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WATER LOSS TO THE ATMOSPHERE OVER THE TIBETAN PLATEAU BASED ON REMOTE SENSING EVAPOTRANSPIRATION DATASETS

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ABSTRACT

In the Tibetan Plateau (TP) region, the foreseeable increase in air temperature may have profound and complex effects on the local hydrological cycle, and is likely to increase water loss from the land surface to the atmosphere through evapotranspiration (ET). Quantifying ET and its regulatory mechanisms are major challenges for understanding the water cycle and land-atmosphere interactions in the TP region. We evaluated the performance of several Earth observation-based ET datasets in the TP region, and explored the spatiotemporal variation of ET in the same region. The accuracy of different global ET datasets was evaluated, and ETMonitor and PML-V2 provide the best accuracy with overall high correlation, low bias, and low root mean square error. ETMonitor ET is also the only product with both high spatial (~1 km) and temporal (daily) resolution. ETMonitor ET may reflect the effect of mountain topography on ET better than other global products, i.e., ET values are higher in the humid valleys with denser vegetation cover and higher soil moisture, and ET values are lower on the mountain slopes at higher elevations with less vegetation cover and colder climate. Other ET products failed to capture the spatial patterns of ET in the mountainous regions, and this suggests that the spatial resolution is not the only dominant factor leading to the poorer performance of these ET products in the mountain regions of the TP. The results show that multi-year average ET is 339 mm/yr in the TP region during 2000-2021, which accounts for about 51% of the total precipitation in the TP region. From 2000 to 2021, ET over the Tibetan Plateau shows an overall increasing trend with large spatial variability.

Index Terms— water loss, evapotranspiration, Tibetan Plateau, ETMonitor, Earth observation

1. INTRODUCTION

The last decade has seen an increasing interest for hydrological processes in cold and high elevation regions, e.g., Tibet Plateau, due to the global warming and its relevance to the downstream water resources issues. The grand challenge of hydrosphere science in high elevation regions is the scarcity and sparseness of data on the multiple variables and processes of relevance and the difficulty of carrying out experiments at the appropriate spatial and temporal scales [1]. Observations from space have the potential of providing observations of several key – variables on the terrestrial water cycle with the required temporal sampling and over extended periods of time.

The water loss variables include evapotranspiration and its components like plant transpiration, soil evaporation, open water evaporation, rainfall interception, and snow and ice sublimation. Accurate estimation of ET is critical for understanding the earth climate system and the complex heat/water exchange mechanisms between the land surface and the overlaying atmosphere. Large uncertainty remains in the magnitude and variations of ET modeling and products due to the complexity of processes involved in evapotranspiration. The satellite remote sensing is considered to be the most efficient way to obtain the spatial and temporal variation of ET from regional to global scales.

ET process over the TP also undergoes significant spatiotemporal variations, which may have important feedback to the climate system, especially the Asian monsoon [2]. The foreseeable increase in air temperatures due to global warming may have profound and complex impacts on the local water cycle and may likely increase water loss from the land surface to the atmosphere through ET. Quantifying ET in TP based on Earth observation datasets is great contribution for understanding the water cycle and land-atmosphere interactions in the TP region.

In this study, we aimed to evaluate the performance of different remote sensing-based ET datasets in the TP region and explore the spatiotemporal variation of ET in the TP region.

2. METHODOLOGY AND DATA

2.1. Remote sensing ET datasets

In this study, we collected 6 global ET datasets, including ET from ETMonitor [3], MOD16 [4], the Penman–Monteith–Leuning Version 2 (PML-V2) [5], the operational Simplified Surface Energy Balance (SSEBop) [6], GLASS [7] and SynthesisET [8]. Most of these ET datasets used the different variables or indices from Moderate Resolution Imaging Spectroradiometer (MODIS) as main inputs, and the latter two products (GLASS, SynthesisET) are ensemble ET products generated by fusing other ET models or datasets. These ET datasets were selected as the mainstream gridded ET products obtained by a variety of typical algorithms applied in TP or globally. All ET data was aggregrated to monthly for validation.

2.2. *in-situ* ET datasets

We collected *in-situ* measurements by the eddy-covariance method at 18 flux towers (Figure 1) to validate ET, including those sites from FLUXNET [9], the Tibetan Observation and Research Platform [10] and the Heihe Integrated Observatory Network [11]. The data quality of flux observation data at each site was evaluated after screening, and those data with poor quality were discarded. The quality of the observed data was carefully evaluated and controlled following previous studies [12]. The hourly LE data was corrected using Bowen ratio energy balance correction method, and was averaged to daily and monthly [13].

