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EVALUATING BIOLOGICAL AND PHYSICAL DRIVERS OF EVAPOTRANSPIRATION TRENDS AT NORTHEASTERN US WATERSHEDS

John L. Campbell, Matthew A. Vadeboncoeur, Heidi Asbjornsen, Mark B. Green, Mary Beth Adams, and Elizabeth W. Boyer[1]

Despite a general consensus that the Earth's hydrologic cycle is intensifying as a result of anthropogenic climate forcing (e.g. Huntington 2006), there remains substantial uncertainty over the consequences of this intensification for terrestrial evapotranspiration (ET; e.g., Hobbins and others 2004, Walter and others 2004, van Heerwaarden and others 2010). Most models indicate that climate change will cause an increase in ET, but evidence from field observations has been inconsistent. Unidirectional changes in ET could profoundly alter local water balances and streamflow dynamics, having important implications for water supply and associated services, including drinking water, irrigation, recreation, wastewater assimilation, and power generation.

We evaluated long-term trends in ET at three small (39 to 123 ha), gauged reference watersheds in the northeastern U.S. with the longest combined records of precipitation and streamflow: Fernow Experimental Forest, West Virginia (FEF); Hubbard Brook Experimental Forest, New Hampshire (HBEF); and Leading Ridge, Pennsylvania (LR). Although these measurements are collected at other small watersheds in the region, the selected watersheds have records that are 25 to 45 years longer than any other comparable watersheds. We estimated ET with the water balance approach (ET=precipitation-streamflow), which assumes that changes in groundwater storage are minimal on an annual basis and seepage loss is negligible. Long-term trends were evaluated with the Mann-Kendall test, which is a non-parametric test that is commonly applied to analyses of long-term hydrometeorological time series data (Helsel and Hirsch 1992). The slope for each trend was calculated as the median of all possible pair-wise slopes (Sen 1968). Reported p values were considered significant at the $\alpha = 0.05$ level.

When all the years of available data were considered, time series analyses showed significant declines in ET at FEF and HBEF and no significant change at LR (Fig. 1). When a common time frame was used (i.e., 1959-2011), the ET trend at FEF remained negative, but was not significant (slope=-0.682 mm yr^{-1}, p=0.101). Use of a common time frame had little effect on the slope and p-value for HBEF because only one year was eliminated from the analysis (i.e. 1958). The lack of consistent trends in ET among watersheds suggests that local influences may override potential broader regional drivers of ET. In addition to significant declines in ET, HBEF also had significant increasing trends in precipitation (slope=5.6 mm yr^{-1}; p=0.002) and stream water (slope=6.9 mm yr^{-1}; p=0.001), whereas the other two watersheds showed no significant trends. Evapotranspiration at the HBEF differs from the other watersheds, in that a smaller fraction of the precipitation entering the watershed is transpired/evaporated (36 percent) compared to FEF (56 percent) and LR (59 percent). This difference is likely due to the longer growing season at the more southerly sites, which provides more opportunity for transpiration.

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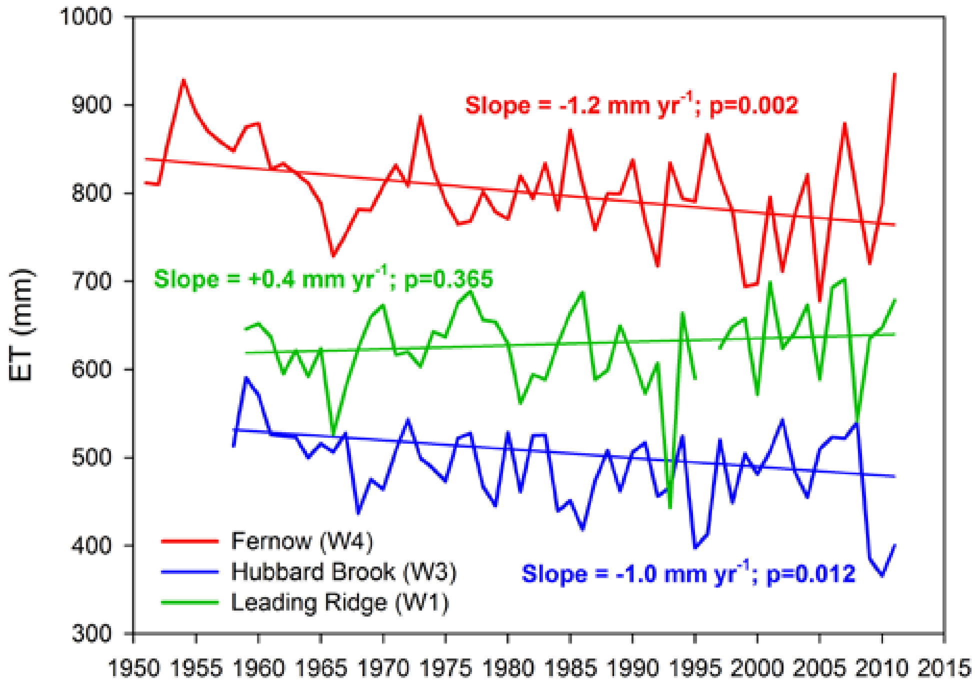

Figure 1—Long-term trends in evapotranspiration (ET) calculated using the water balance approach for gaged watersheds at the Fernow Experimental Forest, West Virginia; Hubbard Brook Experimental Forest, New Hampshire; and Leading Ridge, Pennsylvania.

