Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2015-551, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 2 February 2016


Hydrology and Earth System Sciences
Open Access
Discussions

# Comparison of satellite based evapotranspiration estimates over the Tibetan Plateau

**Jian Peng[1*], Alexander Loew[1,5], Xuelong Chen[2], Yaoming Ma[3,4], Zhongbo Su[2]**

[1] Max Planck Institute for Meteorology, 20146 Hamburg, Germany;
[2] Faculty of Geo-Information Science and Earth Observation, University of Twente, Enschede 7500 AE, the Netherlands;
[3] Key Laboratory of Tibetan Environment Changes and Land Surface Processes, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100101, China;
[4] CAS Center for Excellence in Tibetan Plateau Earth Sciences, Chinese Academy of Sciences, Beijing 100101, China;
[5] Department of Geography, University of Munich (LMU), 80333 Munich, Germany
*Corresponding author: Tel: +49-(0)-89-2180-6515; Fax: +49-(0)-40-41173-350.
E-mail addresses: jian.peng@mpimet.mpg.de

## Abstract

The Tibetan Plateau (TP) plays a major role in regional and global climate. Land-atmosphere interactions are largely influenced by surface latent heat fluxes through evapotranspiration. Despite its importance, accurate estimation of ET over the TP remains challenging, due to its unique and special geographical position and physical environment. Satellite observations allow for ET estimation at high temporal and spatial scales. The purpose of this paper is to provide a detailed cross comparison of existing ET products over the TP. Six available ET products based on different approaches and using different forcing data are included for comparison. Results show that all products capture well the seasonal variability with minimum ET in the summer and maximum ET in the winter. Regarding the spatial pattern, the High Resolution Land Surface Parameters from Space (HOLAPS) ET demonstrator dataset is very similar to the LandFlux-EVAL dataset (a benchmark ET product from the Global Energy and Water Cycle Experiment), with ET decreases from the southeast to northwest over the TP. Further comparison against the LandFlux-EVAL over four sub-regions reveals that HOLAPS agrees best with LandFlux-EVAL having the highest correlation coefficient (R) and lowest Root Mean Square Difference (RMSD). These results indicate the potential for the application of the HOLAPS demonstrator dataset in understanding the and-atmosphere-biosphere interactions over the TP.

**Keywords**: HOLAPS; Tibetan Plateau; Evapotranspiration; Latent heat flux; Water fluxes; Land-atmosphere interactions

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2015-551, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 2 February 2016


## 1. Introduction

Evapotranspiration (ET) is an essential nexus of energy and water cycles through the mass and energy interactions between land and atmosphere (Jung et al., 2010; Peng et al., 2013). In recent years, the estimation of the global distribution of ET has been advanced by several studies generating novel ET data products (Fisher et al., 2008; Jung et al., 2009; Miralles et al., 2011; Miralles et al., 2015). However, the spatial and temporal resolution of these products are normally around one degree in space and monthly means in time, which are still quite coarse for regional studies (Jiménez et al., 2011; Mueller et al., 2011). To address these limitations, Loew et al. (2015) introduced a new framework called HOLAPS (High resOlution Land Atmosphere surface Parameters from Space), which allows for the estimation of land surface energy and water fluxes at sub-hourly timescales and spatial resolutions at the kilometer scale. HOLAPS is currently the only approach that provides surface energy and water fluxes at comparably high spatial and temporal resolutions. It therefore allows resolving much more spatial and temporal details of land-atmosphere interactions than other existing ET data products. In addition, excellent performance of HOLAPS was found when validated against global FLUXNET observations, with Root Mean Square Difference (RMSD) of 53.0 (35.1) W/m² for hourly (daily) latent heat flux (Loew et al., 2015). Note that the energy equivalent for ET is referred as latent heat flux (LE), which is used interchangeable with ET in this paper.

The Tibetan Plateau (TP), known as the third pole of the Earth (Qiu, 2008), is the highest and largest plateau in the world, with very complex terrain and an average elevation higher than 4000 m above sea level (asl) (Figure 1) (Frauenfeld et al., 2005; Ma et al., 2008). Due to its unique and special geographical position and physical environment, the TP has profound thermal and dynamical impacts on atmospheric circulation over China, the whole East Asia and even the entire globe (Cui and Graf, 2009; You et al., 2014). Quantitative estimation of the energy and water cycles over the TP is of great significance for the study of land-atmosphere-biosphere interactions (Sellers et al., 1997; Yang et al., 2014). In order to characterize the distribution of ET over the TP, different methods using micrometeorological measurements or remote sensing products have been investigated over the last decades (Chen et al., 2013; Ma et al., 2014; Zhang et al., 2007). However, accurate estimation of ET over TP is still a challenge due to the limited in situ observations, coarse temporal and spatial resolution of remote sensing products, and complicated topography of the TP (Shi and Liang, 2013).

