J6.7 TEMPORAL VARIATIONS IN MODEL-DERIVED EVAPORATION IN THE NORTHEASTERN AND MIDWESTERN U.S.

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1. INTRODUCTION

Since Peterson et al. (1995) identified a consistent downward trend in pan evaporation at sites in the United States and former Soviet Union, there has been considerable debate in the literature as to the relationship between trends in pan evaporation and actual evaporation. In the United States, the trend in pan evaporation was reported as –3.2 standard anomaly units (sau) per century in the eastern U.S. with a more dramatic –6.3 sau trend in the West. Both trends were found to be significant at the 99% level based on data from 1951-1994. Putting the sau trends into perspective, pan evaporation decreased by almost 100 mm per season over the last 45 years in the west. This is nearly 10% of the 1130 mm of pan evaporation this region averages in a season. Furthermore, the pan evaporation data were found to be correlated (r^2 = 0.48) with the diurnal temperature range, which has also shown a widespread downward trend over the past half century.

Peterson et al. (1995) proceed to suggest that these and other regional decreases in pan evaporation imply a global decrease in terrestrial evaporation. Brutsaert and Parlange (1998) offer a counterpoint. They suggest that well documented increases in global precipitation and cloudiness (Karl et al. 1996) argue for enhanced atmospheric water vapor and hence increased surface evaporation. They argue that in non-humid regions, decreasing pan evaporation (E_{pan}) is actually an indication of increasing actual evapotranspiration (E_{act}). When an adequate supply of water exists at the land surface E_{pan} and E_{act} should behave in a similar fashion for a fixed amount of solar energy. However, when surface moisture becomes depleted, E_{pan} will be unaffected (given an equal amount of energy) while E_{act} will decrease since the availability of water becomes a limiting factor. They suggest that the global increase in precipitation leads to increased soil moisture which implies inadequate surface water supplies occur less frequently, enhancing actual evaporation. Similarly, increases in precipitation and clouds decrease the amount of solar energy available for evaporation. As this governs evaporation from the pan, E_{pan} can decrease while E_{act} increases by virtue of the enhanced water supply.

Golubev et al. (2001), continue this debate by looking at simultaneous observations of pan and actual (based on lysimeter) evaporation. They present data that supports Brusaert and Parlange's argument. At the majority of sites, they found a negative correlation (r^2 between 0.2 and 0.5) between actual and pan evaporation. At the driest sites, negative trends in observed pan evaporation occurred in conjunction with positive trends in actual evaporation. Unfortunately, parallel pan and actual evaporation data were only available at one U.S. location.

In this work we expand upon the work of Golubev et al. (2001), through a pilot study that examines trends in model-derived potential and actual evapotanspiration. Our work focuses on a set of Ohio Valley stations, since the previous study presented data from this region . Stations in Iowa are also examined since the largest decline in E_{pan} was found in the Midwest.

2. MODEL-DERIVED DATA

Observations from National Weather Service first-order weather stations provided the data necessary to compute potential, pan and actual evapotranspiration based on two models. Solar radiation was estimated by the first model using observations of cloud coverage, cloud height, dew point, weather occurrence, visibility, and station pressure. DeGaetano et al. (1995) describe this model and show that its estimates compare favorably with those provided by similar models that rely on surface observations (Maxwell,1998) or satellite data (Pinker et al. 1995). Although the original model is based on human Surface Airways Observations, Belcher and DeGaetano (2004) present a modification that accommodates observations from Automated Surface Observing Systems (ASOS).

Given these solar radiation estimates and observed wind speed, temperature, dew point and precipitation, the modified Penman Monteith Equation is used to compute daily evaporation estimates. The model represents a modification of MORECS, an operational evaporation and soil moisture model used by the United Kingdom Meteorological Office. The computation of E_{pan} and potential and actual evapotranspiration follow a similar procedure. In the case of E_{pan}, the

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stomatal and surface moisture resistance terms are omitted, as is the soil heat flux. Surface moisture resistance is also ignored in the case of potential evapotranspiration. In this case, the stomatal resistance is set to that of adequately watered turf grass. All resistance terms are included for the computation of actual evaporation. In this case, water becomes increasingly more difficult to extract from the soil as the amount of available water decreases. Thus, evapotranspiration is limited by sub-adequate soil moisture conditions. In both evapotranspiration cases, water that is intercepted by the canopy (e.g. dew or rainfall)evaporates, but does not contribute to the daily evapotranspiration total. Aerodynamic resistance also differs between the pan evaporation and evapotranspiration simulations.

