High-Resolution Observations and Modeling of Precipitation Processes in the Great Smoky Mountains: The Importance of Getting the Physics Right

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1. Introduction

Complex orographic landscapes characterized by high space-time gradients of precipitation, and thus complex hydrologic response, appear to orchestrate optimally the interplay of natural hazards leading from heavy precipitation to flooding, debris flows and landslides. The Southern Appalachians and the Great Smoky Mountains in particular provide a unique setting for investigating orographic precipitation processes and associated hydrological response in mountainous areas.

The goal of this study is to elucidate the space-time variability, seasonality and microphysical properties of clouds and precipitation systems which have an impact on regional hydrometeorology, hydrology and ecology. Specifically, we report on detailed studies that show interannual, seasonal and diurnal variability in precipitation frequency and intensity, as well as orographic enhancement of precipitation frequency and duration, modulated by season. Orographic enhancement is particularly clear in the vertical profiles and drop size distributions measured by the micro-rain radars that were in place for several different intensive observation periods (IOPs) in both ridge and valley locations.

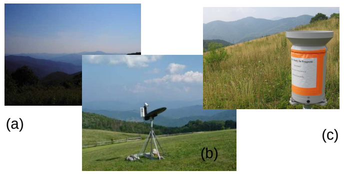
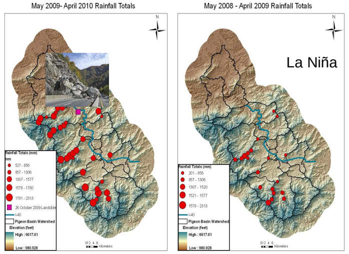


Fig. 1.1: *a) A view of the study region in the Great Smoky Mountains; b) Radar during an intensive observation period in place at Purchase Knob (ridge location); c) One of the tipping bucket rain gauges in the network.*

2. Interannual variability of orographic rainfall

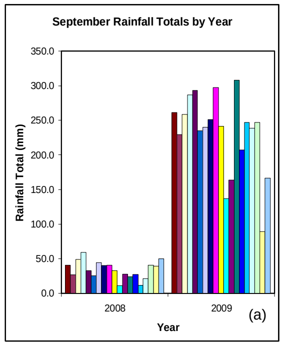
The current configuration of the PMM hydrometeorological network in the Appalachians, including 32 rain gauge stations and one flux tower, was completed in 2009 (Fig.2.1).



Annual amounts in 09-10 (strong EL Niño) compared against annual amounts in 08-09 (moderate to weak La Niña) show an increase in annual rainfall of about **50%.**

Significant increases take place in the months of May, September (Figs 2.2a and b), and December.

Fig. 2.1: *Spatial distribution of annual precipitation totals. The landslide in October 2009 was responsible for keeping I-40 closed for months.*



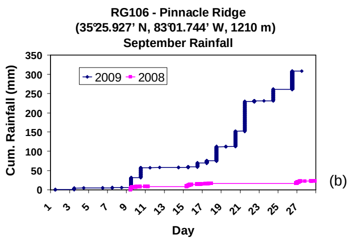
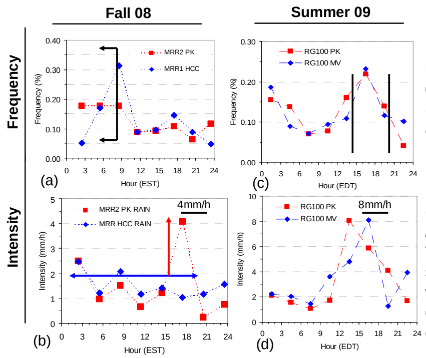


Fig. 2.2: *a) September rainfall totals in 2008 and 2009; b) cumulative rainfall curves.*

The data show that **the difference is** not in number of storms, but **in storm intensity.** This result contradicts previous climatology derived without high elevation data.

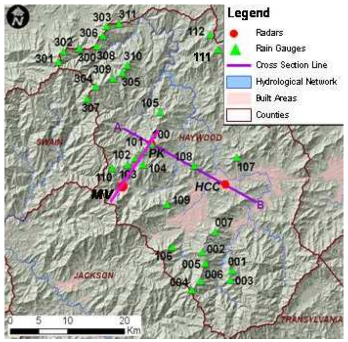
3.1 Seasonal differences in the diurnal cycles of ridges and valleys



In the fall (Fig 3.1.1a), **more than 50%** of precipitation events occurred **between 00:00 and 09:00**. In the summer (Fig 3.1.1c), about **50%** of precipitation events occurred **between 14:00 and 20:00**.

In the fall, the ridge experiences higher rainfall intensity than the valley (Fig 3.1.1b). ***This shows the influence of landform on orographic enhancement.*** The rainfall intensity is greater in the summer than in the fall at both ridge and valley locations (Fig 3.1.1d), indicating the difference between stratiform and convective rainfall by season.