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2015-551, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 2 February 2016


Hydrology and Earth System Sciences
Discussions
Open Access

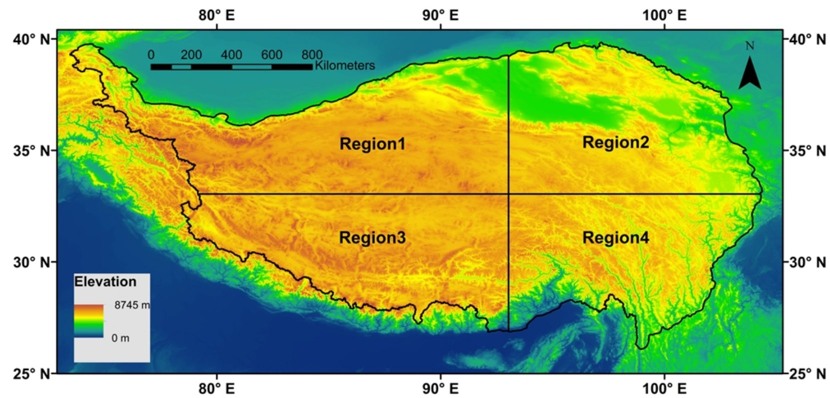


Figure 1: Map of the location and topography of the Tibetan Plateau, and four sub-regions used in this study.

The existing global ET products especially HOLAPS are great potential datasets that can be used in hydrological studies over the TP. Although these global ET products have been validated against FLUXNET measurements, the spatial and temporal patterns of them over the TP are still unknown. Therefore, the main objective of this study is to provide a detailed cross comparison of the different existing ET products over the TP.

## 2. Data and methods

The WACMOS-ET project has recently evaluated several evaporation retrieval algorithms driven by the same forcing dataset at both local and global scales (Michel et al., 2015; Miralles et al., 2015). These algorithms include the Penman-Monteith (PM) algorithm, the Priestley-Taylor (PT) model and the Surface Energy Balance System (SEBS). These three process-based models are widely used for the estimation of ET and are based on different assumptions and parameterizations. The WACMOS-ET project found that the Priestley-Taylor based products performed best among other algorithms over most ecosystems and climate regimes (Michel et al., 2015). Similar to their study, three LE datasets driven by same forcing data are evaluated over the TP. These datasets are $SEBS_{SRB\text{-}PU}$, $PT_{SRB\text{-}PU}$ and $PM_{SRB\text{-}PU}$, which are respectively based on PM, PT, and SEBS algorithms but driven by the same input radiation from Surface Radiation Budget (SRB) and meteorological forcing datasets from Princeton University (PU) (Vinukollu et al., 2011). In addition, to investigate the impact of forcing data on the estimation of LE, another recent released SEBS dataset ($SEBS_{Chen}$) is also included in this study (Chen et al., 2014). Different from $SEBS_{SRB\text{-}PU}$, $SEBS_{Chen}$ is driven by the meteorological forcing data obtained from the Institute of Tibetan Plateau Research, Chinese Academy of Sciences (ITP, CAS).

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2015-551, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 2 February 2016


The HOLAPS LE demonstrator dataset is estimated with the HOLAPS framework, which makes use of meteorological drivers coming exclusively from globally available satellite and re-analysis datasets and is based on a state-of-the-art land surface scheme (Loew et al., 2015). HOLAPS can ensure internal consistency of the different energy and water fluxes and provide estimates at high temporal (< 1h) and spatial (~5 km) resolutions. Good agreement with in situ measurements have also been found by Loew et al. (2015) when compared against 49 FLUXNET stations worldwide. The details of the HOLAPS framework and relevant evaluation results can be found in (Loew et al., 2015).

Since there are no reliable in-situ measurements available over the TP for the current study period, the above LE datasets are cross-compared with LandFlux-EVAL benchmark product in the current analysis. LandFlux-EVAL is a merged synthesis LE product based on a total of 14 datasets including land surface model output, observations-based estimates, and atmospheric reanalyses (Mueller et al., 2013). It should be noted here that LandFlux-EVAL also includes satellite-based LE datasets that are estimated from PM and PT algorithms. However, the $PM_{SRB\text{-}PU}$ and $PT_{SRB\text{-}PU}$ datasets used in the current analysis are different from those datasets. They are based on revised PM and PT approaches, which also account for the evaporation from canopy intercepted precipitation (Vinukollu et al., 2011). In addition, the forcing datasets used for $PM_{SRB\text{-}PU}$ and $PT_{SRB\text{-}PU}$ are also different from that used for PM and PT datasets in LandFlux-EVAL. For example, the radiation used for the $PM_{SRB\text{-}PU}$ is from SRB, while PM dataset from LandFlux-EVAL uses radiation from International Satellite Cloud Climatology Project (ISCCP). A summary of these datasets is given in Table 1. For a detailed information about each product, the reader is referred to the relevant publications.

