Assessment of Surface Energy Balance in Southern Idaho

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Abstract

Proper management of water resources is always a matter of concern in arid regions like southern Idaho such as the Snake River basin where rainfall is limited and the moisture level of atmospheric air is below threshold level most of the time throughout a year. For the proper assessment of water resources it is necessary to quantify the Evapotranspiration (ET) loss in this region and use the available water resources efficiently. A vast quantity of water is moving in the atmosphere under the direct influence of solar energy. So, in order to characterize the behavior of the water cycle, it is important to understand the energy balance of the Snake River basin. ET is an important phenomenon in the water cycle for the estimation and evaluation of the available water resources. If we understand how ET is changing over space and time, then we can more accurately calculate the crop water requirement (CWR) at a high resolution for that region. This study can help water managers and farmers in manage water resources very efficiently. Current research has difficulty projecting how ET is going to change over different locations in the future. Therefore, through this research we are trying to understand the partition of the energy balance components and quantify them to help the water management in southern Idaho. To support this research, we will use the data from both Land Surface Hydrology Model and field observations and present the trends in surface energy balance components.

Introduction

The driving input in the surface energy balance is the net radiation. The net radiation is partitioned into different components at the earth's surface. The three major components of net radiation are; latent heat flux, sensible heat flux and ground heat flux. The largest fraction of the net radiation available at the earth's surface is used to evaporate water from the surface back to the atmosphere. This fraction of net radiation is called latent heat flux (λE). Unlike precipitation (x-mm of rain), rate of evaporation is commonly measured in terms of energy flow leaving the evaporating surface in the form of latent heat of vaporization (Shuttleworth, 2012).

A second fraction of net radiation that carries the heat back and forth to the atmosphere from the surface is sensible heat flux. This fraction of net radiation is used by the atmosphere for the direct warming or cooling the atmospheric air. The third component of the energy balance is ground heat flux that conducts through the soil when the net radiation is positive and radiates out of the soil when the net radiation is negative (Gentine, 2012; Shuttleworth, 2012). Although every component of net radiation impacts the hydrological cycle, this study focuses on the quantification of latent heat flux and employs it to understand the anomalies of evapotranspiration (ET).

ET is an important process for the water exchange between the land surface and the atmosphere. ET plays an important role in the hydrological cycle, so it is essential to estimate ET accurately for the evaluation and management of available water resources. The difference between precipitation and evapotranspiration is the water available for use by animals and nature. Thus the quantitative assessment of ET is essential to maintain a balance between the available water and its consumption. Global warming and natural changes in climate can highly affect the ET process, so it is necessary to understand the interaction between the hydrological cycle and atmospheric parameters (Dingman, 2002; Brown).

The hydrological cycle is a complex process that involves a direct interaction between the atmospheric parameters and surface parameters. It is not yet understood how a reliable prediction can be made in this field (Devonec et al., 2002). One of the approaches researchers use to understand the hydrological behavior is the energy balance approach (Heerwaarden et al., 2010).

According to the first law of thermodynamics, for the energy balance closure the sum of latent heat flux (λE), ground heat flux (G), sensible heat flux (S), and other losses (storage) must be equivalent to net radiation (R_n) at the surface (Wilson et al., 2002). Assuming the change in energy storage is zero, the energy balance equation can be written as shown in Equation 1. Further details regarding the energy budget is explained by Franssen, et.al. (2010), Dingman, (2002), and Wilson et al. (2002).

$$R_n = \lambda E + G + H \qquad \text{Equation (1)}$$

This study used the energy balance approach as explained above to simulate the surface energy fluxes that can be linked to various atmospheric processes. The goal of this study is to understand the partition of the energy balance components and use them to quantify ET in Southern Idaho.

Methodology

Study area

This study was conducted for the Snake River basin in Idaho, which is a semi-arid region with a very low precipitation, concentrated in early spring. The most common land cover types besides farming are alpine forest, sage-brush, invasive cheat-grass, and other native grasses. Geographically, it is roughly located between 41.37° N and 43.75° N latitudes and 112.13° W and 116.15 º W longitudes. In this study, the pixels from the model for two locations, Hollister Sagebrush (HL) and Raft River Grass-land (RR), are used. See Figure 12 (Jaksa, 2011; Mitchell, 2005).

