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Key Points:

- Precipitation partitioning controls vary across the region due to complexity created by the eastern continental divide
- Climate controls, in particular temperature and fraction of precipitation falling as snow, were more important than landscape controls
- Among the landscape controls, elevation was the most influential to precipitation partitioning

Supporting Information:

Supporting Information may be found in the online version of this article.

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Climate and Landscape Controls on the Water Balance in Temperate Forest Ecosystems: Testing Large Scale Controls on Undisturbed Catchments in the Central Appalachian Mountains of the US

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Abstract The long-term water balance of catchments is given by precipitation partitioned into either runoff or evaporation. Understanding precipitation partitioning controls is a critical focus of hydrology and water resources management. A useful theoretical framework that serves their understanding is the Budyko Framework. Our purpose is to understand how Budyko's n parameter is related to different controls and what is its relevance to precipitation partitioning. We investigated the relative importance of the dryness index and the Budyko parameter for precipitation partitioning, then applied partial correlation analysis and multivariate regressions to find out which were the principal partitioning controls. We focused our research in the central Appalachian mountains located in the eastern United States, considered as water towers to metropolitan areas in the eastern and mid-western US (e.g., Pittsburgh, Washington DC), and selected a set of catchments characterized by minimal human disturbance and with large proportions of temperate forests. We found that climate controls such as mean annual temperature and fraction of precipitation falling in the form of snow exert a higher influence on partitioning than landscape controls (e.g., forest cover, Normalized Difference Vegetation Index, and slope). Thus, the importance of vegetation as a primary driver of partitioning could not be confirmed based on regional or basin-wide characteristics. On the other hand, the influence of topography, and elevation in particular, was highly ranked as important. Our study highlights that partitioning controls could differ between basins in the same climate region, especially in a complex, mountainous topography setting.

1. Introduction

The long-term catchment water balance is controlled by the partitioning of precipitation (P) into either runoff (R) or evaporation (E) (defined as the bulk flux of water, including transpiration, bare soil, interception loss, and vaporization of water [Miralles et al., 2020]). According to the Budyko framework, precipitation partitioning is determined by the long-term climate and modulated by catchment characteristics (Budyko, 1974). In other words, this framework combines the water supply, atmospheric water demand, and the characteristics of catchments to explain precipitation partitioning using a partitioning parameter. The Budyko parameter is often understood to be a shorthand for landscape characteristics and ultimately, a reflection of the landcover and vegetation types (e.g., Wang & Hejazi, 2011), although other authors present a broader definition that also includes specific climatic controls (e.g., Roderick & Farquhar, 2011). These conceptual differences or paradigms about Budyko's parameter limit the understanding of complexities in what factors are first-order controls of precipitation partitioning, what is, and ongoing and fundamental question of hydrology (Daly et al., 2019; Peters-Lidard et al., 2018). Here, we focus on the second paradigm to showcase that Budyko's partitioning parameter can be critically associated with other controls besides landscape or vegetation. Notwithstanding the advances in the general understanding of partitioning controls and hydrologic behaviors at different climatic regimes and hydroclimatological regions (e.g., Heidari et al., 2020; Jaramillo & Destouni, 2014; Padron et al., 2017), there is still a need to study how climatic and landscape controls are differentiated within large scale climatic regions.

Therefore, this study aims to unpack the Budyko partitioning parameter n at the intra-regional scale, while considering its collective features of landscape and vegetation controls but also including specific climate

controls. In order to reach that goal, we computed correlations between Budyko's n parameter and various climate and landscape controls to precipitation partitioning in the region of the central Appalachian Mountains. The specific objectives of our study are to (a) quantify the relative importance of the dryness index (DI) and Budyko's parameter n for precipitation partitioning, (b) identify the most important climatic and landscape controls for partitioning, and (c) discuss the importance of controls with respect to future scenarios of climate and landscape for a study region. Our study contributes to fill knowledge gaps about the precipitation partitioning controls using the Budyko Framework, and to demonstrate that some perceived contradictions on the controls of precipitation and their relations to the Budyko parameter are possible.

2. Scientific Background

2.1. The Budyko Framework

The Budyko framework (Budyko, 1974) is a simple energy-water balance model that explains how precipitation partitioning, represented as the evaporative index (EI) (E/P), is determined by a catchment's dryness index (DI) (potential evaporation [E_p]/ P) and modulated by a catchment's characteristics, which are described by a partitioning parameter. Budyko (1974) advanced the understanding of the interaction between water demand and water supply in a diverse set of basins across the world. He helped to popularize this framework in the hydrologic community, and while several equations representing the Budyko framework were developed in the previous century (e.g., Budyko, 1974; Ol'dekop, 1911; Pike, 1964; Schreiber, 1904). The Budyko framework then progressively evolved into parametric functions (Choudhury, 1999; Fu, 1981; Tang & Wang, 2017; Zhang et al., 2004). There are two lines of parametric equations, where the Budyko parameter is denoted as either n (Choudhury, 1999) or w (Fu, 1981; Zhang et al., 2004). These parameters, however, are analogous and explain the same underlying controlling processes (Yang et al., 2008). Budyko's n can be considered as an integrative coefficient of the catchment characteristics that aids in the prediction of E based on the long-term hydroclimatology of a basin (Roderick & Farquhar, 2011). In this study, we used a Budyko equation form derived by Yang et al. (2008) (Equation 1).

$$E = \frac{P * E_p}{\left[P^n + E_p^n \right]^{\frac{1}{n}}} \quad (1)$$

The Budyko framework is graphically exemplified in Figure 1, where catchments from the central Appalachian mountains are presented as a function of the DI (x-axis) and the EI (y axis). The abscissa represents how dry a catchment is on average: Catchments with a $DI < 1$ are considered energy limited/humid since $P > E_p$; and catchments that have a $DI > 1$ are water limited ($E_p > P$) or drier catchments. Catchments are theoretically bound to fall under the *Energy limit* (which follows the identity line), where $E = E_p$, and the *Water Limit*, where the $E = P$. The Budyko parameter n determines the shape of the curve that describes the catchment. Those catchments with a higher Budyko's n are closer to the energy and water limits, meaning that a higher Budyko's n is equivalent to a greater capacity of precipitation partitioning at a given dryness index. Hence, understanding what controls are more related to Budyko's n constitutes a shorthand to the importance of the respective control to precipitation partitioning. While Budyko's n has been related to the landscape characteristics of catchments (e.g., Wang & Hejazi, 2011; Xu et al., 2013), it is worth mentioning that Budyko's n should be considered a "partitioning parameter," that besides landscape also includes climatic aspects that are not directly described by the long-term DI. For instance, Budyko's n has been associated with snow characteristics, storminess, and seasonality (Donohue et al., 2012). Let us succinctly review the main applications of the Budyko Framework and the general views on the Budyko parameters.

While the Budyko framework was been widely used to explain large-scale and long-term precipitation partitioning; with many studies focusing on the controls of landscape and climate on the water balance in China, Australia, and Europe (e.g., Jaramillo et al., 2018; Roderick & Farquhar, 2011; Shao et al., 2012; Teng et al., 2012; Teuling et al., 2019; Wu et al., 2017; Xin et al., 2019); another popular use of the Budyko framework has focused on the attribution of temporal changes in water yield to either climate changes or landscape changes (e.g., Renner & Bernhofer, 2012). A well-known study by Wang and Hejazi (2011) used a decomposition methodology to quantify the contributions of climate and direct human impacts on streamflow in 413 in the contiguous U.S.; adapting that methodology, Patterson et al. (2013) studied climate and

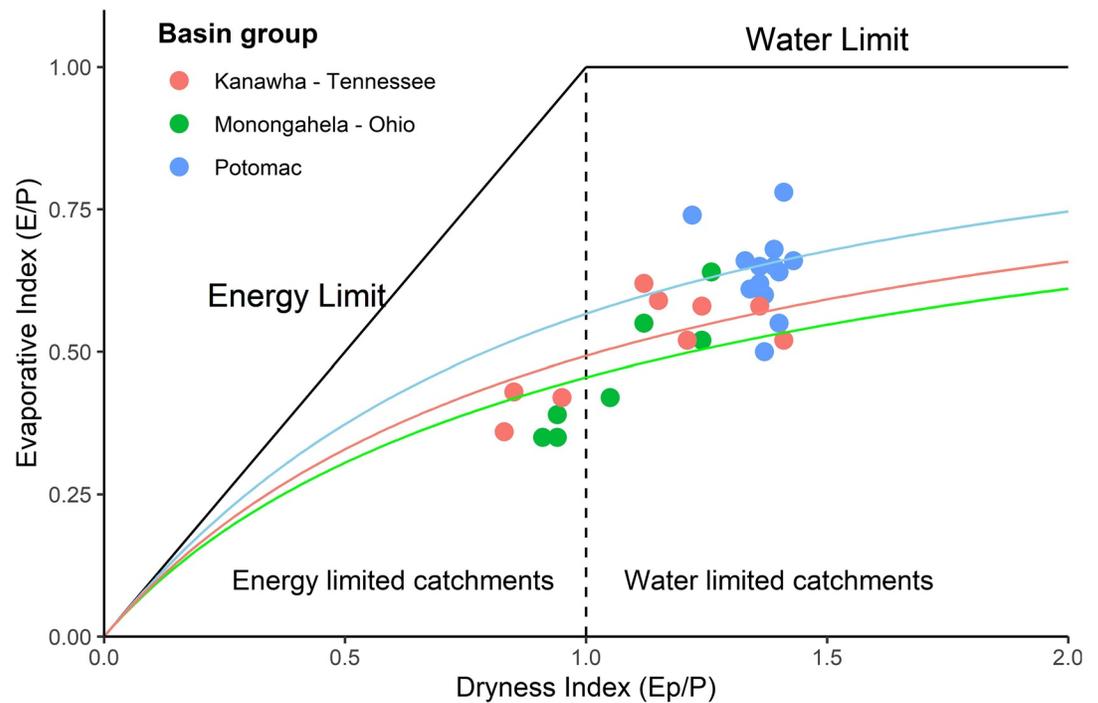


Figure 1. Graphical representation of the Budyko Framework with catchments of the central Appalachian Mountain region plotted on the Budyko space. Plotted Budyko curves are based on the arithmetic mean of the Budyko's n value for each basin group.

