

New Explanation for Evaporation Paradox

— Latest Results from Pan Evaporation Research in Arid Region of Northwest China

Recently a group of scientists led by Prof. CHEN Yaning at the Xinjiang Institute of Ecology and Geography, CAS identified a 30-year-plus downward trend of evaporation in a hyper-arid region of China, and this trend unexpectedly turned upward in around 1993, after investigating the local evaporation dynamics between 1958 and 2010, using a generic physical model based on long-term meteorological data collected at 81 ground-based meteorological stations.

The turn in rate of pan evaporation, as proposed by researchers in their paper published in the May 2013 issue of the prestigious international journal of *Water Resources Research*, could be mostly attributed to changes in the aerodynamic components, with some contributions from regional solar irradiance. Observed near-surface wind speed might be the primary contributor to the decline of pan evaporation during the period from 1958 to 1993, while the combined effect from wind speed and vapor pressure deficit might have contributed to the increase of pan evaporation since 1993.

The new discovery has shed some new light on a long-existing paradox concerning the relationship between global warming and observed pan evaporation, a surrogate device to measure potential evaporation or evaporation demand of the atmosphere in a given region, based on which some conversion can give the calculated values of the actual evapotranspiration.

Evapotranspiration is important in water and energy cycles, playing a key role in global and regional hydrological processes, and has most direct impact on climate change. The essential purpose of evapotranspiration research is to understand the spatial and temporal variability of the water balance's occurrences, causes and controlling factors, so as to quantitatively predict the water balance. Theories on trends of evaporation, their impact on water cycle as well as their response to climate change therefore are sought-after by researchers in the fields of hydrological science and meteorological science; and a theory or a model that can accurately mimic and estimate the evaporation is well anticipated due to its natural importance for research in these areas.

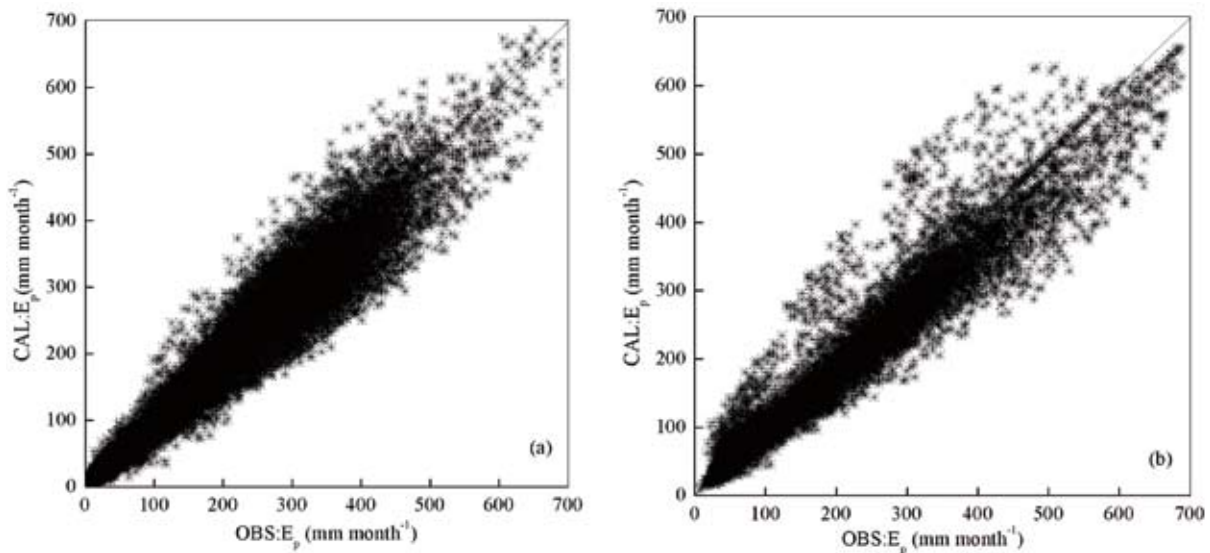


Figure 1: Comparison of observed (OBS) and calculated (CAL) pan evaporation; (a): calibration; (b): validation