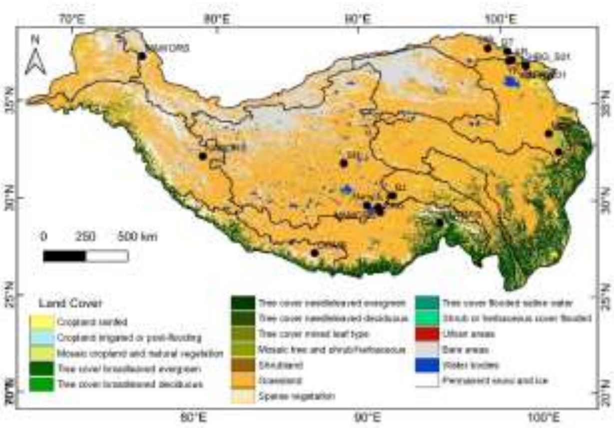

Figure 1. Location of the selected ground flux tower observation sites. The background land cover data is from ESA CCI.

2.2. Validation and analysis

When validating using ground observations, ET values from the pixels where the flux sites were located were directly extracted for comparison. To assess the performance of the ET products comprehensively, the Kling-Gupta efficiency (KGE) is adopted, which is a multi-objective statistical indicator incorporating the correlation, relative variability ratio and mean values ratio. KGE was calculated:

$$KGE = 1 - \sqrt{(R-1)^2 + (\frac{\mu(Y)}{\mu(X)} - 1)^2 + (\frac{\sigma(Y)}{\sigma(X)} - 1)^2}$$

where Y indicates the ET (mm/month) values of different products, X indicates the ground-truth ET (mm/month) values from *in-situ* observations, μ indicates the mean value, σ indicates the standard deviation. KGE is smaller than 1, and higher KGE means better agreement between the observed and the simulated results generally.

3. RESULTS AND DISCUSSIONS

3.1. ET validation

Figure 2 presents the ET validation results. It should be noticed that all the products have different temporal and spatial coverage, e.g., the MOD16 ET product does not provide data in non-vegetation covered pixels (hence no MOD16 ET data for sites of QOMS and NADORS), and the validation results are obtained primarily based on a different number of samples for different products.

Among all these global ET datasets, ETMonitor and PMLV2 ET achieved the highest accuracy with the highest KGE (>0.77), which was comparable with the regional ET product [2]. Most products showed better accuracy at the relative wet sites with dense vegetation (e.g., GT, HBG, ARS, CN-Ha2), judged by relative lower values of KGE, than at the relative dry sites with sparse vegetation or desert (e.g., QOMS, NADORS). The SSEBop products showed the lowest KGE for relative wet sites and desert sites, but showed good accuracy for some alpine steppe sites with sparse vegetation (e.g., SH, YK, NAMORS).

The ensemble ET datasets (GLASS and SynthesisET) do not show better accuracy than others, e.g., both with low KGE (both less than 0.6), which is most likely related to the ensembled data sources and algorithms.

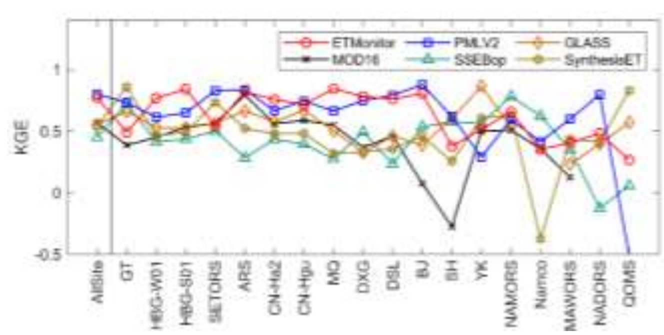

Figure 2. Validation results of ET products against *in-situ* measurements at the monthly scale.

3.2. Performance of ET datasets in the mountain regions

We also evaluated the spatial distribution of ET from different datasets in the mountain regions with complex topography in the southeastern TP (Figure 3). ETMonitor ET could better reflect the effect of mountain topography on ET, i.e., ET values are higher in the humid valleys with denser vegetation cover and higher soil moisture, and ET values are lower on mountain slopes of higher elevations with less vegetation cover and colder climate. The SSEBop ET product also provides clear spatial variation of ET, however with much lower ET values in the humid vegetation-covered regions in the mountain valley. All the other ET products failed to capture the spatial patterns of ET in the mountain regions, even though MOD16 and PML-V2 have higher spatial resolution (500-m). It suggests that the spatial resolution is not the only dominant factor leading to the poor performance of these ET products in the mountain regions of the TP.

