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Toward Characterizing the 4D Structure of Precipitation at the Headwater Catchment Scale in Mountainous Regions

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The classic conceptual model of orographic rainfall depicts strong stationary horizontal gradients in rainfall accumulations and landcover contrasts across topographic divides (i.e. the rainshadow) at the broad scale of mountain ranges, or isolated orographic features. Whereas this model is sufficient to fingerprint the land-modulation of precipitation at the macroscale in climate studies, and can be useful to force geological models of land evolution for example, it fails to describe the active 4D space-time gradients that are critical at the fundamental scale of mountain hydrometeorology and hydrology, that is the headwater catchment. That is, the scale at which flash-floods are generated and landslides are triggered. Our work surveying the spatial and temporal habits of clouds and rainfall for some of the world's major mountain ranges from remotely-sensed data shows a close alignment of spatial scaling behavior with landform down to the mountain fold scale, that is the ridge-valley. Likewise, we find that diurnal and seasonal cycles are organized and constrained by topography from the macro- to the meso- to the alpha-scale of individual basins varying with synoptic weather conditions. At the catchment scale, the diurnal cycle exhibits an oscillatory behavior with storm features moving up and down from the ridge crests to the valley floor and back and forth from head to mouth along the valley with strong variations in rainfall intensity and duration. Direct observations to provide quantitative estimates of precipitation at this scale are beyond the capability of satellite-based observations present and anticipated in the next 10-20 years. This limitation can be addressed by assimilating the space-time modes of variability of rainfall into satellite-observations at coarser scale using multiscale blending algorithms. The challenge is to characterize the modes of space-time variability of precipitation in a systematic, and quantitative fashion that can be generalized. It requires understanding the physical controls that govern the diurnal cycle and how these physical controls translate into spatial and temporal variability of dynamics and microphysics of precipitation in headwater catchments, and especially in the context of extreme events for natural hazards assessments. Toward this goal, we have initiated a sequence of number of intense observing period (IOP) campaigns in the Great Smoky Mountains National Park using radiosondes, tethersondes, microrain radars, and a high resolution raingauge network that for the first time monitors rainfall systematically along ridges in the Appalachians. Along with field observations, a high-resolution coupled model has been implemented to diagnose the evolution of the 4D structure of regional circulations and associated precipitation for IOP conditions and for reconstructing historical extremes associated with the interaction of tropical cyclones with the mountains. A synthesis of data analysis and model simulations will be presented.