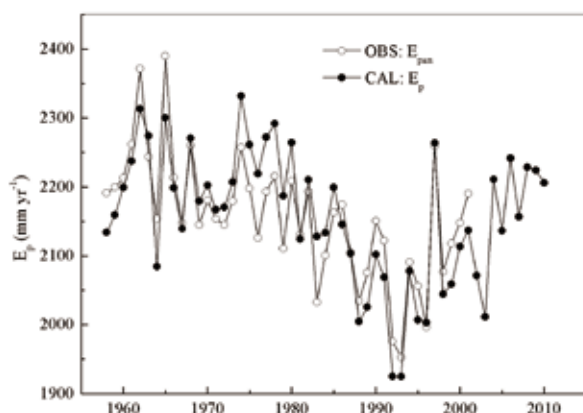


Figure 2: Change of annual pan evaporation in the arid region of Northwest China from 1958 to 2010.

Over the past half century, in conflict with the prediction that global warming could lead to increase in potential evaporation, noticeable decrease in observed pan evaporation, which is deemed to represent potential evaporation, has been found worldwide, especially in the Northern Hemisphere, despite the obvious rise of local air temperature. To explain this paradox, scholars have proposed various theories, and this has resulted in controversy in terms of changes to the hydrological cycle. An example is the discrepancy between such changes expected by using Penman's proportional hypothesis (1948) and Bouchet's complementary relationship (1963) hypothesis. Based on a different understanding of the concept of potential evaporation, Penman defined the pan evaporation as the maximum possible evaporation under a given climate and vegetation conditions, and proposed that actual evapotranspiration might have a proportional relationship with pan evaporation. Bouchet questioned the hypothesis, arguing that it did not consider the complex feedback mechanism between land surface and the atmosphere, and pointed out that the observed decline in pan evaporation did not necessarily mean decline in actual evapotranspiration. They went further and proposed that the observed decline in pan evaporation could be interpreted as evidence for increased actual evapotranspiration in water-limited regions. Therefore, a better physical model is needed to estimate pan evaporation more accurately.

Since evapotranspiration is difficult to measure directly, traditionally measurements of evaporation from pans have been used to represent the evaporative demand of the atmosphere, and often to represent potential evaporation. The scarcity of record on evaporation pan measurements beyond 2001 has posed some difficulty to research on this issue. Many studies, based on empirical meteorological

data until 2001, directly focused on the declining trend of pan evaporation, and often employed statistical analysis, such as correlation and stepwise regression, to identify the controlling climatic variables, yet few studies employed physical-based theories. Recently, some famous scholars developed a PenPan model based on the mass and energy balance in Australia. A limitation of these studies is that they adopted Class-A pans, which have a diameter of 1.21 m and a depth of 0.254 m. However, evaporative pans widely used in China for such studies have a diameter of 0.2 m and a depth of 0.1 m. The research team led by Prof. CHEN Yaning at the Xinjiang Institute of Ecology and Geography, CAS modified the PenPan model to suit it to the estimation model based on the micro-pan used by Chinese researchers, and found that pan evaporation in the region exhibited an obvious decreasing trend until the early 1990s (1993). This declining trend, however, reversed in 1993. Starting from the revised PenPan model, the team went further to obtain the contribution of meteorological variables to evaporative demand via partial derivatives, and found that pan evaporation could be mostly attributed to changes in aerodynamic components.

Results from this study represent a new advance in the research on the widely reported downward trend of evaporation, shedding new light on the "evaporation paradox". It indicates a more difficult reconciliation between the "proportional relationship" and "complementary relationship" evaporation theories, and calls for more innovative solution to this paradox.

"Given the warming trend detected worldwide in the last 50 years," explained LI Zhi, a PhD student with the team and coauthor of the paper: "the reverse of the downward trend of pan evaporation has complex implications: it does not comply with the 'proportional relationship' or the 'complementary relationship'. Therefore this poses some challenge to the reconciliation between the two theories."

This study is part of a program funded by the National Basic Research Program ("973 Program") of China focused on effects of climate change on water cycle and water resources security in arid areas of Northwestern China. The discovery, published in the volume 49 of the *Water Resources Research*, is believed to have great significance for investigating the regional hydrological cycle under the context of climate change. For water managers, the researchers suggested, it is noteworthy to cast attention to the spatial and temporal distribution of water resources caused by variation in water cycle, to secure informed policy-making in the layout, development, utilization, protection and management of water resources in a reasonable and sustainable way.