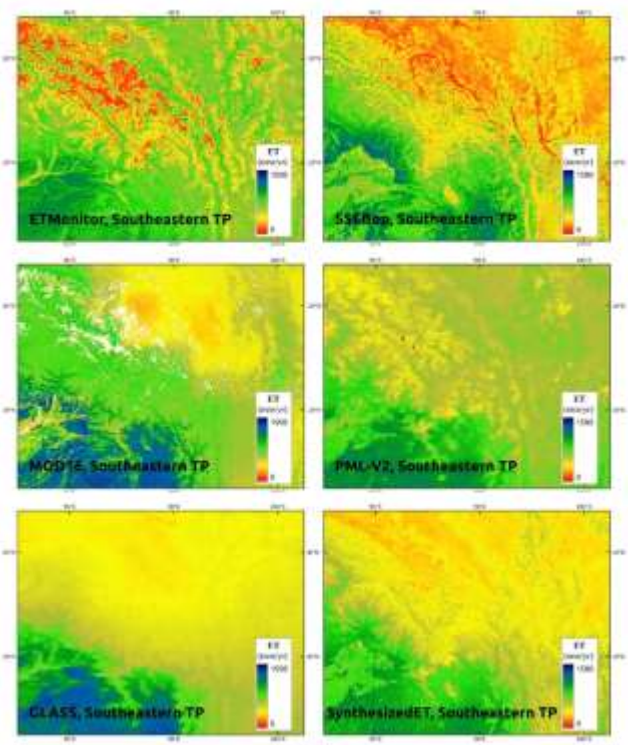

Figure 3. Spatial variation of ET from different datasets in the mountain regions

3.3. ET variation across the TP

Since we find ETMonitor ET could capture the expected ET patterns in the TP well. ETMonitor ET is then adopted to analyze the spatial and temporal trend of ET in the TP region.

Figure 4 presents the spatial variation of multi-year (2000~2020) averaged annual ET from ETMonitor dataset across TP. The results show the multi-year averaged ET is 339 mm/yr in the TP region, roughly accounting for 51% of the total precipitation in the TP region. The histogram of pixel-wise ET showed two peaks: the first peak corresponds to the low ET values of non-vegetation or sparse-vegetation covered regions in the middle and western TP; the second peak corresponds to the high ET values in eastern TP with dense vegetation and relatively humid climate.

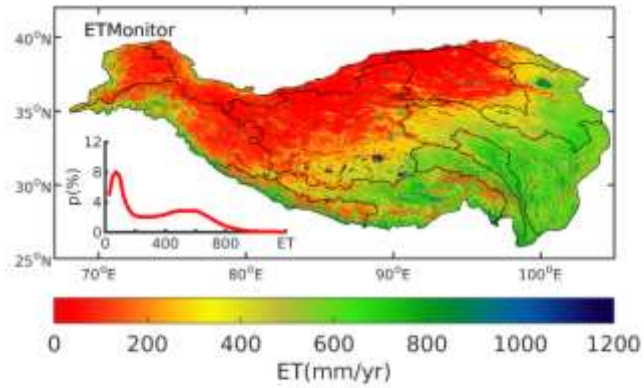

Figure 4. Spatial variation of ET in the Tibetan Plateau by ETMonitor

Figure 5 presents the yearly variation of ET across TP by ETMonitor products. From 2001 to 2020, ET over the Tibetan Plateau shows an increasing trend by an average rate of 0.78 mm/yr. This finding is similar with some previous studies which found ET in TP regions was undergoing an increasing trend since the 2000s, but with a different change magnitude.

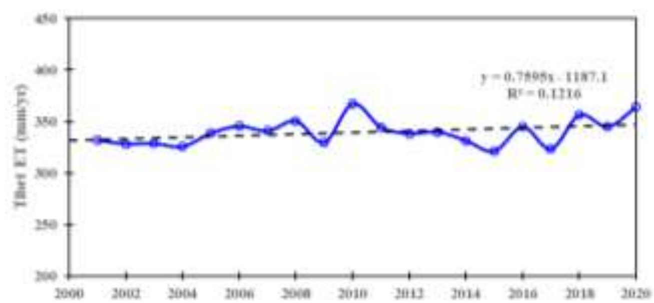

Figure 5. Temporal variation of ET across the Tibetan Plateau by ETMonitor

4. CONCLUSIONS

ET is an important process linking the land surface water and energy cycles. Accurate estimation of ET is critical for understanding the earth climate system and the complex heat/water exchange mechanisms between the land surface and the overlaying atmosphere. Currently, there are several remote sensing-based global ET datasets available for the study of ET characteristics in the TP. In this study, we aimed to evaluate the performance of different global remote sensing-based ET datasets in the TP region and explore the spatiotemporal variation of ET in the TP region

According to our evaluation, the remote sensing high-resolution ET data from ETMonitor showed the highest accuracy by comparing with the in-situ observations. ETMonitor also shows good performance to indicate the spatial variation of ET in the mountain regions with complex topography. The ET magnitude and variation were also analyzed.

5. ACKNOWLEDGEMENTS

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