3. RESULTS

Figure 1 compares observed and modeled pan evaporation totals (June-August) for two sites in the Northeastern United States. The Pittsburgh-Confluence, PA pair is located within the primary focus area of this pilot study. Unfortunately, these stations are separated by more than 80 km. In New England, the Burlington and Essex Junction, VT stations are separated by about 10 km. In both cases, the model and observations are in reseasonable agreement. For the Vermont stations the model overestimates the pan value by less than 3%. At the more distant Pennsylvania stations, the observations are overestimated by 14%. It is

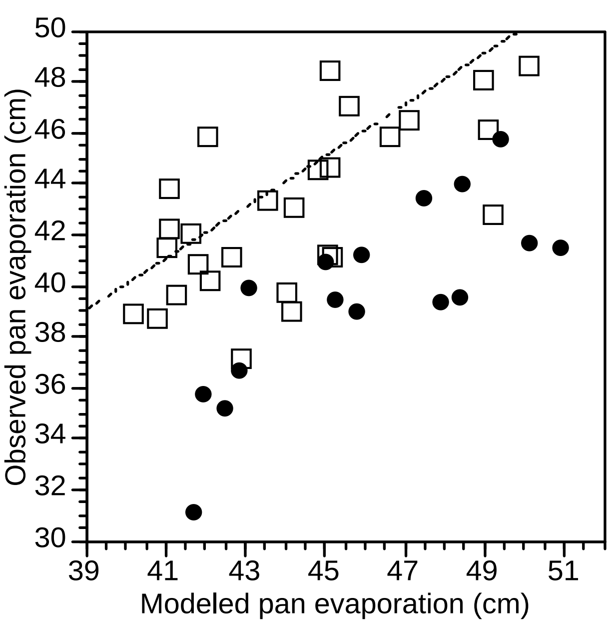

Figure 1. Scatterplot of observed versus modeled pan evaporation at Pittsburgh and Confluence Dam, Pennsylvania (circles) and Burlington and Essex Junction, VT (squares).

curious that the observations at Confluence are less than those at the more northerly location.

In subsequent analyses, modeled pan, potential and actual evaporation from four sites (Pittsburgh, PA; Elkins, WV; Lynchburg, VA; and Youngstown, OH) were used. Likewise, an adequate record of observed E_{pan} was available at five stations (Charles Mill Lake, OH; Tom Jenkins Dam, OH; Philpott Dam, VA; Kearneysville, WV; and Confluence Dam, PA). The record of model-derived evapotranspiration values extended from 1971-2003. Missing data precluded the generation of a longer record. These stations lie primarily to the west of the Appalachian Mountains. They are confined to the westernmost part of Golubev et al.'s (2001) Northeastern region.

Figure 2 compares the time series of standardized actual and potential evapotranspiration anomalies (model-derived) with the standardized pan evaporation (both modeled and observed) anomaly series. In all cases, the data are based on total evaporation from May through October. Standardized anomalies are calculated separately for each station-month and used to compute a single seasonal anomaly by simply averaging across all available months and stations in a given season. Each series increases with time with slopes ranging from 0.14 to 0.30 sau per decade for observed pan and potential evapotranspiration, respectively. These represent small seasonal changes of approximately 2.0 and 2.8 mm per decade. The pan value is of the same magnitude but opposite sign as that reported by Peterson et al. (1995). This is likely the result of differences in period of record. Figure 3 shows that a longer time series of observed pan evaporation data from the set of Ohio Valley stations shows a marked downward trend.

The Ohio pan evaporation series presented in Golubev et al. (2001) shows an increasing trend from the 1970s onward, in qualitative agreement with our results. Golubev et al. (2001), however, qualitatively show a decrease in observed actual evaporation at the Ohio site from (1971-1998), in contrast to the increase indicated here. They also show virtually no correlation $r^2 = 0.00$, between observed pan and actual evaporation. This is also in disagreement with the model results that show a modest ($r^2 = 0.121$) positive relationship between actual and pan evaporation.

Golubev et al. (2001) show that the strongest decrease in observed pan evaporation (-3.4%/decade for 1957-1998) across the U.S. occurred in the Midwest. Based on data from a similar climate type in the former USSR, they interpret this decrease in pan evaporation to reflect an increase in actual evaporation. To test this conclusion, evaporation data were modeled for the period 1971-2003 at a set of four Iowa first-order stations.