human contributions to streamflow change in the south Atlantic US; and Li et al. (2013) in a global river study investigated the importance of vegetation in controlling the Budyko parameter but indicates that at different scales even climatic seasonality can be an important control of the parameter. Similarly, Jiang et al. (2015) uses the decomposition method to study the streamflow change in the Weihe River but advances the method by including climate change into the causes of change in the Budyko parameter. Besides decomposition, authors have also looked at the direction and magnitude of temporal changes in partition, for example, Jaramillo and Destouni (2014) show that certain directions of change in the Budyko space should be attributed to landscape changes. Generally, such attribution studies, although sometimes not explicitly, present the notion of equivalence between the Budyko's parameter to landscape components, and even to just vegetation characteristics. Rightly so, the Budyko parameter has been found to be highly related to the vegetation characteristic of catchments. For instance, Zhang et al. (2001) found that vegetation is closely related to the Budyko parameter, likewise Donohue et al. (2007) that vegetation dynamics needs to be incorporated to the Budyko framework. However, another paradigm around the Budyko framework considers the Budyko's partitioning parameter to be controlled by "other factors" (Gudmundsson et al., 2016). This approach, thus takes a broader view of the partitioning parameter and does not limit it to landscape factors. Examples of this view include the work by Milly (1994), highlighting the importance of storminess, by Berghuijs et al. (2017) indicating that snow can affect partitioning; and by Petersen et al. (2012) work on the phases of seasonal cycles of precipitation. Notwithstanding this knowledge, the question of what controls precipitation partitioning is still part of important debates (Berghuijs et al., 2020; Padron et al., 2017; Xing et al., 2018), and so is the need to continue to unpack the Budyko's partitioning parameter. Therefore, this paper's novelty centers on unpacking the Budyko's partitioning parameter by investigating the effects of a mountain range on differentiated climate and landscape controls over partitioning within the same climatic region.

Partitioning controls are generally divided into climate and landscape controls. Climate controls are important for partitioning since they influence water supply, in terms of amount, intensity, frequency, type, and seasonality of P (Milly, 1994); water demand (magnitude and seasonality of E_p); and the interaction between water supply and demand, since the synchronization of the seasonal cycles of P and E_p is determinant of

more or less water surplus or shortage (Fernandez & Zegre, 2019; Stephenson, 1990). The landscape controls refer to the abiotic variables as landforms but also biotic factors as the vegetation cover. Landscape controls include topographic characteristics that are important for partitioning since, for instance, steeper catchments favor runoff by reducing the time water stays in the catchment (Shao et al., 2012) and a larger catchment size can create more conditions for evaporation to occur (Choudhury, 1999). Moreover, soil characteristics, such as texture and depth (Donohue et al., 2012; Milly, 1994) influence a catchment's potential water storage that can be available for plant transpiration, which exert important controls on the water balance in broad-leaf forests of temperate latitudes, such as the Appalachian Region (Brown et al., 2005; Ford et al., 2011; Knighton et al., 2020; Li et al., 2013; Zhang et al., 2001). The influence of these controls is expected to have similar behaviors within the same climate regions (Padron et al., 2017), but other factors like landforms have been found to play a role in hydrologic behavior in the future (Heidari et al., 2020). Heidari et al. (2020) investigated the associations of movements in the Budyko space with the regional hydroclimatic characteristics in the US, indicating that not only climate type but also landforms are associated with different hydrologic behaviors for future scenarios of change. Yet, a few studies have looked at how hydrologic behavior differs between basins that are part of the same climate type and landform (Gaertner et al., 2020; Fernandez & Zegre, 2019).

3. Methods

3.1. Study Site

To investigate the importance of different controls and how precipitation partitioning can vary within a climatic region, we focus on the heavy forested region of the central Appalachian Mountains in the eastern USA. The area can be considered a water tower (Viviroli et al., 2007), as it provides freshwater to ~9% of the US population (Gaertner et al., 2019). Understanding what specific catchment characteristics drive the EI is critical since such high elevation regions provide water to large populations and vast land areas in other areas around the world, making catchment and land management vital for water security in such humid regions (Praskievicz, 2019). Furthermore, aridity in high-elevation catchments in the Appalachian region is projected to increase at a disproportionately higher rate compared to the lower lying areas (Fernandez & Zegre, 2019) calling into question the sustainability of contemporary water use management for important population centers in the eastern USA.

This study is focusing on catchments located in the central Appalachian Mountains region in the eastern US. We included 29 catchments in the states of Maryland, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia, extending from 34° to 42° North and 75° to 85° West (Figure 2). The selected catchments (Table S1) are part of the Hydro-Climatic Data Network (HCDN) (<https://water.usgs.gov/osw/hcdn-2009/>). The HCDN network is a subset of USGS stream gauges with relatively low levels of human disturbance and a long-term record that permit for hydroclimatological analysis (Lins, 2012). The 29 catchments used in this study were previously studied by Gaertner et al. (2019) that examined growing season length trends in temperate broad-leaf forest and Gaertner et al. (2020) that examined streamflow sensitivity to climate change. Summary information of the study site is presented in Table 1. For the purpose of this study, due to their geographical location and the low number of HCDN catchments, they were categorized into three groups: the Ohio - Monongahela, Kanawha-Tennessee, and the Potomac. The basins are classified according to the climate Köppen-Geiger type cold without a dry season and with mild/hot summers (Dfa/Dfb) (Peel et al., 2007). The first two basin groups are located west of the eastern continental divide, with the Potomac located on the east and predominantly leeward side of eastern continental divide (Figure 2).

3.2. Data

3.2.1. Budyko's n

We obtained Budyko's n values for each catchment from Table 1 in Gaertner et al. (2020), which were originally calculated using a numerical calibration to solve Equation 1 with long-term P, Ep, and E as inputs.

