy can be important in supporting the rainfall variations, but this argument is less conclusive. The concept of Walker circulations and the Ψ-vector method can over-simply the three-dimensional circulation, and caution is appropriate for using them.

The West African Sahel is vulnerable to damaging floods, which is a combined result of frequent intense storms and insufficient infrastructure to accommodate flooding. These floods can be catastrophic, causing life and property loss. To better predict these floods, it is important to improve the understanding of major rainfall systems over the region. I am currently studying storms over the West African Sahel using reanalyses, precipitation observations and convective-permitting modeling. This will provide insights on regional storm characteristics and environmental factors important for storm development.

Future Research Directions:

My past and current research focuses on how large-scale and local environmental factors influence regional rainfall on interannual and synoptic time scales. Expanding on this, I plan to evaluate extreme events in current climate and their changes with global warming. This involves characterizing intensity and frequency of severe storms and investigating physical mechanisms that control the development of extreme storms. I plan to use convective-permitting modeling to simulate the extreme storms, and the output can be validated with precipitation observations. Comparing the simulation output with that of general circulation models will reveal how high model resolution and independence of convection parameterization influence the representation of diurnal cycle and storm development. The potential impacts of global warming can also be studied with the convective-permitting modeling that is prescribed with projected CO_2 concentration and environmental conditions.

Another direction is to study regional impacts of rainfall variations in terms of vegetation, agriculture, flooding prediction and land-use planning. This will integrate rainfall changes due to climate internal variability and global warming with land-surface processes. Observational vegetation datasets, dynamic vegetation models and hydrological models are possible tools to understand land-surface responses. Methods developed in these projects will be widely applicable globally.