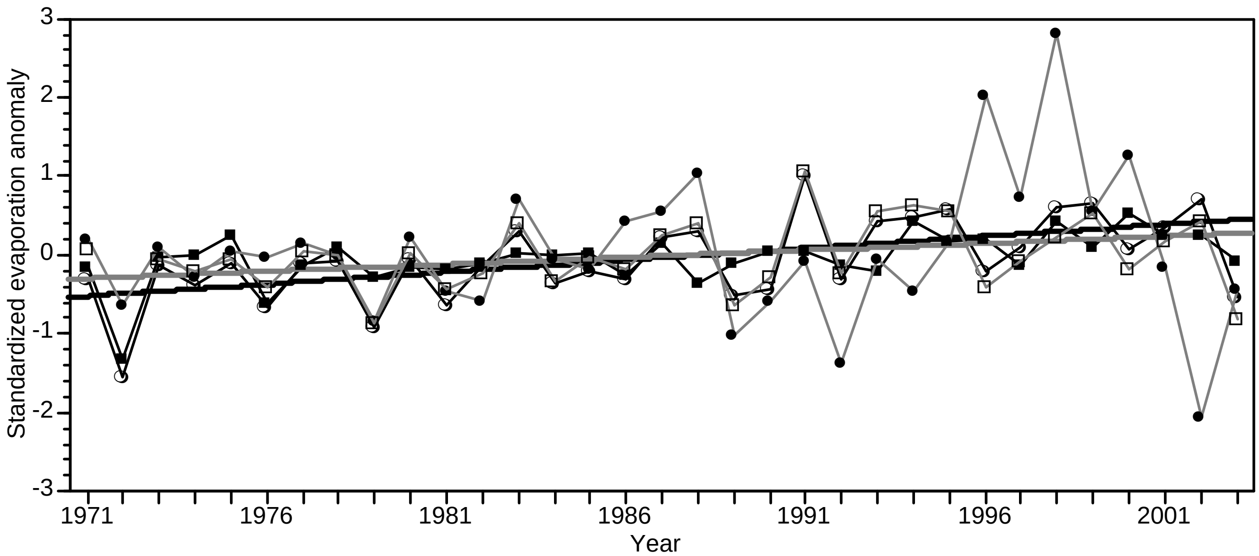

Figure 2. Time series of potential (open circles) and actual (solid squares) evapotranspiration and modeled (open squares) and observed (solid circles) pan evaporation, plotted as standardized anomalies. Least squares regression lines are shown for actual evapotranspiration (thick gray) and observed pan evaporation (thick black).

Subjectively, the Golubev et al. (2001) time series shows its greatest decrease in the post-1970 period. Overall, Figure 4, matches the trends shown by Golubev et al. (2001). Pan evaporation shows a slight (0.02 sau/decade) decrease with time, while actual evaporation increases over the same period. The increase in actual evaporation is larger in magnitude at 0.14 sau/decade. Likewise, at the Iowa sites, there is little correlation (r^2 = 0.003) between modeled pan and actual evaporation.

An interesting feature of Figure 4 is the behavior of the actual and pan evaporation series during two specific years. In the drought year of 1988, pan evaporation experiences its largest positive anomaly, while the actual evaporation anomaly is among the most negative. Conversely in the extremely wet year of 1993, pan evaporation exhibits a large negative anomaly, while the actual evaporation anomaly is slightly positive. Although not shown, solar radiation anomalies track the pan evaporation values quite closely. This suggests that pan evaporation trends in this region are influenced primarily by the availability of solar energy, while trends in actual evaporation integrate changes in both solar energy and moisture availability.

4. SUMMARY

Hourly first order weather station observations have the potential to provide estimates of pan and actual evaporation data at more than 200 sites across the country. The results from this pilot study show good qualitative agreement with the limited trends reported in the literature. The modeling approach would provide a direct measure of temporal changes in both actual and pan evaporation, rather than relying on pan observations to infer time-dependent changes in actual evaporation. As the models are based on a suite of meteorological variables, this approach would lend itself to identifying the causal mechanism or mechanisms for the trends in modeled evapotranspiration.

