A Comparison of the Standardized Precipitation Evapotranspiration Index Using the Penman-Monteith and Thornthwaite Parameterizations for Potential Evapotranspiration

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Abstract

The Standardized Precipitation Evapotranspiration Index (SPEI) is a drought index which incorporates a simple difference between precipitation and potential evapotranspiration (PET). The simple Thornthwaite approach is commonly utilized in the SPEI to calculate PET because the only requirement is mean monthly temperature. To potentially improve the ability of SPEI identifying drought conditions a more physically based PET approach such as the Penman-Monteith is desired, however, temperature, wind speed, vapor pressure, and solar radiation are required. This study uses a recently developed high resolution (4-km) bilinearly interpolated and bias corrected NLDAS-2 gridded dataset to compare two versions of SPEI using the Thornthwaite (SPEI-Th) and Penman Monteith (SPEI-PM) approaches calculated at a variety of time scales over the contiguous United States (CONUS) from 1979 through 2010. SPEI-Th and SPEI-PM were both correlated to monthly and annual standardized streamflow from three different mountainous regions of the country with contrasting climates. The three regions include southwestern California (hot and dry climate), the Cascade Range in Washington (cool and moist climate), and the Appalachian Mountains in North Carolina (humid continental climate). As expected, major differences in PET rates are found between the two PET models, however, SPEI-Th and SPEI-PM are very similar over much of the CONUS at all time scales. The largest differences between SPEI-Th and SPEI-PM are found over the desert Southwest at short time scales. Although using the temperature based Thornthwaite approach in SPEI leads to slightly higher correlations to streamflow, it is well established that the Penman-Monteith approach for PET is a better indicator of atmospheric demand. SPEI is unable to detect these differences due to the departure from the mean approach, and we therefore recommend using SPEI-PM if data is available.

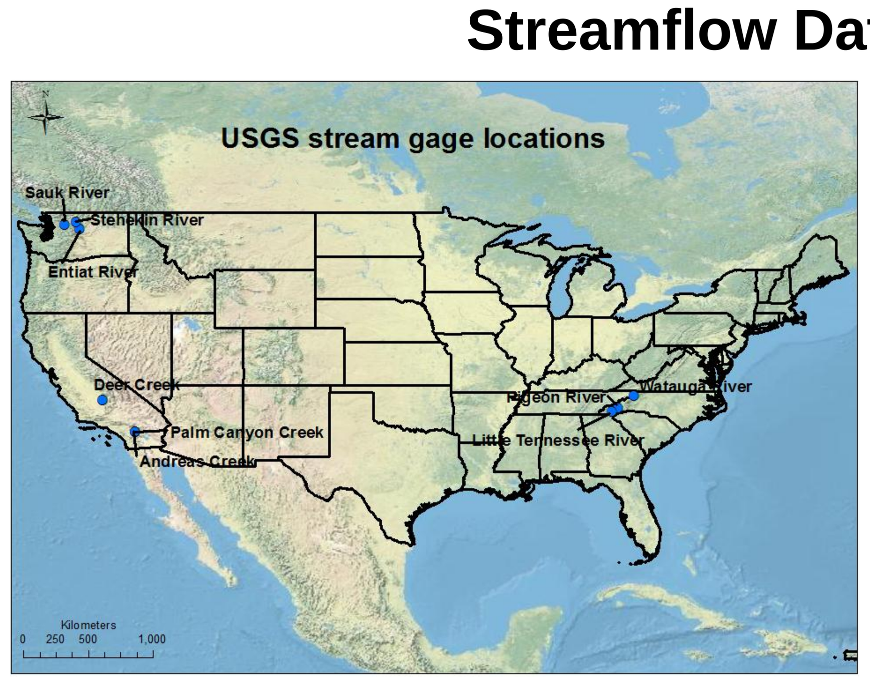
Meteorological Gridded Data

- NLDAS-2/PRISM hybrid data set (**Abatzoglou, 2011**)
- Spatial resolution: 4-km
- Temporal resolution: daily
- Period of record: 1979-2010
- Region: Contiguous United States
- Variables: precipitation, temperature (daily maximum and minimum), relative humidity (daily maximum and minimum), surface downward shortwave radiation (daily mean), and wind velocity (daily mean)