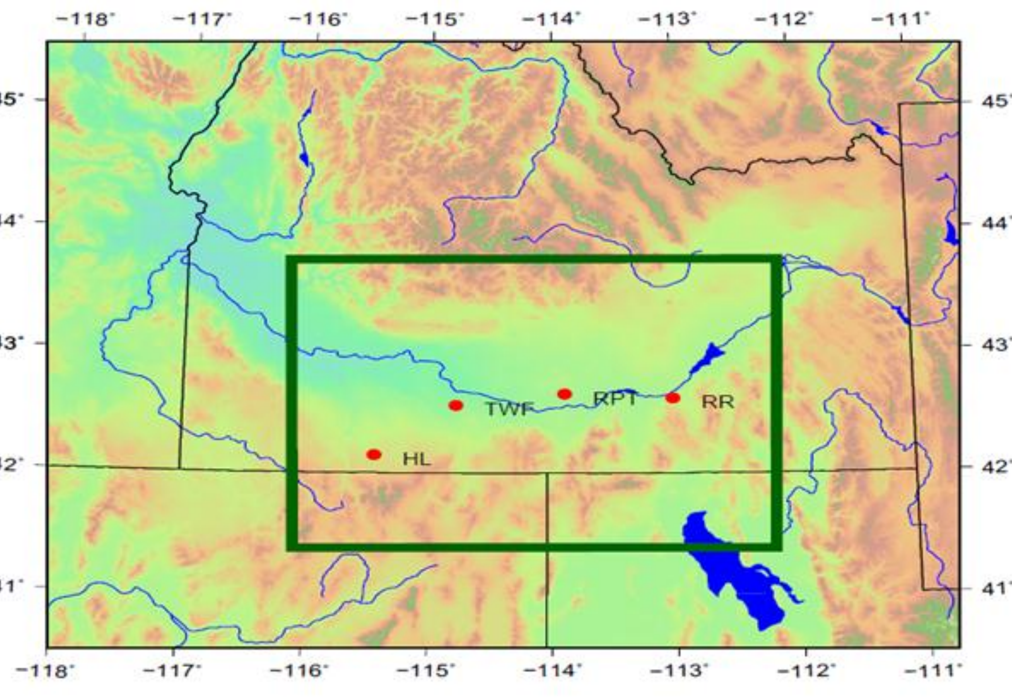

Figure 12: Snake River Plain, Southern Idaho (Jaksa, 2011)

Meteorological and satellite data

A long term data from field observation available at ET Idaho (http://data.kimberly.uidaho.edu) was used for this study. This dynamic web page allows us to access historical ET data for the state of Idaho at various locations. These data are based on National Weather Service (NWS) and Agrimet weather stations. Hourly, monthly, and annual weather data for both of the sites discussed in this study are available at ET Idaho web site. For this study monthly data of last 80 years for potential and actual ET were used.

Model simulated data

The Noah Land Surface Model (Noah-LSM) is used to simulate the data using High Resolution Data Assimilation System (HRLDAS). Noah LSM model is a land surface algorithm widely used to simulate energy and water balance components. A working schematic diagram of the LSM is shown in Figure 13 (Jaksa, 2011; Mitchell, 2005).