The pilot study also raises some questions as to the quality of the historical pan evaporation record. In constructing trends in these observations, it was clear that the current data base is plagued by erroneous values and missing data. Physically unreasonable daily

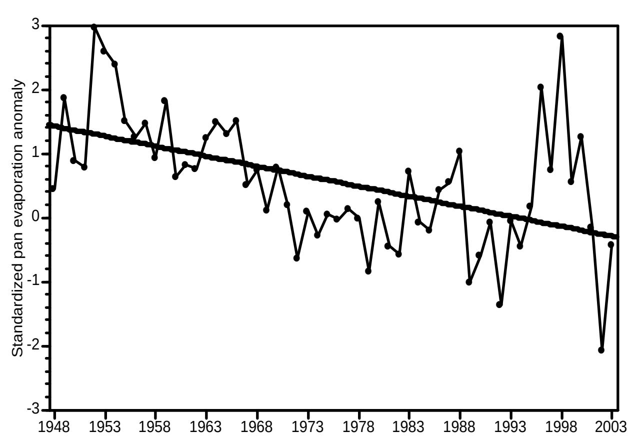

Figure 3. As in Figure 2, but for pan evaporation over the period 1948-2003.

evaporation observations (>12.7 mm) were common in the data base, as were months with several missing daily values. Further work to quality control the historical pan evaporation data base, perhaps through comparison with model-derived values is also warranted. Means to account for missing daily evaporation observations are also needed. In some cases, a single missing observation may alter the monthly evaporation total by more than 5%.

Finally, refinements to the solar radiation and evaporation models, particularly with regard to how they handle missing hourly observations, is warranted. Such a modification would allow a greater than 50-year time series of evapotranspiration estimates to be generated. This is critical since a difference in slope is indicated between series starting in the 1950s and 1971. Such a change point is characteristic of several other climatological time series.

5. ACKNOWLEDGMENT

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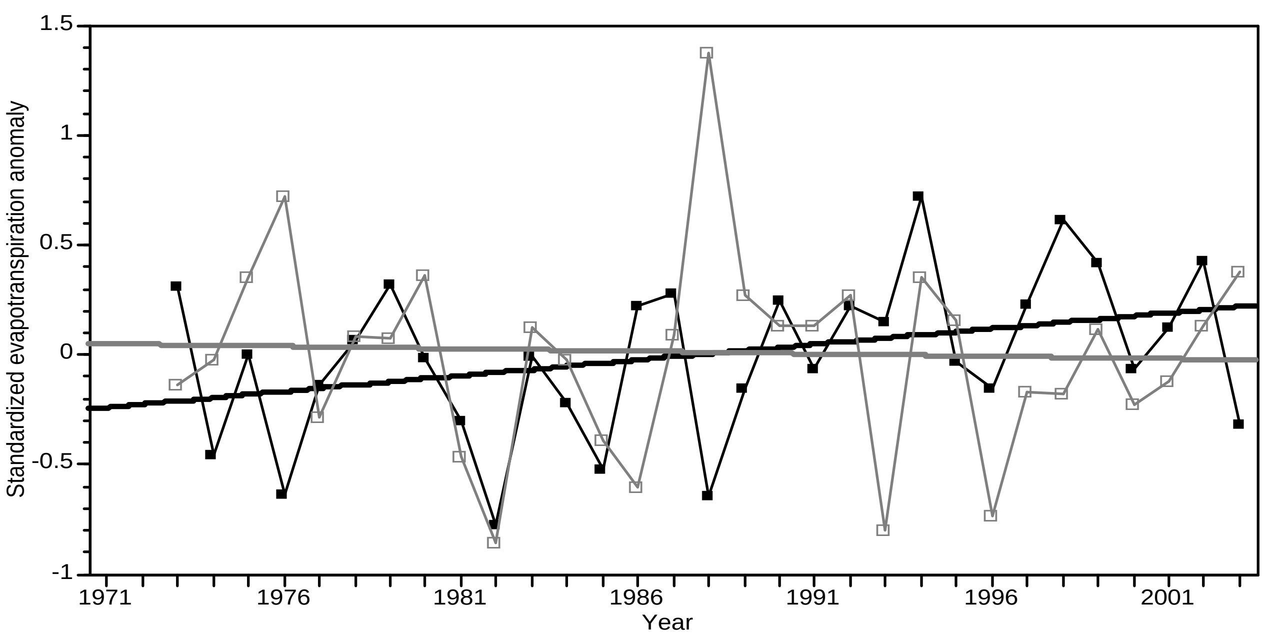

Figure 4. As in Figure 2, but for modeled actual evapotranspiration (black, solid squares) and modeled pan evaporation (gray, open squares) at four Iowa stations.