Table 1: Summary of the datasets used in our study.

| Dataset | ET scheme | Spatial resolution | Temporal resolution | Reference |
|---|---|---|---|---|
| $PM_{SRB\text{-}PU}$ | Penman-Monteith | 1° | daily | *(Vinukollu et al., 2011)* |
| $PT_{SRB\text{-}PU}$ | Priestley-Taylor | 1° | daily | *(Vinukollu et al., 2011)* |
| $SEBS_{SRB\text{-}PU}$ | SEBS | 1° | daily | *(Vinukollu et al., 2011)* |
| $SEBS_{Chen}$ | SEBS | 0.1° | daily | *(Chen et al., 2014)* |
| HOLAPS | Priestley-Taylor | 5 km | half hourly | *(Loew et al., 2015)* |
| LandFlux-EVAL | Synthesis product | 1° | monthly | *(Mueller et al., 2013)* |

In order to compare the accuracy of these LE products, all of them are firstly aggregated to monthly mean values over the common time period 2001 -2005 which corresponds to the time period currently covered by the HOLAPS demonstrator dataset (Loew et al., 2015). Then the spatial and temporal variation of different LE products are compared and analyzed over the whole TP. The performance of different LE products is also evaluated against the LandFlux-EVAL benchmark product over

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2015-551, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 2 February 2016

Hydrology and Earth System Sciences
Discussions

the whole TP and four sub-regions (see Figure 1).

# 3 Results and discussion

## *3.1 Spatial and temporal variability of different LE products*

Figure 2 displays the spatial pattern of annual mean values for different LE datasets. Although these LE products have been reported performing well against FLUXNET measurements at point scale, they exhibit differently in terms of spatial pattern over the TP. The differences between $SEBS_{SRB\text{-}PU}$, $PT_{SRB\text{-}PU}$ and $PM_{SRB\text{-}PU}$ are attributed to the differences of the models. But also for the same model, different forcing data lead to different results ($SEBS_{SRB\text{-}PU}$ and $SEBS_{Chen}$). These results suggest that model and forcing are equally critical for the estimation of ET (Vinukollu et al., 2011). Overall, the HOLAPS dataset is found to have good agreement with the benchmark product (LandFlux-EVAL) with similar spatial pattern of LE. The LE decreases from the southeast to northwest over the TP, which also corresponds well with the variation of elevation. The Figure 3 further shows the annual mean spatial patterns of 25th-percentile and 75th-percentile of the LandFlux-EVAL multi-datasets ensemble. It can be seen that HOLAPS is within the range of different independent LE products. In addition to the spatial comparisons of annual average values, the time evolution of all datasets is also explored to test their self-consistency. Figure 4 presents the time series of the area mean LE for different LE datasets, and the inter-quartile range between 25th-percentile and 75th-percentile of the LandFlux-EVAL ensemble. In general, all products capture well the seasonal variability with minimum LE in the summer and maximum LE in the winter. However, the mean values of different LE products differ substantially. There is a spread of about 35 $W/m^2$ at the annual cycle peak. Compared with the other products, the HOLAPS seems to be closer to the LandFlux-EVAL benchmarking product. The $SEBS_{SRB\text{-}PU}$ and $SEBS_{Chen}$ seem to be more distinctive with LE from most months outside the inter-quartile of LandFlux-EVAL ensemble. However, when compared to the climatology calculated from flux tower measurements around the TP the SEBS estimates seem to be close to the flux tower measurements (Chen, 2011). Typical monthly mean LE fluxes over summer time typically range between 80 $W/m^2$ and 100 $W/m^2$ (Chen, 2011), while the LandFluxEval estimates range between 60 $W/m^2$ and 80 $W/m^2$. In the next section, the performance of each product will be further discussed based on the comparison results against the LandFlux-EVAL benchmark product.