Drought Index

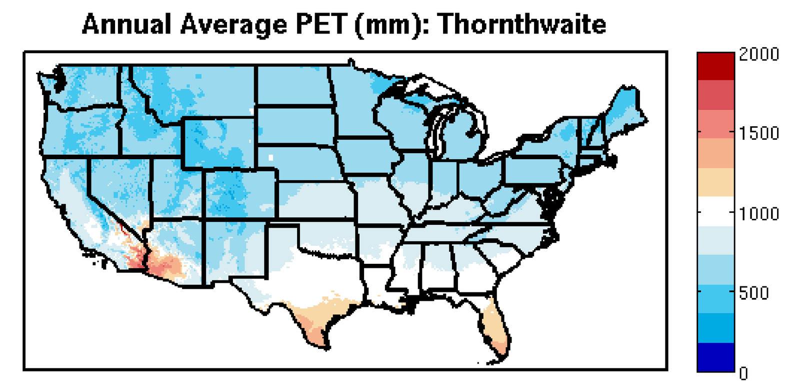
- Standardized Precipitation Evapotranspiration Index (**SPEI; Vicente-Serrano et al. 2010)**
- Inputs: total monthly precipitation (P) and total monthly PET
- Index computed from **P-PET** timeseries
- Accumulated time scales: 1, 3, 6, 9, 12, 15, 18, and 24-months
- Computed using Thornthwaite (SPEI-TH) and Penman-Monteith (SPEI-PM) parameterizations for PET

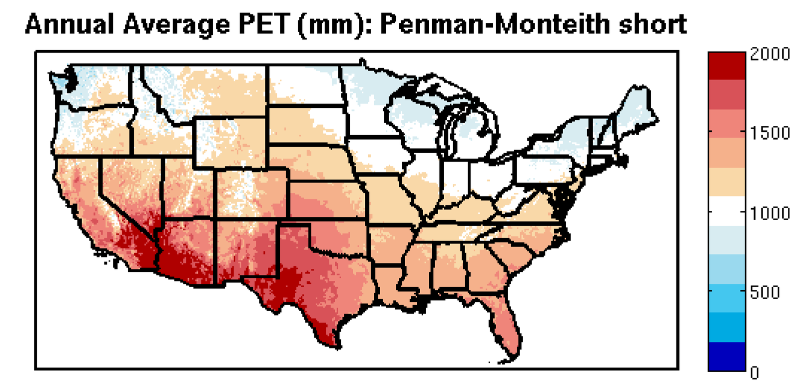
Streamflow Data

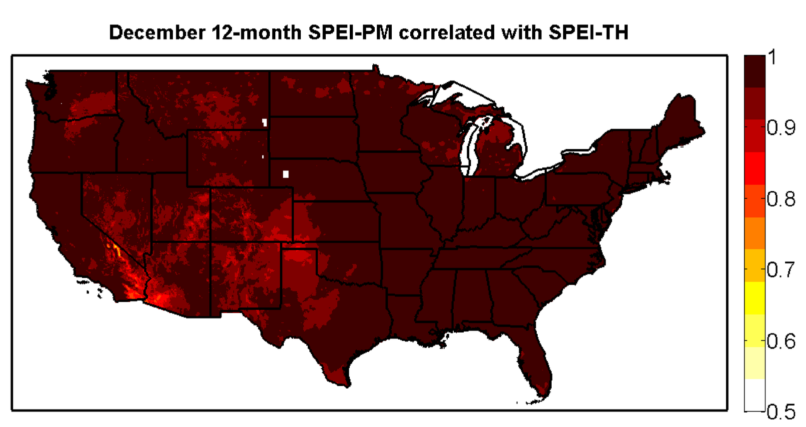


- 9 United States Geological Survey (USGS) gages
- Daily data summed to monthly time steps
- Streamflow data standardized following same approach as SPEI
- 1-month and 12-month standardized streamflow then correlated (Pearson) with SPEI-PM and SPEI-TH at all SPEI time scales