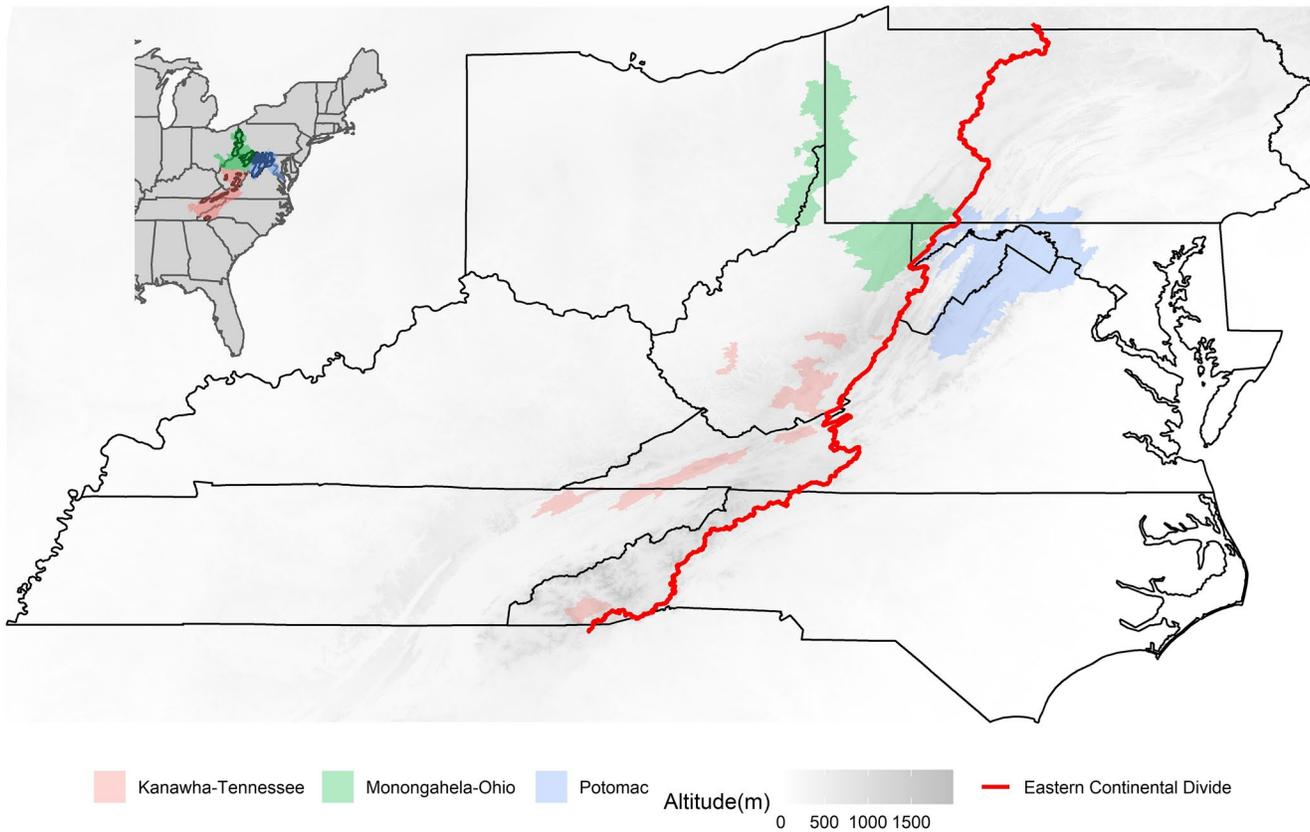


Figure 2. Location map of the selected USGS HCDN catchments studied in the central Appalachian mountain region and the eastern continental divide in the US. The relative location inset in the upper left corner shows the coverage of the three basin groups.

3.2.2. Climatic Controls

We used climatic controls that were found to be important to precipitation partitioning as summarized in Pardon et al. (2017)'s global meta-analysis. These include annual averages of precipitation, minimum and maximum temperature, potential evaporation, and soil moisture, which were obtained at monthly scales from TerraClimate (Abatzoglou et al., 2018). Daily precipitation was obtained from gridMET (Abatzoglou, 2013). Gridded data in both gridMET and TerraClimate have a spatial resolution of $1/24^{\text{th}} \sim 4$ km. The time frame selected for the analysis was 40 years, spanning from 1979 to 2018, since it was the longest common time frame between the data sets. The climatological controls derived from these data sets represent

Table 1
HCDN Catchment Characteristics Summarized by Basin Group and Region (Data From Gaertner et al. [2020])

Variable	Kanawha-Tennessee	Monongahela-Ohio	Potomac	Central Appalachian Mountain Region
Area (km ²)	1,285	887	1,413	1,246
Precipitation (P)[mm]	1,238	1,183	1,015	1,125
Runoff (R) [mm]	612	649	365	510
evaporation (E) [mm]	626	534	651	615
Potential evaporation (Ep) [mm]	1,355	1,247	1,385	1,342
Dryness index (DI)[unitless]	1.12	1.07	1.37	1.22
Evaporative index (EI) [unitless]	0.51	0.46	0.64	0.56
Budyko's <i>n</i> [unitless]	0.98	0.88	1.22	1.06

Table 2

Description of Climate Controls and Their Theoretical Effects on Precipitation Partitioning in the Central Appalachian Mountain Region

Variable (Abbreviation)[unit]	Description	Theoretical effect on precipitation partitioning
Mean Annual Temperature (MAT) [°C]	Long-term average annual temperature.	Higher temperatures increase atmospheric water demand and evaporation.
Mean Annual Precipitation (MAP) [mm]	Total annual precipitation over long-term periods.	Expected to increase runoff in energy limited and increase E in water-limited catchments, as more water is available.
Average Storm Depth (ASD)[mm]	Reflects the magnitude of an average storm by showing the average rainfall of rainy days.	Larger storms satiate soil storage and increase runoff.
Storm Arrival Rate (SAR)[days]	Reflects how often it rains calculated as the amount of rainy days in a year.	For energy-limited catchments, a continuous supply of water would increase runoff; for water-limited catchments, more rainy days decrease radiation and favor runoff.
Fraction of Precipitation Falling as Snow (FSNOW) [unitless]	Reflects the proportion of total precipitation that occurs in the form of snow; calculated based on months with mean temperature <2°C.	More snow in both humid and arid catchments should favor runoff as it melts, especially when soils are saturated and if rainfall over snow occurs. Sublimation processes might increase E.
Maximum Accumulation Monthly Surplus (MAMS) [mm]	Reflects the maximum water storage of a catchment; calculated by determining the maximum amount of water accumulated in consecutive months from the difference of monthly P - Ep (Williams et al., 2012).	Higher water accumulation increases runoff.
Seasonal Surplus Index (SSI) [mm]	Reflects the condition if water surplus is more or less seasonal; calculated by subtracting MAMS from the long-term surplus (P - Ep).	An increase in runoff should be expected in water-limited catchments since it reflects periods when rainfall exceeds Ep. The effect should be less important in energy-limited catchments since water availability generally exceeds water demand.
Soil Moisture (SM) [mm]	Reflects storage or the amount of water present and available for evaporation or runoff.	The influence of more or less water depends on the energy balance of the catchment; in energy-limited catchments, runoff will be favored and in water-limited catchments, it contributes to more evaporation.
Relative amplitude of the seasonal cycles of P, SAR, and Ep (SEAS.P, SEAS.SAR and SEAS.Ep) [unitless]	Reflects seasonality, that is, the extent of differences between maximums and minimums relative to annual averages. Calculated as the coefficient of the differences of monthly maximum and monthly minimum between the annual mean.	More seasonal precipitation and storm-arrival rates would increase runoff for specific periods.
Phase shift of the seasonal cycles of precipitation and potential evaporation (PS.P.Ep) [unitless]	Reflects if water supply and demand are synchronized or not. Calculated as the negative correlation between monthly P and Ep.	Highly influential for partitioning if the two variables are in phase larger evaporation is possible. If the two variables are out of phase runoff is likely to increase.

precipitation, snow and temperature, seasonality, and storage controls (Padron et al., 2017). A detailed description of the controls and their theoretical effects on precipitation partitioning are shown in Table 2.

3.2.3. Landscape Controls

We selected a set of landscape controls known to be influential to precipitation partitioning (Padron et al., 2017). Controls are based on the topographic characteristics of each catchment ($n = 29$), including elevation, slope, aspect, and compound topographic index. Most variables were derived from the Hydro1K data set (Earth Resources Observation And Science (EROS) Center, 2017). Two vegetation variables were included in the analysis: Mean growing season length from 1981 to 2012 from Gaertner et al. (2019) and average Normalized Difference Vegetation Index (NDVI) (1982–2012) during growing season months (June, July, and August) for the Northern Hemisphere extracted from Advanced Very High Resolution Radiometer

(AVHRR) sensors on NOAA satellites (Guay et al., 2015). We also included Land Use and Land Cover spatial data, consisting of a 300 m spatial resolution data from the European Space Agency Climate Change Initiative - Land Cover Project 2017, using the ESA-CCI-LC v.2.0.7 data set (www.esa-landcover-cci.org). We used the land cover map of 2015, considering that land cover changes were relatively low in HCDN catchments in the region (Gaertner et al., 2019). Since, the ESA-CCI-LC v.2.0.7 has a wide range of specific land cover types, we grouped together similar land cover (e.g., “Coniferous forest” and “Broad-leaf forest” into “Forest”) in order to quantify the percent cover in each catchment of forests, grasses, crops, urban/bare, and water bodies. Finally, we included catchment morphological parameters of catchment area, compactness ratio, elongation ratio, and linearity index. A detailed description and their theoretical effects on precipitation partitioning are presented in Table 3.

3.3. Analysis

We began our analysis by finding the relative importance of Budyko's n and the DI for the partitioning of precipitation. Specifically, the squared semi-partial correlation was calculated to find the variance of the EI that is solely explained by the DI (E_{DI} , Equation 2) and the variance of the EI that is solely explained by Budyko's n (E_n , Equation 3):

$$E_{DI} = \rho_{EI(DI,n)}^2 = \frac{\left[\rho_{(EI,DI)} - \left(\rho_{(EI,n)} \right) * \left(\rho_{(DI,n)} \right) \right]^2}{1 - \rho_{(DI,n)}^2} \quad (2)$$

$$E_n = \rho_{EI(n,DI)}^2 = \frac{\left[\rho_{(EI,n)} - \left(\rho_{(EI,DI)} \right) * \left(\rho_{(DI,n)} \right) \right]^2}{1 - \rho_{(DI,n)}^2} \quad (3)$$

Where $\rho_{x(y,z)}$ represents the correlation between variables X and Y after the influence of Z is removed (Pardron et al., 2017). Hydrologically, these terms represent how important the variance of the DI (or Budyko's n) is to explain the amount of water that evaporates in the catchments after removing the influence of the other variable. Then, the redundant variance (Rd) was calculated, which hydrologically represents the part of the variance in EI that is, given by both Budyko's n and DI's variance (Equation 4). Thus, the explained variance has a lower limit (Equation 5a) that would correspond to either E_{DI} or E_n , and an upper limit (Equation 5b) which is computed by adding Rd . Finally, the relative importance of each Budyko component was calculated using Equations 6 and 7. Since the components share a redundant variance, the relative importance of each component has a lower limit and an upper limit.