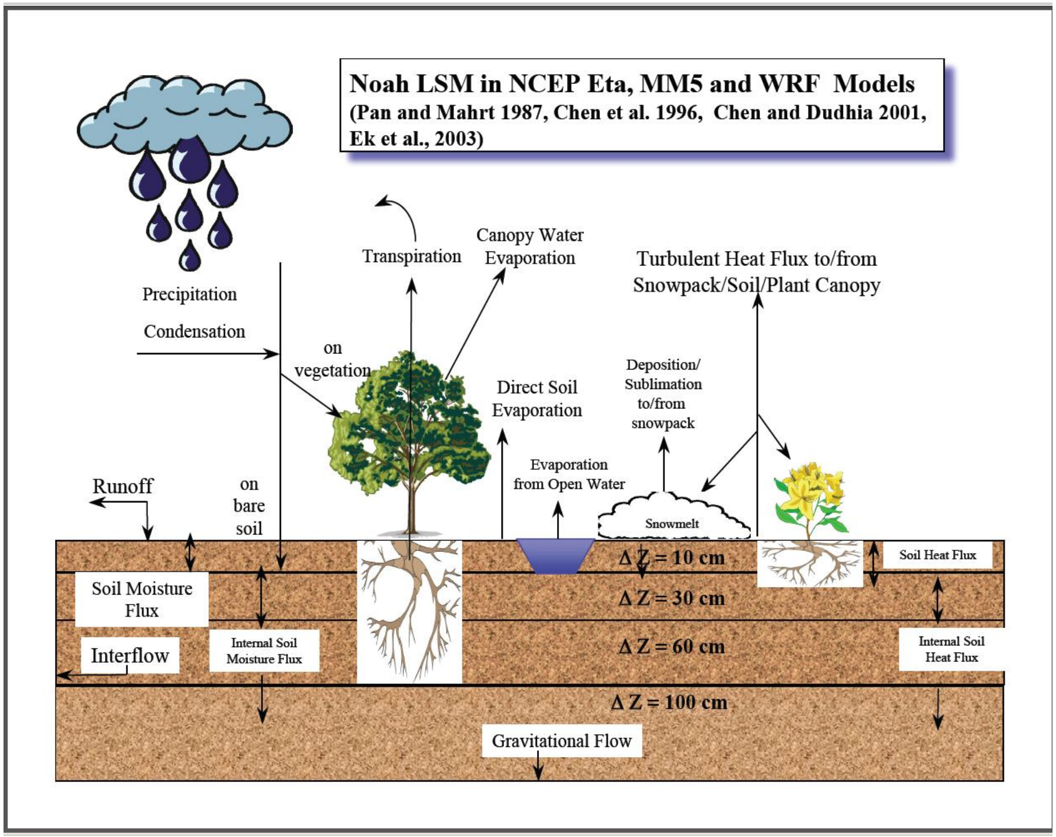

Figure 13: The Schematic Diagram of the Noah LSM (Mitchell, 2005)

The model was validated by comparing the results obtained from the simulated data against the results from meteorological stations. More about the comparison is discussed in the results section.

Results

Comparison of ETs and PETs

Data analysis was performed by comparing ET and PET of both the Raft River and Hollister sites. First of all ET and PET from both field observed data and model simulated data were compared separately (see the top two panels of F), and then ET and PET from field observed data was compared against the LSM output (see the bottom two panels of F). This comparison helped us to validate the simulated data as well as to see how ET and PET changed in 2009 and 2010.