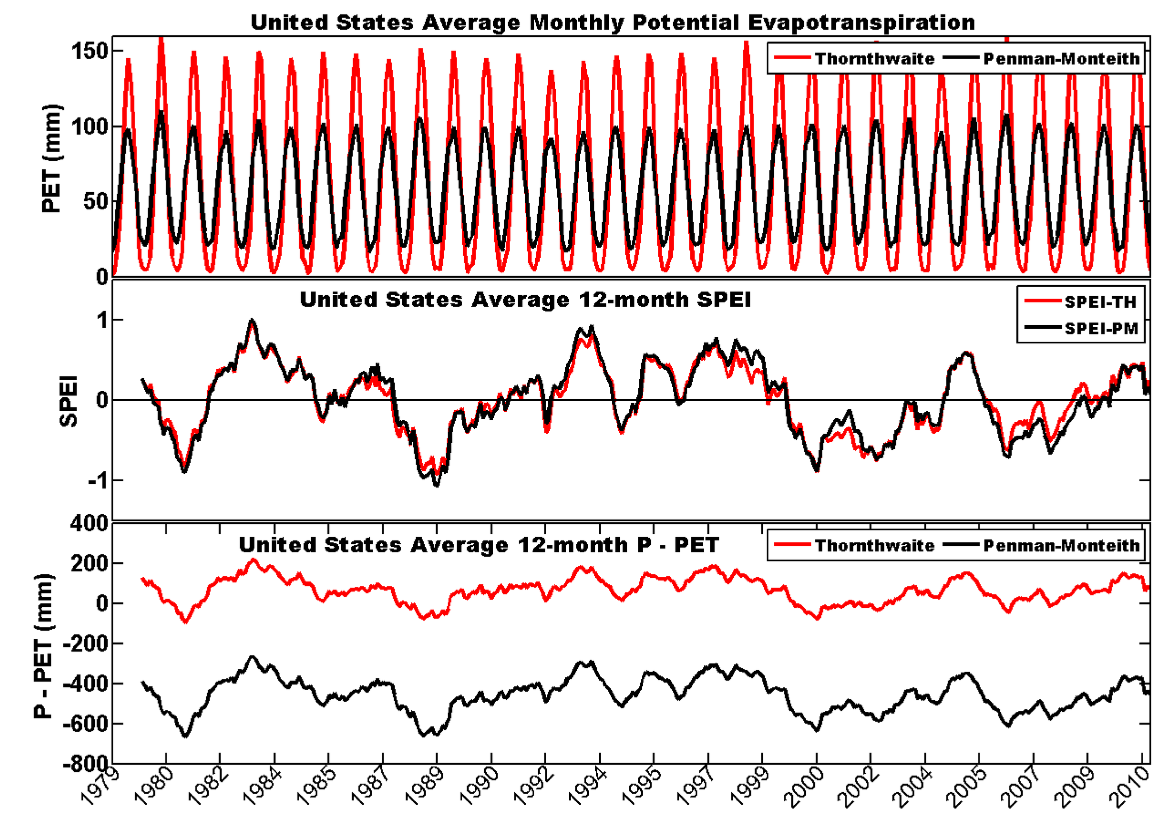
PET and SPEI Comparisons

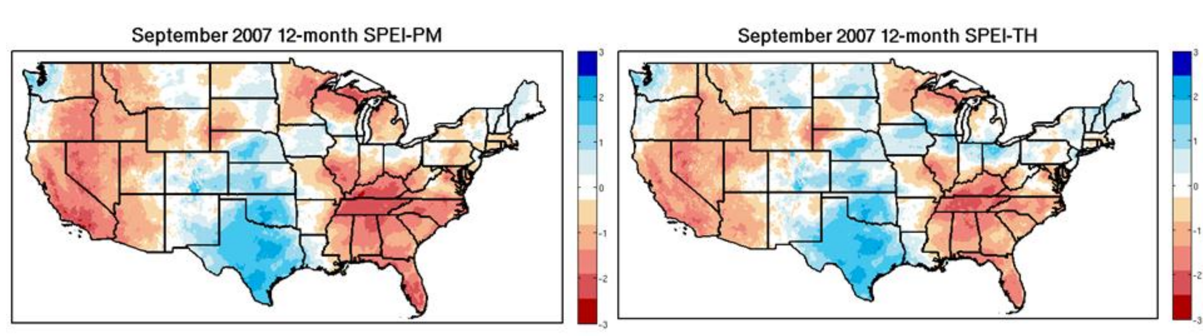






- High correlations (R > 0.8) exist between SPEI-PM and SPEI-TH over much of the United States.
- The widespread high correlations are simply a reflection of the departure for the mean approach used in SPEI
- Lower correlations found over the western United States with the lowest value (R = 0.68) occurring in the desert region of southeast California.





- Nation wide, differences between Thornthwaite and Penman-Monteith are great, however both PET methods exhibit similar annual cycles (maximum in summer and minimum in winter).
- This leads to similar cycles of the P – PET time series, and when standardized the resultant SPEI values are similar with both PET methods
- These results highlight a weakness in the PET component of SPEI. It has been well established that the Penman-Monteith approach provides a more realistic estimate of atmospheric demand when compared to Thronthwaite, especially in the arid western United States. The departure from the mean approach used in SPEI does not account for these differences in aridity found between the two PET methods