$$Rd = \rho_{EI,DI}^2 - \rho_{EI(DI,n)}^2 = \rho_{EI,n}^2 - \rho_{EI(n,DI)}^2 \quad (4)$$

$$EV = E \left(\text{explained variance lower limit} \right) \quad (5a)$$

$$EV = E + Rd \left(\text{explained variance upper limit} \right) \quad (5b)$$

$$RI_{DI} = \frac{EV_{DI}}{E_{DI} + E_n + Rd} \quad (6)$$

$$RI_n = \frac{EV_n}{E_n + E_{DI} + Rd} \quad (7)$$

We carried out this procedure for the whole region to understand how the Budyko components influence partitioning, and to contrast if at this scale of study, the importance of the DI and Budyko's n is similar to previous reports for the snow/temperate climate regimes reported in large-scale studies. We also looked at the behavior in importance at each separate basin group after we used the Kruskal-Wallis test (Hollander,

Table 3
Landscape Controls Descriptions and Theoretical Effects on Precipitation Partitioning for the Appalachian Region

Variable (Abbreviation)[unit]	Description	Theoretical effect on precipitation partitioning
Aspect [<i>unitless</i>]	Reflects the main geographical orientation to where the hillsides face in a catchment.	Aspect influences the amount of solar radiation received by the catchments depending on their latitude; thus in the Northern Hemisphere, South facing catchments that receive more radiation would favor partitioning toward evaporation.
Compound Topographic Index (CTI) [<i>unitless</i>]	Reflects the relief of the terrain with respect to the slope and the drainage contributing area. It can be considered a proxy of a steady state soil wetness.	Higher CTI represents more potential for larger soil water accumulation favoring increased evaporation.
Elevation [m]	Reflects terrain altitude derived from the digital elevation models.	Higher elevations are associated with colder temperatures, higher cloudiness, more precipitation, and a lower potential evaporation; creating conditions that favor runoff.
Slope [%]	Reflects the terrain steepness.	Steeper terrain will favor partitioning toward runoff since water residence times in the catchments are reduced.
Length of the Growing Season (LOS)[days]	Reflects average length of the vegetative growing season.	A longer growing season indicates higher evaporation as broadleaf forest have more capacity to transpire and interception is higher for longer periods of the year.
Normalized Difference Vegetation Index (NDVI) [<i>unitless</i>]	Reflects the amount of vegetation present in the catchments, also considered a measure of greenness.	Larger NDVI would indicate more evaporation capacity due to the increased transpiration by more plants.
Percent cover of different Land uses (Forest C, Grass C, Crop C, Bareland C, and Waterbodies C) [%]	Reflects the percentage a particular land use cover has over the total area of a catchment.	Generally, land covers that slow the movement of water in the landscape (e.g., forest) should favor evaporation and reduce runoff due to higher interception, transpiration, and infiltration. Barelands or urban developments should increase runoff as they decrease storage.
Area [km ²]	Reflects the surface area of the catchment.	The size of a catchment will mostly influence partitioning at the extent of the variability of the characteristics of the catchment.
Compactness ratio (Compact)[<i>unitless</i>]	Reflects the complexity of a polygons shape, it is calculated by dividing the area by the perimeter.	More complex catchment shapes can be related to terrain complexity, but the effect on runoff is not clear.
Elongation ratio (Elongation)[<i>unitless</i>]	Reflects the shape of a catchment.	Catchments that have a more oblong shape will have longer residence times than catchments that have more circular shapes, meaning that E might be favored in oblong catchments.
Linearity index (Linearity) [<i>unitless</i>]	Reflects how well a polygon can be described by a straight line; calculated based on a regression analysis of the polygon's node coordinates.	More linear watersheds can slow down runoff accumulation favoring evaporation.

et al., 2013) to determine if basin groups influenced the EI and Budyko's n . The Kruskal-Wallis test is a ranked one-way ANOVA, which is useful to understand if samples come from the same or from different distributions, conveying the relevance of carrying out analysis on the basis of the basin groups.

A second analysis examined the relationship between controls and partitioning using two approaches. First, we looked at the relationship between each individual climate and landscape control variable (including each landcover type) (Tables 2 and 3) and Budyko's n (sensu Padron et al., 2017) while controlling for the geographical location of each catchment through the following procedure: (a) multilinear regressions

between the variable and the latitude and longitude of the centroids of each catchment is computed; (b) the residuals from the regressions are obtained; and (c) a Pearson correlation between the residuals of the variable and the residuals of Budyko's n is calculated. Land cover controls with very low presence (<1%) in the catchments were not included in the partial correlation analysis. Partial correlation p-values were adjusted (Benjamini & Hochberg, 1995) to avoid the overstatement of the significance of the climate and landscape controls. Correlations were considered significant at $\alpha = 0.05$. The second approach consisted of building a set of candidate multivariate models to identify robust predictors of long-term evaporation (sensu Younger et al., 2020). To build these linear models, we selected the variables that had the highest correlations with Budyko's n and were the most significant from the previous approach. Besides selecting those variables, we also decided to include the DI. We created a new data set with these variables that included the whole study region and begun an iterative process for the calculation of multilinear regression models. This process included a backward and forward stepwise regression, adding or removing independent variables. From a large set of models, we selected the candidate models by using the Akaike Information Criteria (AIC) and Mallow's P.

Code, calculations, and statistics for the different controls and analysis were carried out using R statistical software (R Core Team, 2019) and the following packages: *tidyverse* for data management (Wickham et al., 2019); *rgdal* (Bivand et al., 2019), *raster* (Hijmans, 2020), *sp* (Bivand et al., 2013), and *whitebox* (Wu, 2020) for spatial analysis; *ppcor* (Kim, 2015) for correlation analysis and *MASS* (Venables & Ripley, 2002) for stepwise regression.

4. Results

4.1. Climate and Landscape Controls of Central Appalachian Catchments

Generally, the basins examined in this study do not present large differences in their climate characteristics, although there are some important exceptions (Table 4, Figure 3). For instance, precipitation (MAP) was lower in the Potomac basin (12% lower than the Monongahela-Ohio and 20% lower than the Kanawha-Tennessee). Another important difference was that the seasonal surplus index (SSI), on average 92 mm, was three times larger in the Potomac (Figure 3, Table 4). Also, maximum accumulation monthly surplus (MAMS) in the Potomac was 40% less than the other two basin groups (Figure 3). It rains roughly 60% of the days in a year, as shown by the storm arrival rate (SAR) of 223 days of rain per year, with less rainy days in the Potomac (Figure 3). The fraction of precipitation that falls on average as snow (FSNOW) in the region was 0.15. Precipitation is well distributed across the year and more variable in the Potomac (Figure 3). Mean annual temperature (MAT) had a regional average of 11°C, with the Potomac as the warmest basin with 11.4°C, followed by Kanawha-Tennessee with 11.29°C and Monongahela-Ohio with 9.9°C, as the coldest basin. Seasonality of potential evaporation was higher than the seasonality of precipitation variables since there is more energy available during the summer months. Finally, the phase shift of the seasonal cycles of precipitation and potential evaporation (PS.P. Ep) was on average -0.21 , meaning that precipitation and potential evaporation occur slightly in phase.

Mean catchment elevation ranged between 157 and 915 m with the Potomac presenting the lowest elevations (Figure 4). Average slopes were 10.73%, ranging from 4% to 22%, with Kanawha-Tennessee being the steepest basin group (Figure 4). Aspects were similar between most of the catchments except the ones in the Potomac. The main land use and land cover was represented by forest (76.34%) and grasses (21.58%); however, several catchments in the Potomac had low forest cover (<30%) (Figure 4, Tables 4 & S1). Grass cover was smaller in the Kanawha-Tennessee basin and similar in the Potomac and Monongahela-Ohio basin groups (Figure 4). The remaining land cover types included cropland, urban/bare lands, and water bodies, which together represented less than 3% of the total area (Table 4), yet, it is worth mentioning that a catchment in the Potomac had 1.46% cropland, high in comparison to the rest of the catchments (Table S1). The regional average of the length of the growing season (LOS) was 179 days and was similar between basin groups (Figure 4). NDVI was on average 0.89 and lowest and more variable in the Potomac (Figure 4).