Hydrometeorological data from each site was used to explore some of the potential underlying climatic mechanisms that could explain the variability in ET. Stepwise multiple linear regression (backwards elimination) was used to identify the most important climatic factors that affect ET. We considered several potential drivers including summer (June, July, August) minimum and maximum air temperature, vapor pressure deficit (VPD) at 1400 EDT (www.ncdc.noaa.gov), Palmer Drought Severity Index (http://www.ncdc.noaa.gov/cag), and annual and growing season precipitation. At LR, the only significant term was growing season precipitation, which showed a significant positive effect (R^2=0.18). At FEF, a more complex model explained more of the variability in ET (R^2=0.61) with annual precipitation, growing season VPD and maximum air temperature showing significant positive effects, and summer minimum air temperature showing a negative effect. At HBEF, the best model included only summer precipitation, which interestingly, showed a significant negative relationship with ET (R^2= 0.10) and was counter to our expectations. Including year as a covariate improved the model at HBEF (R^2=0.16), but had no effect at LR and only slightly improved the model at FEF (R^2=0.67). The positive relationship between summer precipitation and ET at FEF and LR indicates that ET is sometimes limited by water availability at these watersheds. It is unclear what is driving the negative relationship between ET and summer precipitation at HBEF, but may be related to factors that were not quantified, such as cloudiness or soil moisture-temperature interactions. Nevertheless, the negative relationship suggests that water availability is not limiting ET at HBEF and that it is more likely limited by energy at this cooler site.

To further evaluate controls on ET, we analyzed tree ring chronologies collected from 5 individuals (3 cores per tree) of three dominant tree species at each of the three study watersheds. Ring widths were measured to the nearest 0.01 mm (Velmex Measuring System and measureJ2X software) and cross-dated (verified with the COFECHA program, Holmes 1983). Autoregressive standardization (ARS) was used to convert raw ring-width series into growth indices that contain detrended patterns in variation that are representative of the stand. Pearson correlation coefficients (Table 1) indicated that ARS chronologies were correlated with ET at FEF (except sugar maple) and LR, but not at HBEF. At FEF and LR, trees tended to grow better during wet summers (low VPD, high precipitation, high PDSI), and less during warm summers (high max temp, high VPD). These patterns are consistent with the hydrometeorological-ET relationships and indicate that water stress plays a role in limiting ET at these sites. At HBEF, there were no significant relationships between climate variables and ARS chronologies, though notably the relationships were opposite of the other two watersheds, trending towards less growth in wet summers, and more growth with higher maximum temperatures.

Future work will involve analyses of carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopes in tree rings to further elucidate ET patterns. Tree ring $\delta^{13}C$ can be used to identify changes in water use efficiency, and $\delta^{18}O$ assists in determining whether those changes in water use efficiency are due to changes in photosynthetic rate (e.g., because of changes in nutrient supplies or environmental stressors such as acid deposition) or stomatal conductance (e.g., in response to changes in VPD). These advances are providing critical insight into patterns of ET within the Northeast region, enabling a better understanding of the relative importance of site-specific and regional drivers of ET.

Table 1—Pearson correlation coefficients of ARS tree ring chronologies and climatic variables for watersheds at the Fernow Experimental Forest, West Virginia; Hubbard Brook Experimental Forest, New Hampshire; and Leading Ridge, Pennsylvania.

	ET	Temperature		Water stress		Precipitation	
		Summer Tmin	Summer Tmax	Summer VPD	Summer PDSI	Annual	Summer
Fernow							
Sugar maple	0.072	0.046	-0.133	-0.274*	0.086	0.092	0.331*
Red oak	0.246*	0.146	-0.176	-0.291*	0.403*	0.265*	0.419*
Tulip poplar	0.307*	0.100	-0.315*	-0.282*	0.435*	0.373*	0.311*
Leading Ridge							
Sugar maple	0.332*	-0.033	-0.281*	-0.451*	0.094	0.215	0.408*
Red oak	0.367*	0.104	-0.337*	-0.243	-0.030	0.310*	0.258
White pine	0.307*	-0.012	-0.300*	-0.035	-0.206	0.105	0.172
Hubbard Brook							
Sugar Maple	-0.141	-0.082	0.058	0.180	-0.207	-0.116	-0.014
American Beech	-0.125	-0.223	0.040	-0.044	-0.121	-0.249	-0.079
Red spruce	0.051	-0.021	-0.129	0.220	0.101	-0.095	-0.002

* Indicates statistical significance at the α=0.05 level.

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