SPEI correlations with streamflow

1-month standardized streamflow

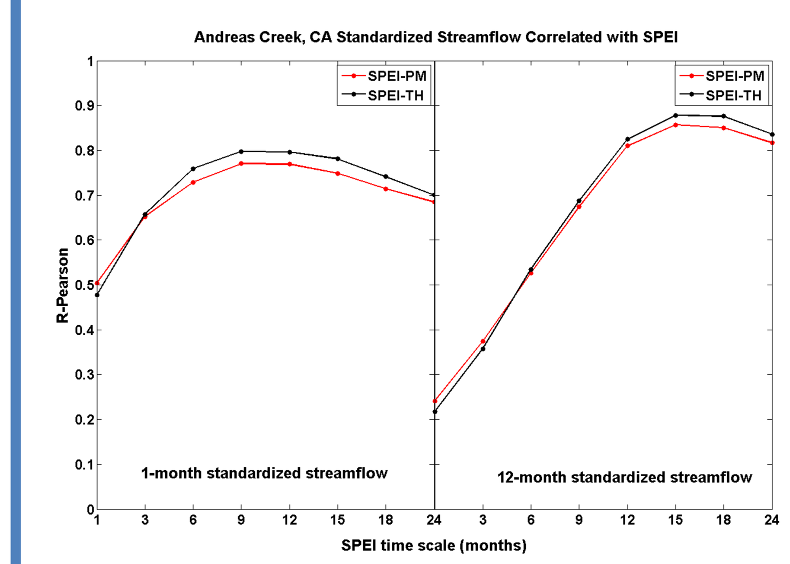
USGS gage name	continious: SPEI-TH max. R/time scale	continious: SPEI-PM max. R/time scale	monthly: SPEI-TH max. R/time scale/month	monthly: SPEI-PM max. R/time scale/month
Andreas Creek, CA	0.80/9-month	0.77/9-month	0.91/12-month/April	0.88/9-month/April
Paly Canyon Creek, CA	0.64/9-month	0.63/9-month	0.84/3-month/January	0.86/3-month/January
Deer Creek, CA	0.81/12-month	0.81/12-month	0.93/12-month/June	0.94/12-month/June
Entiat Rive, WA	0.65/12-month	0.64/12-month	0.90/15-month/July	0.89/15-month/August
Sauk River, WA	0.51/3-month	0.51/3-month	0.90/1-month/October	0.91/1-month/October
Stehekin River, WA	0.51/9-month	0.51/9-month	0.86/15-month/July	0.86/15-month/July
Little Tennessee River, NC	0.87/3-month	0.87/3-month	0.93/6-month/October	0.93/3-month/July
Pigeon River, NC	0.81/3-month	0.80/3-month	0.91/3-month/September	0.90/3-month/September
Watauga River, NC	0.78/3-month	0.79/3-month	0.91/3-month/August	0.90/3-month/August