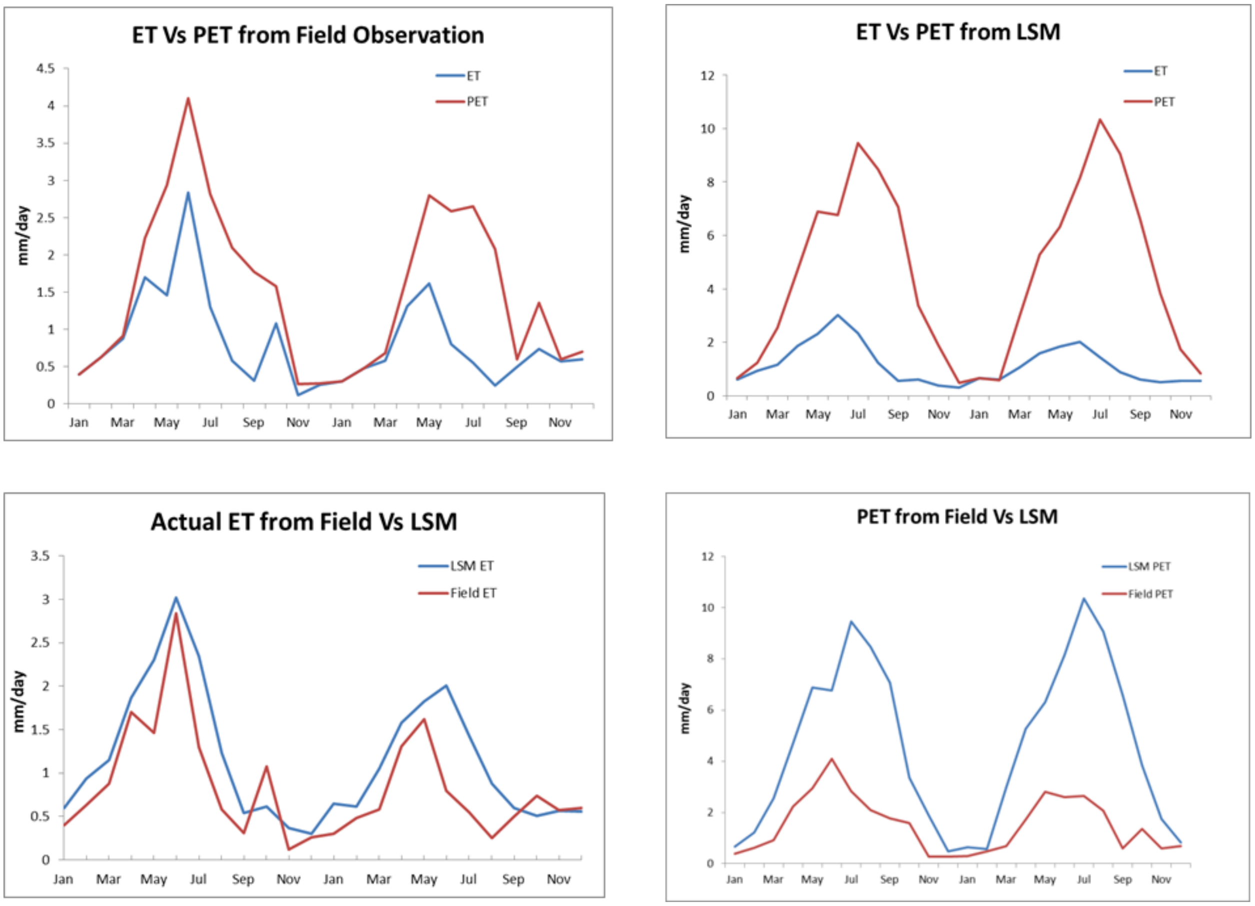

Figure 14: F-Graphs comparing the ETs and PETs from field observation and LSM model for two years (2009-2010) for Hollister site.

Energy balance closure

Average day and night energy budget for Raft River (Cheat Grass) pixel and Hollister (Sagebrush) pixel are given in Table 1 and Table 2, respectively. This average energy budget was computed from the two years of Noah-LSM simulated data.

Table 1: Average Day and Night Energy Budget for Raft River (Cheat Grass) Pixel

	Day	**Night**
$\mathbf{R_n}$	222	-74
H	125	-47
G	37	-35
λE	60	9

Table 2: Average Day and Night Energy Budget for Hollister (Sagebrush) Pixel

	Day	**Night**
R_n	177	-71
H	75	-36
G	46	-46
λE	55	11

Comparison of energy fluxes between two sites

All four components of energy budget were compared between the Raft River and Hollister. The results showed that the net-radiation for Raft River (Cheat grass) was higher than that of Hollister (Sagebrush). See Figure 15. Contrary to the higher net-radiation, Rift River showed a lower intake of ground heat flux (G).

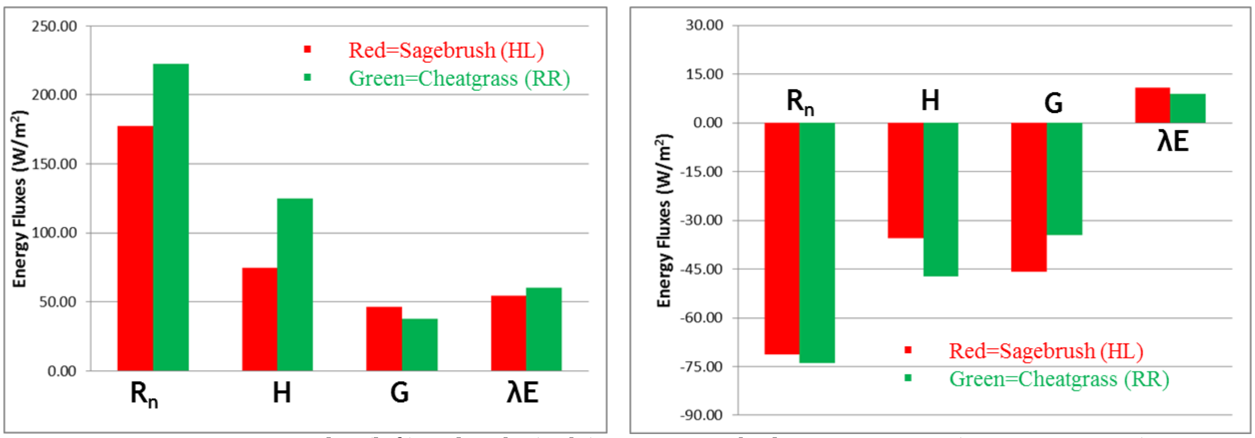

Figure 15: Average day (left) and night (right) time energy budget components (LSM 2009-2010)

