Towards Understanding the Climate and Landuse Change Impacts on Hydrological Cycle and Water Resources

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Many regions in the world are facing serious water shortage and this situation will be more chaotic due to the climate and landuse change. It is desired to understand the climate and landuse change impacts on hydrological cycle and water resources. Using the data of northern China in the last second half century, it will explain the changes in water balances and vegetation, and the inside mechanism from a coupled water-energy balance perspective. And this top-down methodology will be useful for prediction in ungauged basins.

Increase in air temperature and decrease in pan evaporation was found to be common worldwide during the past half century. This results in controversy in view of the changes to the hydrological cycle. Increases in precipitation have been expected due to the Clausius–Clapyeron relation in that the specific humidity increases exponentially with the greenhouse-gas induced temperature increasing and confirmed by measurements over northern extratropical land areas. The hydrologic cycle is expected to be intensified (or accelerated). However, the decreased pan evaporation is found to be well related to the global dimming, i.e., the decreased solar radiation induced by the pollution increasing, thus evaporation (i.e., the latent heat flux) should be steadily decreasing from the energy balance perspective. Many researchers explained that the potential evaporation (usually measured by pan) is decreased with increasing of precipitation; however, the increased soil moisture (due to precipitation increasing) can be evaporated because of extra energy available. Therefore, the actual and potential evaporation are in complementary relationship, which is expected to unify the controversy between global warming and dimming. This means that pan evaporation decrease implicates acceleration of the global hydrologic cycle, i.e., increase in the terrestrial evaporation. Based on the complementary theory, many operational formulae have been introduced to estimated actual evaporation from the potential evaporation.

Our recent water balance analysis of 108 catchments in non-humid regions of China has shown that there are no general opposite trends between potential and actual evaporation in the same period. A novel phenomenon has been found that the complementary relationships in evaporation are distinctly confirmed when the annual actual and potential evaporation are plotted against annual precipitation; However, complementary relationships disappear in many catchments when actual and potential evaporations are plotted against the time (year) during the same period. This means that complementary idea cannot provide universally correct predictions on the trend of actual evaporation only from the potential one.

Budyko proposed an operational hypothesis for coupling water-energy balance, $E/P=\varphi\left(E_0/P\right)$ where E_0/P is the dryness index; φ denotes the general form of empirical Budyko curves which are always similar. Particularly, an analytical solution to the Budyko hypothesis has been derived based on phenomenological considerations and dimensional analysis, which is called Fu's equation.

$$E/P = 1 + E_0/P - \left[1 + \left(E_0/P\right)^{\varpi}\right]^{1/\varpi} \quad (1)$$

where ϖ has been demonstrated to indicate landscape characteristics. The Budyko hypothesis can be invoked for understanding the change of actual evaporation with the time (t), i.e.,

$$\frac{\delta E}{\delta t} = \frac{\partial E}{\partial E_0}\frac{\delta E_0}{\delta t} + \frac{\partial E}{\partial P}\frac{\delta P}{\delta t} + \frac{\partial E}{\partial \varpi}\frac{\delta \varpi}{\delta t} \quad (2)$$

Since the vegetation needs much longer time to adapt to the steady change of climate, the landscape characteristics are relatively stable, i.e., $\varpi = const$, $\frac{\delta \varpi}{\delta t} = 0$. This yields

$$\frac{\delta E}{\delta t} = \frac{\partial E}{\partial E_0}\frac{\delta E_0}{\delta t} + \frac{\partial E}{\partial P}\frac{\delta P}{\delta t} \quad (3)$$

where $\partial E / \partial E_0$ and $\partial E / \partial P$ are in the range of $(0, 1)$ and can be estimated using Fu's equation. When $E_0 / P = 1$, $\partial E / \partial E_0 = \partial E / \partial P$; when $E_0 / P < 1$ for the humid regions $\partial E / \partial E_0 > \partial E / \partial P$; when $E_0 / P > 1$ for the non-humid regions, $\partial E / \partial E_0 < \partial E / \partial P$. The controlling factors (i.e., the values of $\partial E / \partial E_0$ and $\partial E / \partial P$) can be determined by the dryness index (climate conditions) and the ϖ values (landscape conditions), which show significant geographical variability.

From Equation (3), the hydrological cycle implications of global warming and dimming can be explained from Budyko's couple water-energy perspective. Regarding the landuse change impact on the hydrological cycle, an open question is how to estimate $\frac{\delta \varpi}{\delta t}$ in Equation (2)? This will be future research topic from the ecohydrology perspective.