12-month standardized streamflow

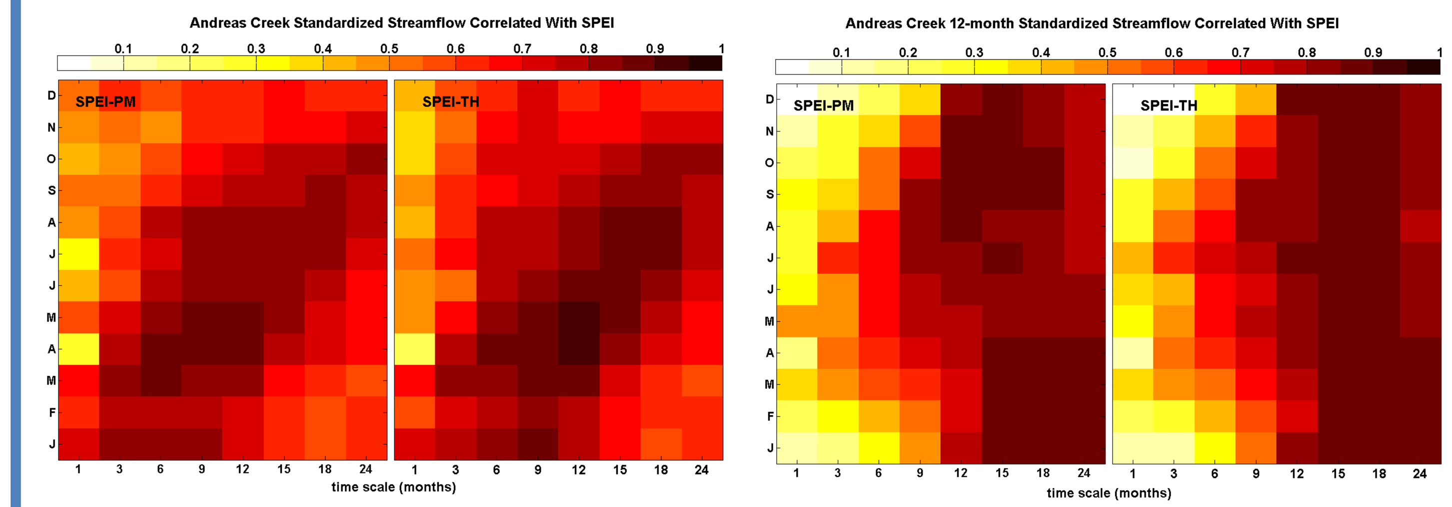
USGS gage name	continious: SPEI-TH max. R/time scale	continious: SPEI-PM max. R/time scale	monthly: SPEI-TH max. R/time scale/month	monthly: SPEI-PM max. R/time scale/month
Andreas Creek, CA	0.88/15-month	0.86/15-month	0.90/24-month/February	0.90/15-month/January
Paly Canyon Creek, CA	0.86/15-month	0.85/15-month	0.90/15-month/January	0.89/15-month/February
Deer Creek, CA	0.88/18-month	0.87/18-month	0.94/24-month/March	0.94/24-month/March
Entiat Rive, WA	0.86/18-month	0.85/18-month	0.95/12-month/September	0.94/12-month/September
Sauk River, WA	0.80/15-month	0.79/15-month	0.95/12-month/September	0.95/12-month/September
Stehekin River, WA	0.78/18-month	0.76/18-month	0.92/12-month/September	0.92/12-month/September
Little Tennessee River, NC	0.96/15-month	0.96/15-month	0.97/15-month/June	0.97/15-month/July
Pigeon River, NC	0.93/12-month	0.92/12-month	0.96/12-month/May	0.96/15-month/September
Watauga River, NC	0.90/15-month	0.90/15-month	0.95/12-month/April	0.94/12-month/April