Table 4
Basin Group Summaries of Climatic Controls in Central Appalachian HCDN Catchments

Variable	Kanawha-Tennessee	Monongahela-Ohio	Potomac	Central Appalachian mountain region
MAP (mm)	1,243	1,136	994	1,105
ASD (mm)	5.62	4.82	5.00	5.15
SAR (days)	224	249	209	223
MAT (°C)	11.3	9.9	11.4	11.0
FSNOW (<i>unitless</i>)	0.13	0.20	0.14	0.15
SEAS.P (<i>unitless</i>)	0.10	0.10	0.12	0.11
SEAS.SAR (<i>unitless</i>)	0.06	0.05	0.07	0.06
SEAS. Ep (<i>unitless</i>)	0.14	0.16	0.15	0.15
PS.P. Ep (<i>unitless</i>)	−0.15	−0.26	−0.22	−0.21
MAMS (mm)	380	347	217	299
SSI (mm)	42	54	146	92
Soil moisture (mm)	1,022	870	968	961
Aspect (<i>unitless</i>)	0.02	0.01	0.06	0.04
Elevation (m)	696	534	318	487
Forest cover (%)	78	61	62	67
Grass cover (%)	20	34	34	30
Cropland cover (%)	0	0	0	0
Urban/bareland cover (%)	1	3	2	2
Water bodies cover (%)	1	1	0	1
LOS (days)	179	179	179	179
NDVI (<i>unitless</i>)	0.89	0.90	0.88	0.89
Slope (%)	15.16	8.78	8.70	10.72
CTI (<i>unitless</i>)	4.54	5.18	5.04	4.92
Elongation ratio (<i>unitless</i>)	0.56	0.56	0.62	0.59
Compactness ratio (<i>unitless</i>)	0.03	0.04	0.03	0.03
Linearity index (<i>unitless</i>)	0.25	0.36	0.55	0.41

4.2. Budyko's n Parameter Exceeds Dryness Index in Relative Importance for Precipitation Partitioning

Based on the semipartial correlation analysis, Budyko's n was more influential than the DI on precipitation partitioning across the region and basin groups (Figure 5). The relative importance of Budyko's n was nearly 10 times greater (55.3%) than the DI (4.8%). Moreover, there are important interactions between both variables, as is shown by the importance of the redundant variance (39.9%), being almost as high as the importance of the Budyko n parameter, which can be understood as the influence that the DI has over processes that will change the Budyko n parameter. For instance, a higher DI will influence a catchment's vegetation characteristics, which will in turn alter the catchments Budyko parameter.

We analyzed the relative importance of the DI and Budyko's n for each of the basin groups (Figure 5) after confirming through a Kruskal-Wallis test that basin groups were influential on the evaporative index (chi-square = 16.64, p -value < 0.05) and Budyko's n (chi-square = 12.84, p -value < 0.05). Results showed that the Kanawha-Tennessee basin group had the highest DI importance, although still low (3.2%) and the second highest relative importance explained by Budyko's n (75.4%), with only 21.4% redundant explained variance by both factors. The Monongahela-Ohio had the highest redundant explained variance (89.1%), extremely low importance of DI (0.1%), and low importance of Budyko's n parameter (10.8%). Finally, the Potomac redundant variance was negative (−0.8%) since DI and Budyko's n were negatively correlated, implying that

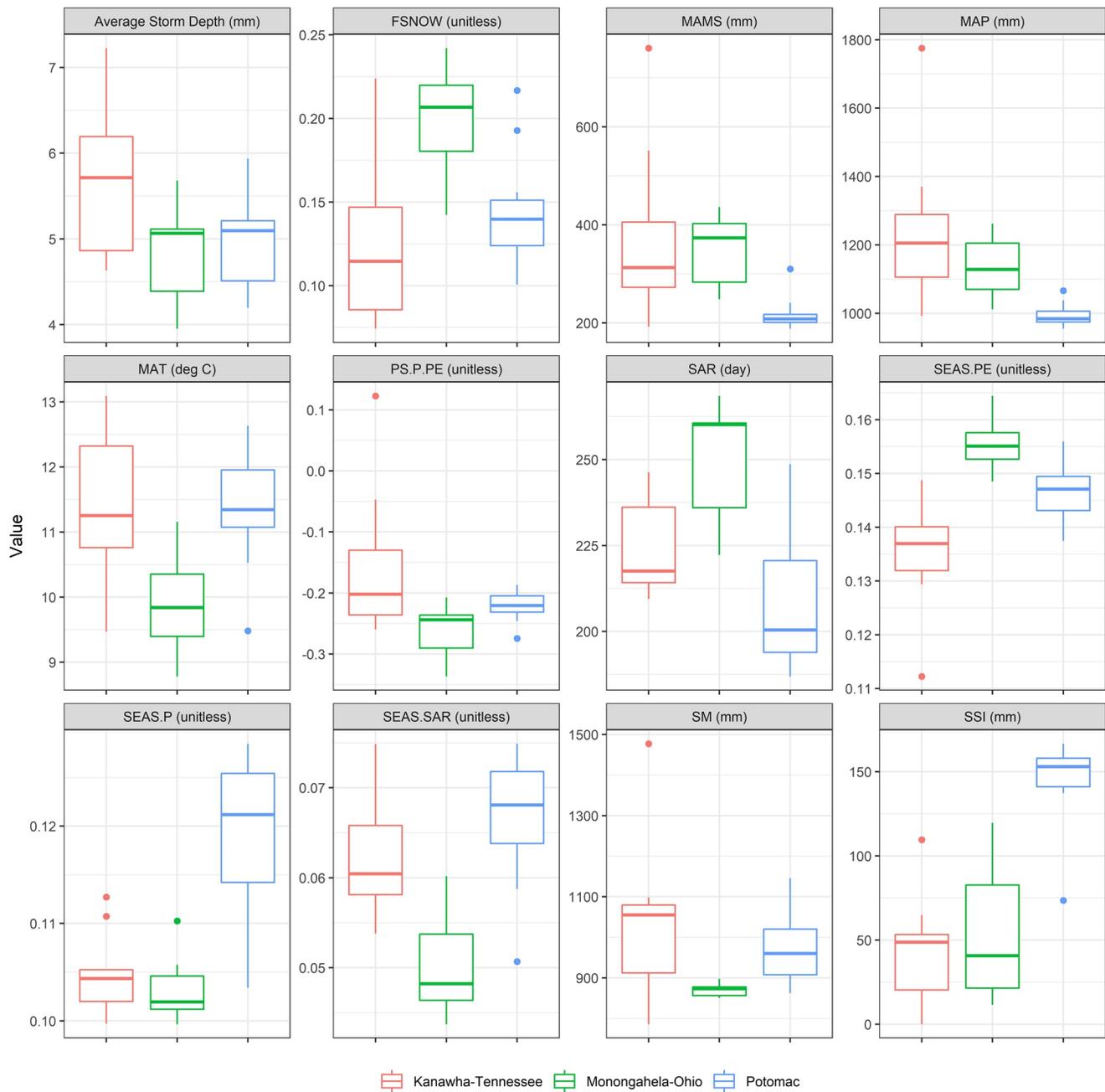


Figure 3. Boxplot of climate controls for central Appalachian Hydro-Climatic Data Network (HCDN) catchments. Dots represent outliers.

different controls than the DI are relevant for partitioning (Figure 5). The importance of the Budyko's n in the Potomac was the highest (99.7%), while DI was minimal (1%).

4.3. Climate Controls Correlations With Budyko's n

Of the climate controls analyzed in this study, temperature-related variables were the most important climate controls for precipitation partitioning (Figure 6 and Table S2). Mean annual temperature (MAT) (0.52, p value < 0.05) and the fraction of precipitation falling as snow (FSNOW) (-0.52 , p -value < 0.05) were the only two climate controls that were statistically significant. Other controls, such as seasonal surplus index (SSI), soil moisture (SM), and maximum accumulation monthly surplus (MAMS) were also strongly