Historical trend of ET and PET in Southern Idaho

A long term data from field observation was plotted for various time intervals for both Hollister site and Raft River site. This historical analysis was started by plotting 80 years of data. A trend of increasing slope was observed (see Figure 16). Keeping time as a variable, several plots were observed. While doing so, a decreasing slope was obtained for the plot of ET after 1995 (see Figure 17).

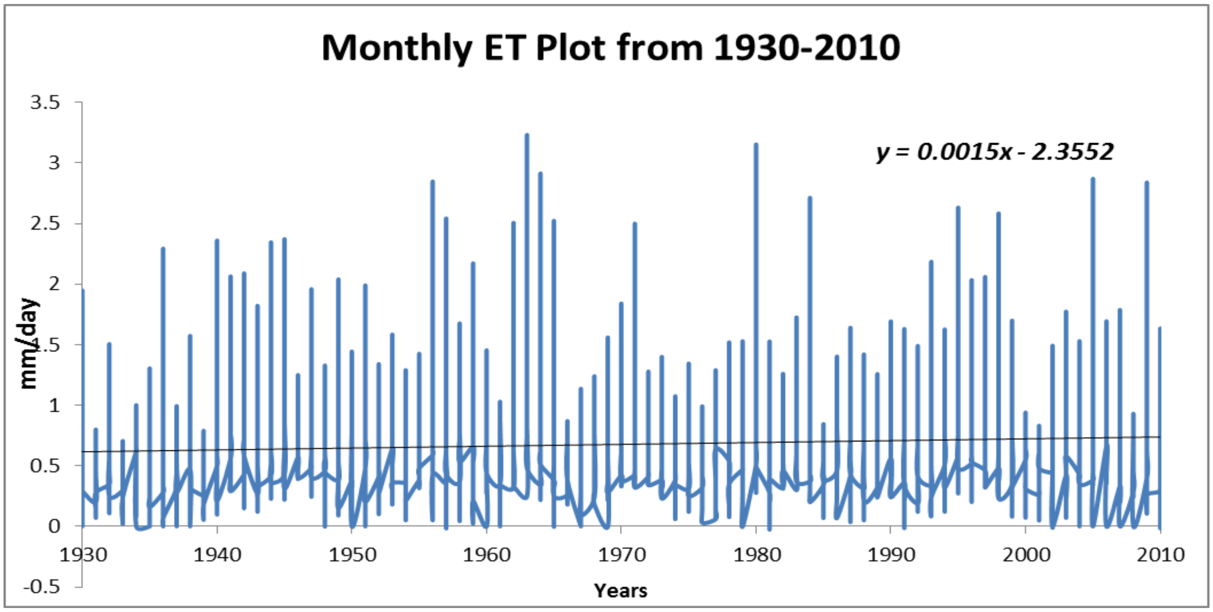

Figure 16: Monthly ET for Hollister Site (1930 – 2010)