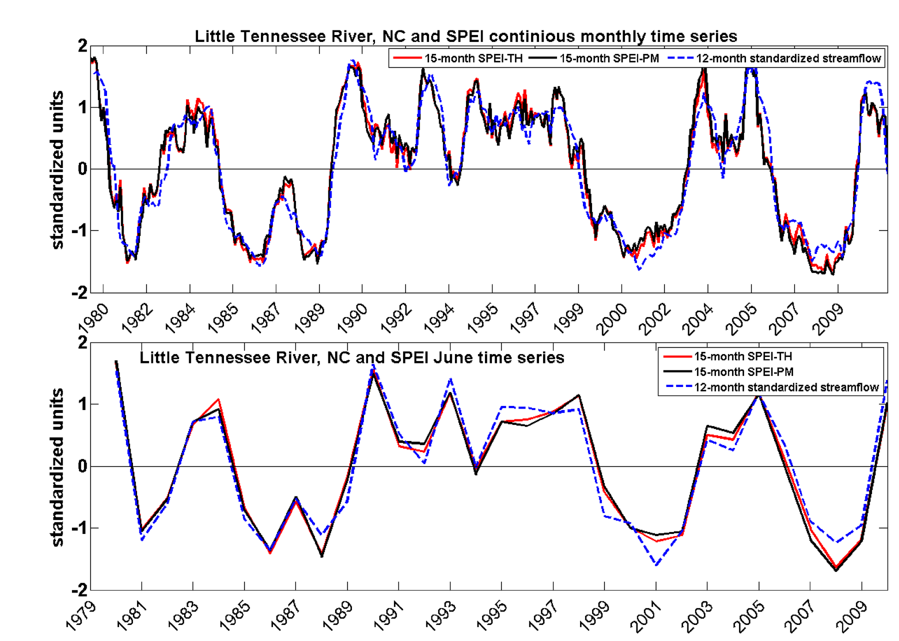
- In general, high correlations (R > 0.75) were found between SPEI (TH and PM) and standardized streamflow (1-month and 12-month)
- The strongest relationships (R > 0.95) were found in the Appalachian region with 12-month standardized streamflow and SPEI while the weakest relationships occur in the Cascades region
- The weak correlations (R < 0.50) found for the continuous 1-month standardized streamflow in the Cascades may be a reflection of the deep snow pack that forms in this region which, often times, can persist throughout the summer. This leads to weak relationships between streamflow and SPEI, especially in the spring months when streamflow and temperature are highly variable.

Streamflow examples



- Annual standardized streamflow at Andreas Creek (southern CA) is highly correlated to both SPEI-TH and SPEI-PM at the 15-18 month time scales and 1-month standardized streamflow at 6-12 month time scales
- Slightly higher correlations were found with SPEI-TH.
- However, these results do not support the use of TH over the more physically based PM as the differences are very small, and a major flaw in SPEI is that is simply relies on departure from mean of P-PET, which does not provide any information about soil storage and actual water availability





- Strong relationships also exist between standardized streamflow and SPEI in the humid-continental climate of the southern Appalachians.
- Again, the small differences found between SPEI-TH and SPEI-PM are simply a reflection of the departure from the mean of P-PET.
- Thornthwaite approach for PET greatly under estimates atmospheric demand in this region, which is not reflected in SPEI

Conclusions

- Major magnitude differences found between Thornthwaite and Penman-Monteith PET are largely not reflected in SPEI-TH and SPEI-PM using a period of record of 1979-2010 due to the fact that the departure from the mean P-PET is only being considered.
- A longer period of record (i.e. 1900-2010) is needed to fully capture the dramatic temperature changes experienced over the last century.
- The water limited regions of the Desert Southwest appear to be the most sensitive to choice of PET parameterization in SPEI.
- Since the physically based Penman-Monteith offers a more realistic estimate of atmospheric demand we recommend using this method for SPEI, and the temperature based Thornthwaite approach only be used in SPEI calculations if data are not available for calculating Penman-Monteith.
- SPEI appears to be useful for identifying hydrologic drought, but further development of a drought index which relies on climatological land surface feedbacks and utilizes a true soil-water balance is needed to improve drought monitoring.

Selected References

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Acknowledgements

This work was partially supported by the U.S. Bureau of Reclamation Nevada Water Resources Evaluation Program, funded by a grant under Public Law 109-103, section 208(a), cooperative agreement 06FC204044. Partial support for funding was also provided by the National Oceanic and Atmospheric Administration (NA08OAR4310661).