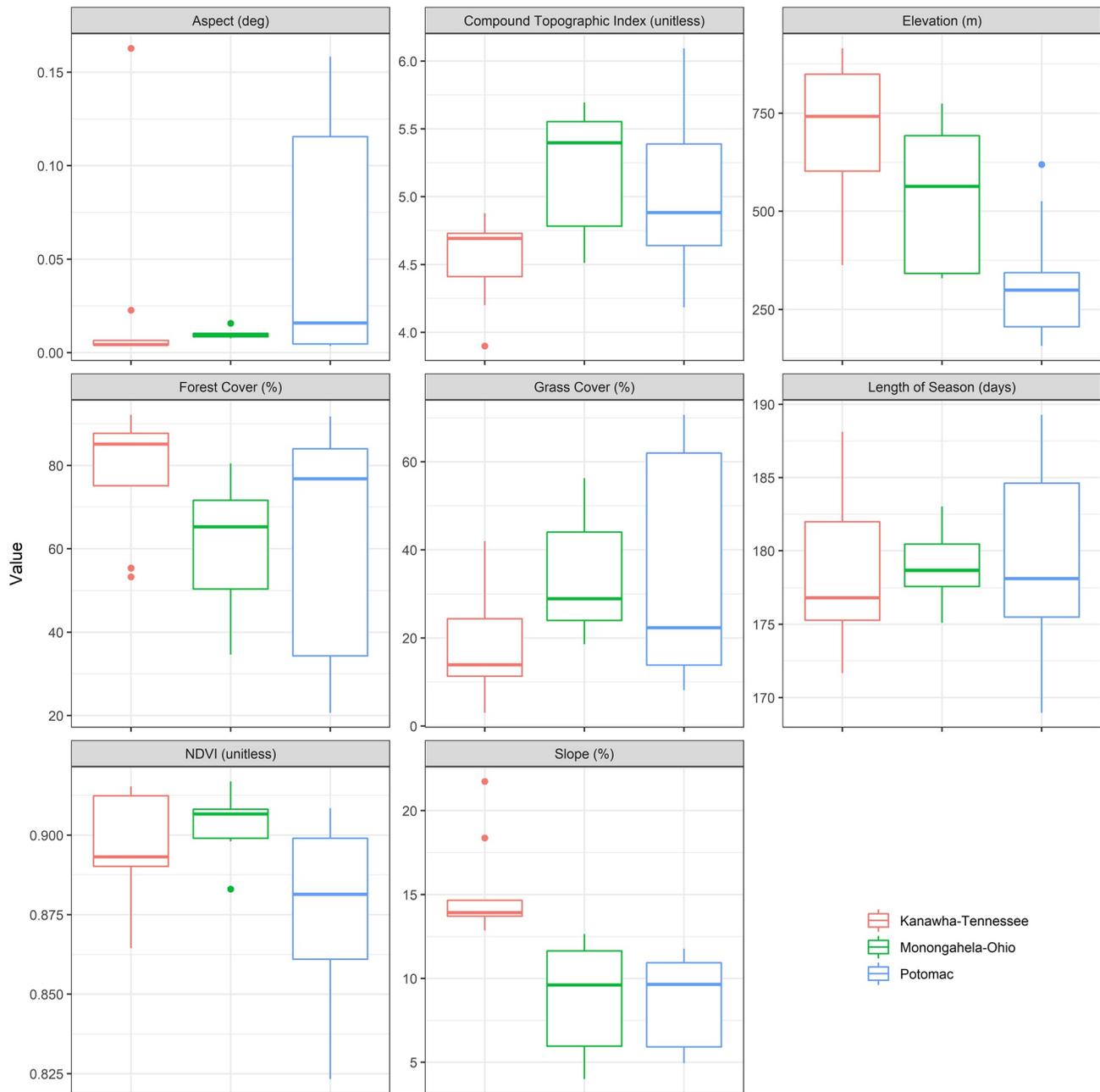


Figure 4. Boxplot of landscape controls for central Appalachian Hydro-Climatic Data Network (HCDN) catchments. Dots represent outliers.

correlated, but not significant (Figure 6, Table S2). Correlation analysis for the Kanawha-Tennessee, the southernmost basin group, showed several strong correlations that favored runoff: maximum accumulation monthly surplus (MAMS) (-0.82 , p -value = 0.25), precipitation (-0.79 , p -value = 0.25), and average storm depth (ASD) (-0.77 , p -value = 0.25), but none were statistically significant. In the Kanawha-Tennessee basin group, the variables that favored evaporation were only temperature, soil moisture, and seasonal surplus index. The Monongahela-Ohio basin group had two variables that were statistically significant: mean annual precipitation (-0.99 , p -value < 0.01) and seasonal surplus index (0.99, p -value < 0.05). In contrast to the other two basin groups, the Potomac had the most variables favoring evaporation, from which the most important was the storm arrival rate (0.61, p -value = 0.24) followed by mean annual precipitation, maximum accumulation monthly surplus, and fraction of precipitation falling as snow; the strongest climate

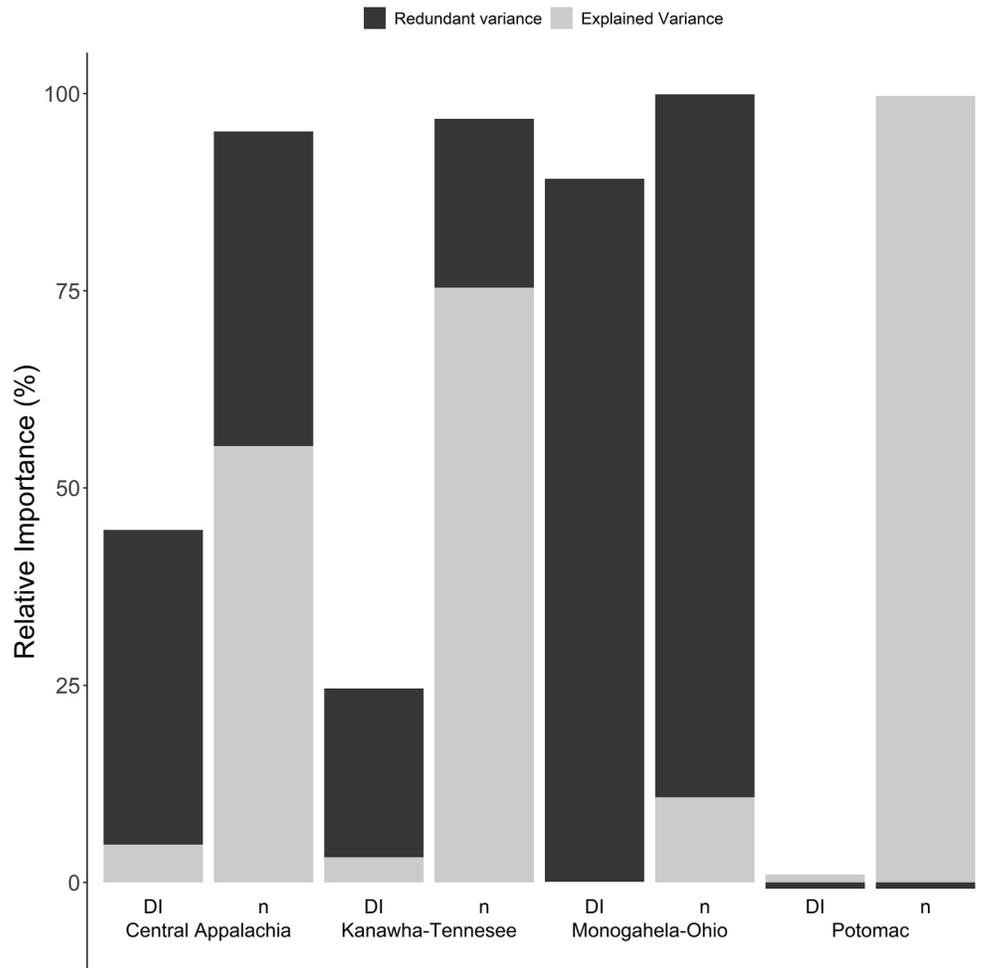


Figure 5. Relative importance of the Budyko's n and dryness index for precipitation partitioning for central Appalachian Hydro-Climatic Data Network (HCDN) catchments, Kanawha-Tennessee, Monongahela-Ohio, and Potomac basin groups. Notably, the Potomac basin is the most different as its redundant variance was negative due to the negative correlation between the dryness index and Budyko's n .

controls favoring runoff were the seasonality of the storm arrival rate and the seasonal surplus index. Partial correlations between the climate controls and Budyko's n are shown and Table S2.

In addition to the partial correlation analysis, we found through the examination of scatter plots of the climate controls that there were differences between the Potomac and the other two basin groups (Figure S1). Two examples were maximum accumulation monthly surplus (MAMS) and precipitation: In the Monongahela-Ohio and Kanawha-Tennessee basin groups, the two controls have a negative slope, that is, higher maximum accumulation monthly surplus and precipitation are related to lower Budyko's n and more runoff. On the other hand, the Potomac shows that increasing maximum accumulation monthly surplus and precipitation is related to higher Budyko's n values allowing more evaporation to take place.

4.4. Landscape Controls Exert Low Influence on Partitioning

Of the landscape controls analyzed in this study, only elevation was significant (-0.54 , p -value < 0.05) (Figure 6) while slope had the lowest correlations favoring runoff in the central Appalachian mountain region. There were no statistically significant variables in the basin-based analysis; yet, we found the indication of importance differences in the hydrologic behavior between the basin groups. In the Kanawha-Tennessee basin group, the highest negative correlations were elevation, forest cover, and urban/bare cover. In the