Fig. 3.1.1: *a) Fall 2008 rainfall frequency; b) Fall 2008 rainfall intensity; c) Summer 2009 rainfall frequency; d) Summer 2009 rainfall intensity. See Fig. 3.1.2 for the locations of the MRR and rain gauges.*



Several different field campaigns were conducted using micro rain radars (MRRs). An MRR was deployed at Purchase Knob (PK) during the fall of 2008 and the summer of 2009. During each of those periods, an MRR was deployed in a valley location as well. During the fall of 2008, an MRR was located at Haywood Community College (HCC); during the summer of 2009 an MRR was placed in Maggie Valley (MV). Locations are plotted on the map to the left and lines are drawn to clearly indicate their relation to PK.

Fig. 3.1.2: *Locations of the MRRs during the intensive observation periods discussed in Section 3.*

3.2 Seasonal differences in the vertical profiles of ridges and valleys

The figures below show longer duration rainfall events in the ridge than the valley (Figs 3.2.1 a and b), with the difference most pronounced in the fall. Light rainfall is significantly more frequent at high elevations during this season. Rainfall intensity during concurrent events is most similar in terms of height above sea level.

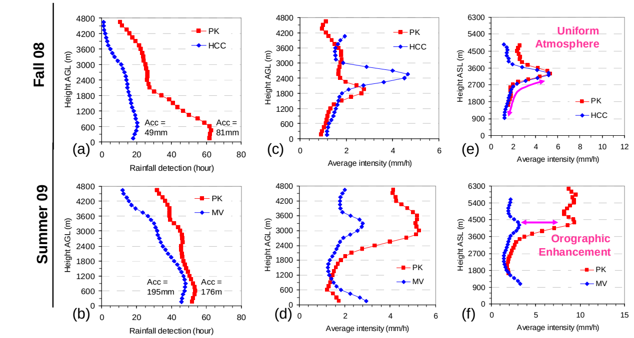
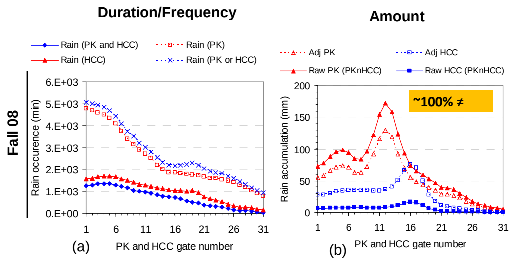


Fig. 3.2.1: *a) Fall 2008 rainfall detection; b) Summer 2009 rainfall detection; c) Fall 2008 average intensity above ground level (AGL); d) Summer 2009 average intensity AGL; e) Fall 2008 average intensity above sea level (ASL); f) Summer 2009 average intensity ASL. See Fig. 3.1.2 for the locations of the MRR.*

3.3 Orographic enhancement



Figures 3.3.1(a and b) show MRR precipitation measurements during the fall 2008 field campaign. The data show clear contrasts between the ridge and valley locations in terms of both parameters.

Fig. 3.3.1: *a) Fall 2008 rainfall duration/frequency; b) Fall 2008 rainfall intensity. See Fig. 3.1.2 for the locations of the MRR.*

4. Microphysics - Drop size distribution

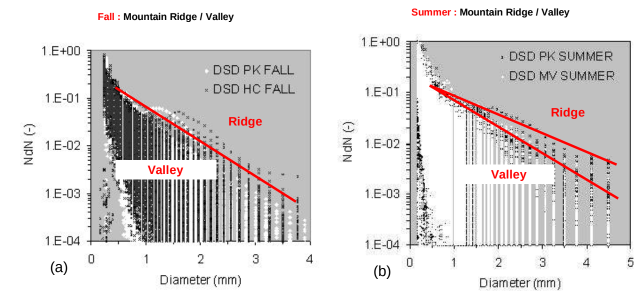


Fig. 4.1: *a) DSD measurements from the MRR during fall; b) DSD measurements from the MRR during summer. See Fig. 3.1.2 for the locations of the MRR.*

Similar drop size distributions were measured by the MRR in ridge and valley locations in the fall, but in the summer the ridge has a much heavier right tail in its distribution than the valley, indicating the presence of larger-sized drops at the ridge location. This corresponds to summer thunderstorms in the mountains.

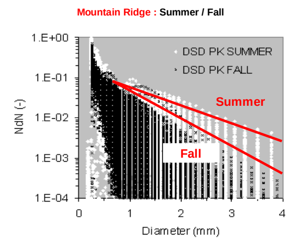


Fig. 4.2: *DSD measurements from the MRR at the ridge location during summer and fall.*

The heavier right tail of the distribution in the summer for the high elevation location points to enhanced coalescence efficiency. Numerical modeling experiments have shown that coalescence is the dominant microphysical mechanism for the rain rates often observed in mountainous regions. The data support the hypothesis that coalescence is the microphysical process primarily responsible for orographic enhancement.

5. Acknowledgments

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