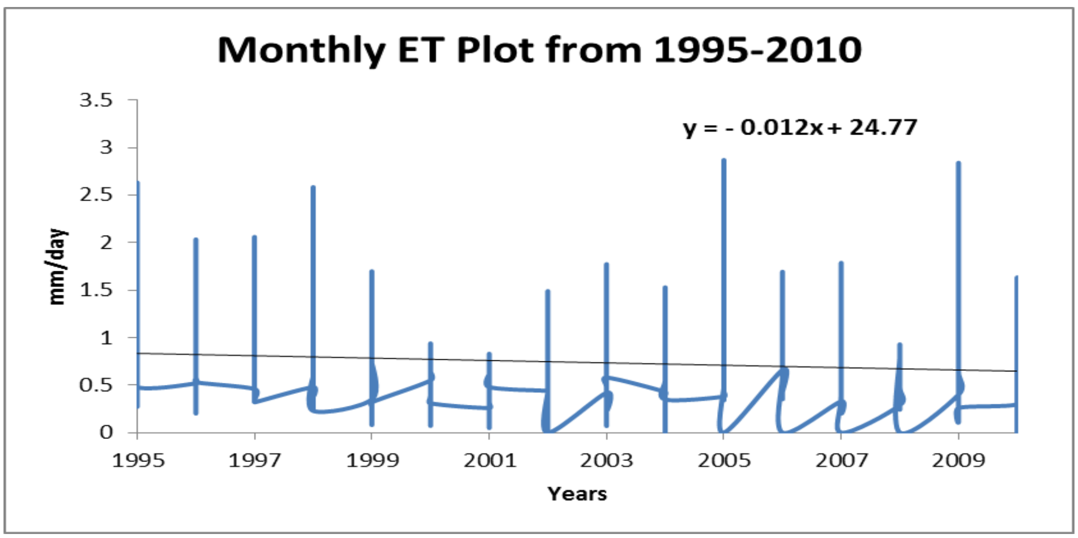

Figure 17: Monthly ET for Hollister Site (1995 – 2010)

Discussion

Model vs. field observation

As the first step of data analysis, comparison of ET and PET from the observed data against the LSM simulated data helped us to validate the Noah LSM model. As shown in F, good match for actual ET from field observation and the model output was evident, whereas we found that the model overestimated the PET for both of the sites.

Second, arithmetic average of hourly data for the energy fluxes from LSM was computed (see Table 1and Table 2), and the result was used to check the energy balance closure. This showed us energy balance closure was possible with reasonable accuracy (off by ± 1.5%). Positive fluxes during the day indicate that the space acts as a source of energy during the day were as negative values of the fluxes indicate that the space acts as a sink during night. During day short wave radiation from the sun and long wave radiations emitted by clouds and other components of the atmosphere combined and reach the earth surface. While during night the earth surface will radiate long wave radiation back to the space forming a negative net radiation.

Fluxes comparison

One of the main causes of a significant difference in net radiation between any two sites can be the difference in latitude But in the case of this study, both of these sites are not that far from each other, so the difference in net-radiation might be due to the difference in vegetation type or moisture content of soil and atmosphere (Bagayoko et al., 2006). This argument is further supported by the higher ground heat flux (G) for Hollister, indicating that most of the soil is barren in this site. Lands covered by less vegetation contain less moisture in both soil and atmospheric air near the surface. Lower moisture content means that only a little fraction of net-radiation is used as latent heat flux (λE) and sensible heat flux (H), and there will be a larger fraction of net radiation available for ground heat flux (G).

Historical trend

A positive slope of the trend line in the historical plot ET for the last 80 years indicates a gradual increase in ET. An increase in ET can be mainly because of more availability of soil moisture. Due to increasing irrigated cropland surrounding these study sites, it is reasonable to assume that the moisture content for these sites has increased since 1930. But on the contrary, a decreasing trend was obtained for the time period after 1995 (see Figure 17). This decreasing trend of ET is further supported by lower ET and PET in 2010 compared to 2009 (see Figure 14). Precipitation is one of the driving factors of ET for non-irrigated land, so further study including precipitation is suggested for a better understanding of anomalies behind the variation of ET trend.

Conclusion

As a key component of the hydrological cycle, ET was analyzed using energy balance approach in this study. Net radiation and its components (latent, sensible and ground heat fluxes) were compared between the two study sites. From this comparison it was concluded that vegetation type controls the latent heat flux for that area. There will be higher moisture content in both land surface and atmospheric boundary layer for the area with fully vegetated land than there will be for land with bare soil surface. The higher the moisture content, the higher the latent heat flux, which results in higher ET.

As a residual component of net-radiation, latent heat flux was quantified by subtracting ground and sensible heat fluxes. The quantified latent heat flux was then used to estimate the ET losses from the surface.

Finally a historical trend analysis showed an interesting result of gradual increase in ET till 1995 and a decreasing trend after 1995. A deeper analysis including precipitation is required to understand the complex variability of ET.

Acknowledgements

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