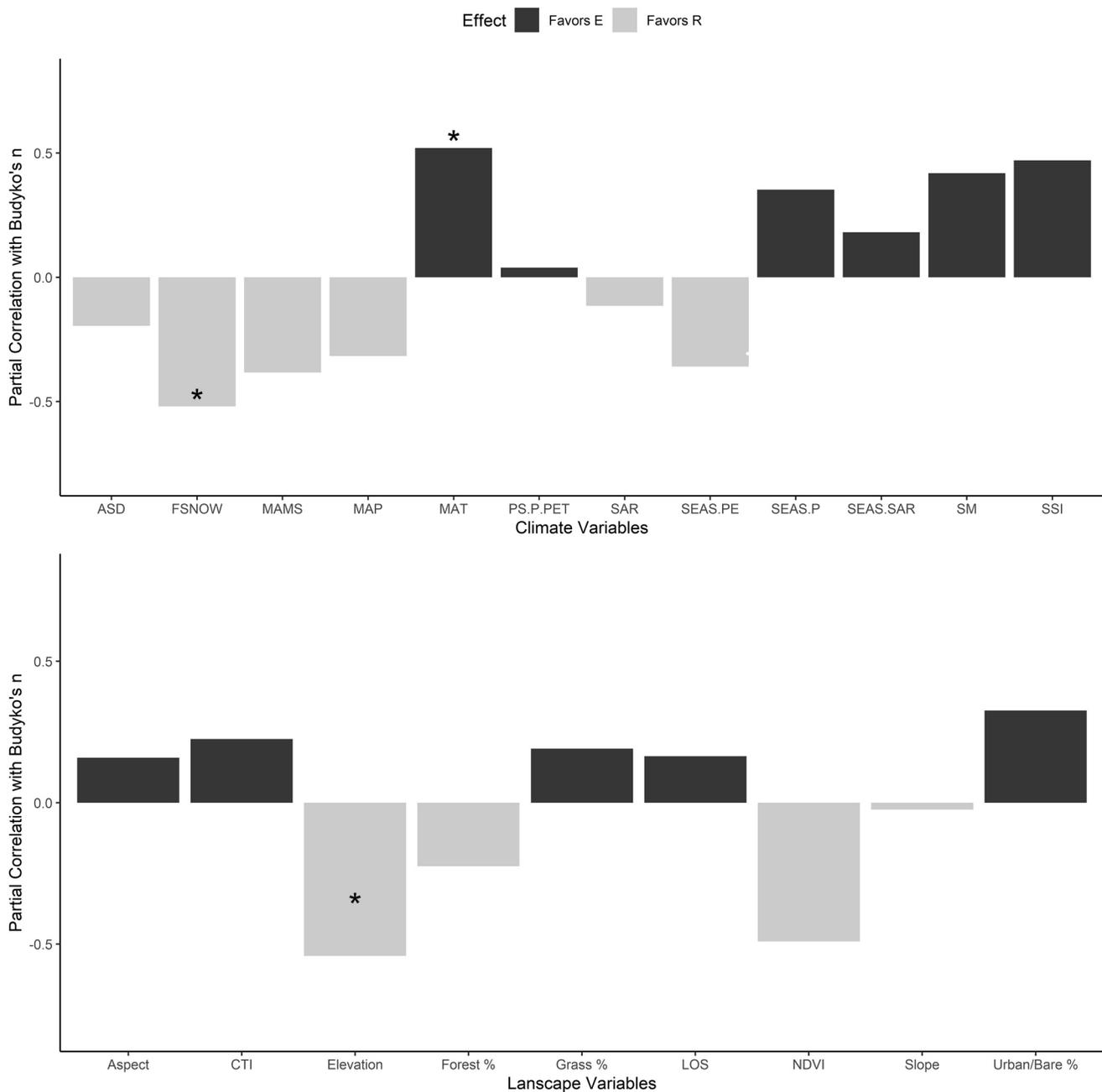


Figure 6. Partial correlations between climate controls (upper panel), landscape controls (lower panel), and Budyko's n . Statistically significant (p -value < 0.05) controls are denoted by * according to the adjusted p -value.

Monongahela-Ohio basin group, aspect had the strongest negative correlation and length of season had the most important positive correlations. In the Potomac basin, grass cover favored evaporation the most. Three variables favored runoff: forest cover, slope, and NDVI (Figure S7). The morphological controls (area, compactness index, elongation ratio, and linearity index) did not show high or significant correlations for the central Appalachian mountain region; but the elongation correlation was >0.4 in the Monongahela-Ohio and the compactness ratio was >0.4 in the Potomac (Figure S2).

Contrary to the climatic controls, where the Potomac basin had a different behavior in several of the controls, scatter plots, and regressions of the landscape controls and Budyko's n did not exhibit stark differences in most trend directions between the three basin groups (Figure S3). In terms of the landscape controls, the

Table 5
Regression Results for the Best Six Models That Explain Evaporation and Important Partitioning Controls

Model #	Variable	Estimate	Std. Error	t value	Pr (> t)	model P	Adjusted R ²	AIC
1	MAT	59.09	12.03	4.91	3.88E−05***	0	0.4522	335.5523
2	FSNOW	−1,357.62	292.83	−4.636	8.10E−05***	0	0.4226	337.0761
3	MAT	51.03	17.49	2.918	7.17E−03**	0		
	NDVI	−530.1	826.72	−0.641	5.27E−01	0.000204	0.44	337.0973
4	MAT	59.69137	12.35983	4.829	5.27E−05***	0.000235	0.4337	337.4202
	MAP	0.02895	0.08404	0.345	7.33E−01			
5	MAT	60.02171	13.45856	4.46	1.40E−04***	0.000246	0.4317	337.5208
	SSI	−0.04459	0.26538	−0.168	8.68E−01			
6	MAT	57.915	14.71181	3.937	0.000551***	0.000247	0.4316	337.5292
	Elevation	−0.01044	0.07243	−0.144	0.886529			

Note. The DI was not selected among the best 5 models.

main differences are present only with slope and elevation. The Potomac is the only basin that has increasing Budyko's n values at higher elevations and steeper slopes. In the other two basin groups, the Budyko's n decreases, meaning that higher elevation and steeper terrain favor runoff.

Finally, the stepwise multivariate linear regression analysis showed that mean annual temperature (MAT) and the fraction of precipitation falling as snow (FSNOW) were the most important variables that explain the variability in evaporation throughout the central Appalachian mountain region (Table 5). Models with a larger set of variables did not improve the model fit, but instead reduced the model's adjusted R², p-values, and AIC (Table 5 and S3).

5. Discussion

Through our study, we found that Budyko's n is not solely related to the landscape controls but instead showed higher relations to specific climate controls. The first key result from our study is that precipitation partitioning was different depending on the scale and that it varied within the region due to the complexity created by the eastern continental divide. We found that the relative importance of the DI and Budyko's n in determining precipitation partitioning in the central Appalachian Mountains had a similar behavior to catchments denoted as “snow” in Padron et al. (2017): In our study, the relative importance of the DI was 4.8% and Budyko's n was 55.3%, similarly, snow catchments in Padron et al. (2017) showed lower relative importance of DI (17.4%) than that of Budyko's n (36.1%). These results corroborate the influence that regional climatologies have on precipitation partitioning found by Padron et al. (2017). However, we discovered that for the central Appalachian Mountains, classifying catchments based on regional climate obfuscates important complexities about the controls of precipitation partitioning when intra-regional analyses are made. In other words, we noticed that the controlling factors of partitioning are scale dependent, meaning that results could change dependent on the analytical unit chosen (e.g., region or sub-region). We found large divergence between basins that were geographically located either east or west of the eastern continental divide. The relative importance of DI and Budyko's n to partitioning in each of the basins was dissimilar and, if studied separately, the basins could no longer be considered solely as “snow” catchments. This was particularly true in the case of the Potomac basin, located leeward of the eastern continental divide and showed water-limited characteristics, in which the relative importance of DI and Budyko's n were negatively correlated, similar to the characteristic of “arid” catchments in Padron et al. (2017). The same less humid nature of the Potomac basin in comparison to the Kanawha-Tennessee and Ohio-Monongahela basin groups has been previously reported by Gaertner et al. (2020) and Fernandez and Zegre (2019), which are consistent with the known effects that the eastern continental divide has on the central Appalachian climate and meteorology (Wiley, 2008). Therefore, taking an intra-regional approach can complement water research's understanding on the influence of regional climates on partitioning, by showing that not all the

basin groups might fit a general partitioning classification based on the large-scale climatic regime; this consideration is more relevant when topographical climatic divides are found in the area.

Considering intra-regional complexities provides insight into how specific variables control precipitation partitioning. For instance, energy-limited catchments west of the eastern continental divide would partition higher amounts of summer precipitation toward higher runoff but could mean larger partition toward evaporation and low contributions to runoff in the water-limited catchments east of the eastern continental divide. Consequently, the less humid nature of the Potomac helps explain the contrasts in partial correlations between climate controls and Budyko's n . Controls that relate to increased water availability, such as fraction of precipitation in the form of snow, maximum accumulation monthly surplus, precipitation, and storm arrival rate effectively favored evaporation in the Potomac instead of favoring runoff, as occurred in the other two basin groups and as would be expected for the region considering large-scale climate drivers (Fernandez & Zegre, 2019). The characteristics of the Potomac basin (e.g., located leeward of the continental divide; lower elevations; and lower precipitation) result in a higher DI, permitting larger amount of water inputs to be partitioned toward evaporation than in the other two basin groups. In the Potomac, the seasonal surplus index was similar to previous reports of arid basins (Padron et al., 2017; Williams et al., 2012). We also found negative correlation between temperature and the seasonality of potential evaporation with Budyko's n in the Potomac basin. These can be explained by warmer temperatures in winter months that create fast snowmelts increasing winter runoff or by higher temperatures are associated with precipitation events of larger magnitude, such as summer convective precipitation events. Monongahela-Ohio and the Kanawha-Tennessee basin groups, on the other hand, behaved as expected for their "snow" climate type where the precipitation-related variables were highly important to favor runoff. These distinct characteristics in the partitioning processes can be related to the differentiated coevolution of intra-regional climates and landscapes (Carmona et al., 2014), influenced by the eastern continental divide.

Another critical finding of our study is that climatic controls were more important than landscape controls. Mean annual temperature and fraction of precipitation falling in the form of snow were the most related variables to the Budyko partitioning parameter n , contributing the most to the precipitation partition process as has been previously reported for "snow"-type climates (Padron et al., 2017) and for a set of HCDN catchments in the contiguous US (Abatzoglou & Ficklin, 2017). Moreover, our results indicate that few landscape controls exert importance on partitioning. For example, elevation was found as an influential landscape control contributing to precipitation partitioning, which we deem to be related to the higher precipitation magnitudes that occur at higher altitudes; however, slope was not found as an important factor, contrary to other studies (e.g., Padron et al., 2017 or Abatzoglou & Ficklin, 2017), studies should continue to look at the relationships between elevation, slope, and the Budyko parameters as other regions might show similar results. Unexpectedly, our results also showed, similarly to Padron et al. (2017) large scale study, that vegetation variables were not important to the partitioning process, which is contrary to previous studies that have highlighted the importance of vegetation to the partitioning process (Donohue et al., 2012; Mercado-Bettin et al., 2019; Ning et al., 2020; Tran et al., 2019; Yang, et al., 2008; Zhang et al., 2001). We found that NDVI and forest cover favored runoff, when we should have expected the opposite, given the general understanding of vegetation's effects on partitioning is to increase evaporation (e.g., Brown et al., 2005; Ford et al., 2011; Knighton et al., 2020; Li et al., 2013; Xu et al., 2013; Zhang et al., 2001). One explanation could stem from the contribution of orographic precipitations prevalent in the headwater catchments of the region, which could mask the role of vegetation partitioning. Thus, the location of forest at higher elevations and near the continental divide could explain why vegetation is correlated to higher runoff. Yet, other studies have shown that vegetation (or NDVI) can be negatively correlated to Budyko's partitioning parameter. Abatzoglou and Ficklin (2017) found negative correlations between Budyko's parameter and NDVI and the Net Primary Production (NPP) for catchments in the US, suggesting higher partitioning toward runoff at a given dryness index when more vegetation was present. Bai et al. (2020) reached that conclusion after the analysis of small catchments in China and indicate that these could be caused by the added complexity of the hydrologic behavior of smaller catchments. Similarly, Yang et al. (2009), found that the Hai River Basin, a vast plain area in northern China had negative correlations between vegetation and Budyko's n , which could be caused by the non-linear relationship between E and P. In particular, to the southern Appalachian Mountains, Younger et al. (2020) found that only needle evergreen forest favored evaporation while deciduous forest favored runoff and total forest cover had no significant relationship to evaporation.

There, elevation, temperature, and available soil water storage were better related to evaporation than the vegetation cover (Younger et al., 2020). Interpretation of such results can take several avenues, such as a hydrologic paradox (Teuling, 2018); a matter of scale (Zhang et al., 2017) or even to novel considerations of how vast forested areas affect the water balance (Ellison et al., 2012; Sheil, 2018).

It is important to denote some caveats of our study. Our statistical analysis showed that only few controls were significantly correlated with the Budyko's n , a result that contradicted previous findings (Padron et al., 2017). Yet, creating multivariate regression models to describe evaporation helped to confirm that only a few variables could describe most of its variance. Although we consider this information valuable, our results could mask the importance of other processes that occur in the catchments, especially if the studies are carried out at smaller scales where vegetation might exert a higher influence on partitioning (Zhang et al., 2017). We investigated a region that is heavily forested with deciduous species, meaning that we could not study the role of other land use classes in detail. Moreover, different forest types and cover densities were lumped into one category; future studies could make a differentiation between forest types, as it has been shown that needle evergreen forests and broadleaf forests have different effects on precipitation partitioning at the regional scale (Younger et al., 2020). Increasing the sample size and investigating a larger share of catchments in the regions, but keeping the catchment as study unit, could result in better statistical models of evaporation that include a larger number of variables or a correlation analysis that demonstrates that Budyko's n is strongly correlated to a larger number of environmental controls. Moreover, another caveat in the study are the strong correlations that exist between some variables, for example, between fraction of precipitation falling as snow and mean annual temperature or elevation and precipitation (see correlogram in Figure S4). It is also important to reiterate that we limited the study to catchments with low human disturbance (e.g., low amount of urban areas, crops, and impoundments) meaning that anthropogenic activities that affect the water balance (e.g., use of water for irrigation or industrial processes) were not represented and, consequently, assessing the influence of human-driven activities on the partition of precipitation is beyond the scope of this study. Additional improvements to the study design could be made by including variables that represent the soil characteristics of the catchments; yet, variables as the slope and compound topographic index can give an indication of general soil depths.

Although, we indicate that vegetation does not exert a high influence over precipitation partitioning, we consider that the importance of vegetation might change in the future due to three main factors. First, expected regional climatic changes will affect energy and water balance seasonalities and their interaction (Fernandez & Zegre, 2019). Dryness index is projected to increase in central Appalachia according to future downscaled projections of climate change (Fernandez & Zegre, 2019), which could mean that more energy is available for forest transpiration in humid catchments. Heidari et al., 2020 found that the movement in the Budyko space can vary according to the different climate change scenarios, and a wetting of the eastern US is possible, yet, a dry scenario could mean that the eastern regions can still maintain higher evaporative indexes. Also, US National Forest in mountainous landforms (which are significant in the central Appalachian region) are predicted to see larger changes due to climate than those in low-lying areas (Heidari et al., 2021). Second, potential changes in forest species composition can mean a different use of water resources. Climate change is predicted to create shifts in the suitable habitat for multiple tree species (Iverson et al., 2019). Moreover, the evidence shows that major changes have already occurred due to multiple interacting factors (McEwan et al., 2011), as climate mesophication (Kutta & Hubbart, 2018; McEwan et al., 2011), fire management and suppression (Nowacki & Abrams, 2008, 2015), pathogens that have eliminated important species (Paillet, 2002), and air pollution that reduces the growth of different tree species (Horn et al., 2018; Mathias & Thomas, 2018). These factors are triggers of forest disturbances, which interact with changes in climate and could affect runoff (Young et al., 2019); hence, the understanding of how forest types might change is important to assess the future water balance in Appalachia (Younger et al., 2020). Third, cascading effects of climate change also influence forest ecosystem processes related to evaporation. One example is longer growing seasons in the region, that allow for longer periods of transpiration (Gaertner et al., 2019); also tree-specific transpiration rates could be affected by higher magnitudes of vapor pressure deficit in a warmer climate (Guillén et al., submitted); and reduced transpiration could occur due to increased water use efficiency as an effect of higher concentrations of ambient CO₂ (Warren et al., 2011). We deem, therefore, that the study of climate and landscape controls to be even more important in the future.

Our findings reaffirm the importance of devoting research to understanding the implication of the climatic variables for precipitation partitioning and confirm results from large-scale studies (Padron et al., 2017) and regional studies (Younger et al., 2020). The projected changes in the DI and the fact that those will be spatially heterogeneous for the Appalachian region (Fernandez & Zegre, 2019) and diverse at each hydro-climate region (Heidari et al., 2020), are another reason for increased regional studies on partitioning. Moreover, besides advancing water resources research, noticing the importance of climatic controls in partitioning could also contribute to improving regional water security. In this regard, enhanced attention should be given to climate drivers when designing policies for watershed management. For instance, the effects of maintaining/increasing forest cover should be contextualized and integrated to climate change mitigation and adaptation strategies, since there are examples where climate-related controls can be more important to partitioning than vegetation (Soulsby et al., 2017). Looking at climate drivers should not lessen the continued focus on secondary controls that can be directly influenced by land use management and policies. Finally, there are inherent mismatches between the scales in which research and management activities take place and bridging those differences should be considered when designing future water resources research.

6. Conclusions

Our study shows that the partitioning of precipitation in the central Appalachian Mountain region is primarily driven by the Budyko parameter n , and secondarily driven by the DI. Partitioning in the region is heterogeneous and influenced largely by the eastern continental divide that influences climate and weather. Additionally, climate controls were more important than landscape controls on precipitation partitioning in general and within basin groups. Mean annual temperature and fraction of precipitation falling as snow were the most important controls of partitioning and explain, each on its own, the highest variance in evaporation according to multivariate regressions. Elevation was the most important landscape control for precipitation partitioning and was positively correlated to runoff. Collectively this information contributes to the understanding of the complexities around the Budyko parameter.

To maintain sustainability in water resources and enhance regional water security, we need to understand that catchments will behave differently depending on their specific characteristics. Here, we showed that methodologies used for a global review can be adapted to a regional approach by using spatially averaged data. We also highlighted that catchments pertaining to the same regional climates (e.g., snow dominated), can have distinct hydrological characteristics and precipitation partitioning controls, especially if they are influenced by the effect of mountain ranges. Similar cases to the central Appalachian Mountains might exist in other regions of the world, where medium elevation mountain ranges do not affect large-scale climate regimes but are still capable of influencing basin precipitation controls. Finally, we encourage scientists to continue the conversation about important controls for precipitation partitioning as a fundamental research question for the hydrologic community and as a tool for improved adaptation to climate change.

Data Availability Statement

All the data used for this study are publicly available and can be found in the referenced sources found in the data section of our methods.

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