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2015-551, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 2 February 2016

Hydrology and Earth System Sciences
Discussions
Open Access

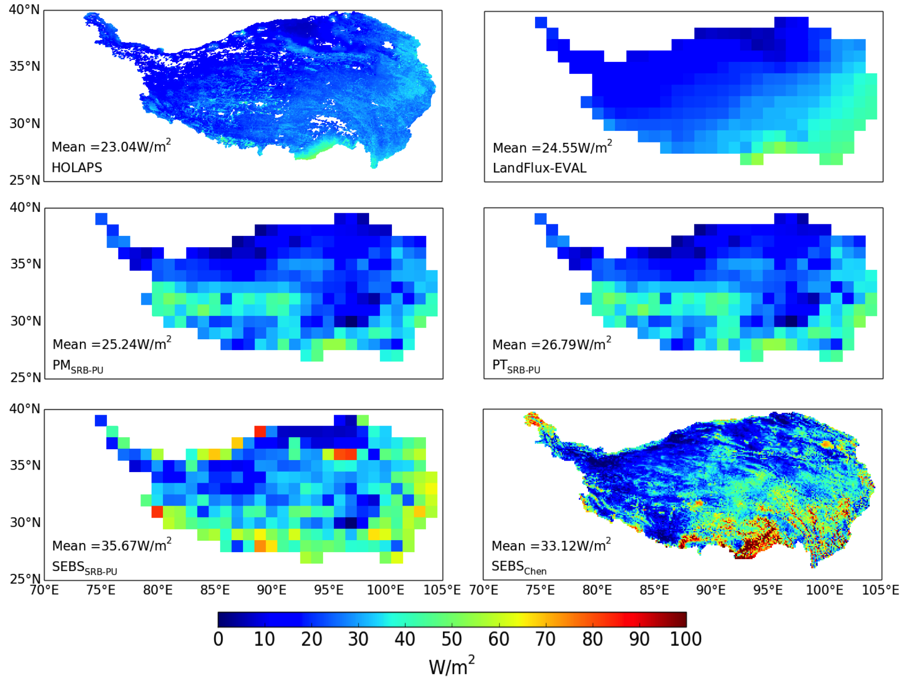


Figure 2: Spatial distribution of annual mean LE for each dataset over the TP.

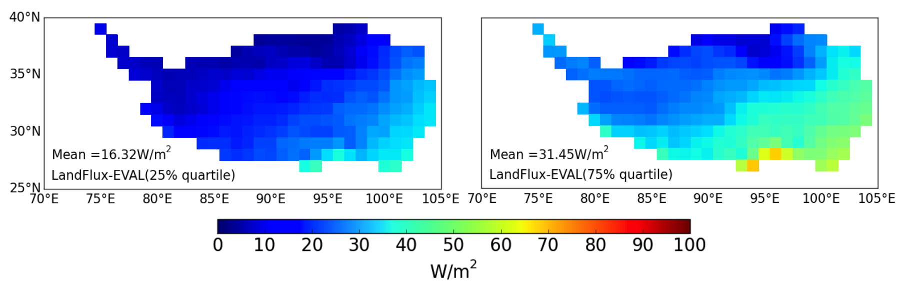


Figure 3: The annual mean spatial patterns of 25th-percentile and 75th-percentile of the LandFlux-EVAL multi-datasets ensemble.

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2015-551, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 2 February 2016

Hydrology and Earth System Sciences
Discussions
Open Access

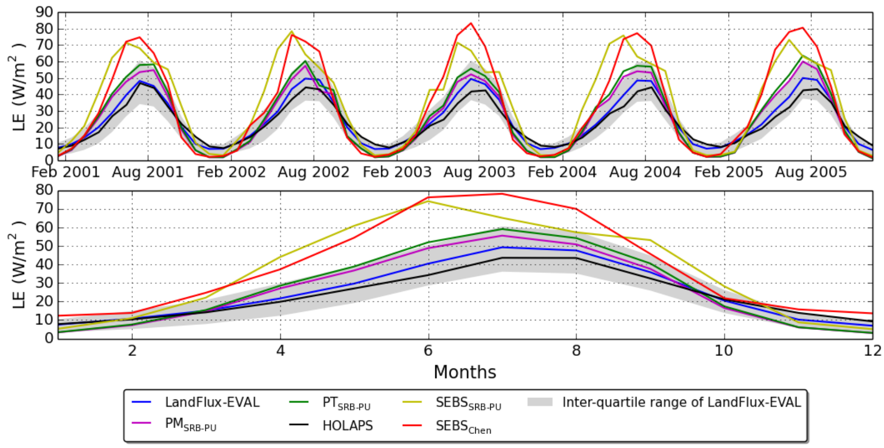


Figure 4: Temporal variability of the area averaged LE for each dataset over the TP. The grey shadow displays the inter-quartile range between 25th-percentile and 75th-percentile of the LandFlux-EVAL multi-datasets ensemble.

### *3.2 Comparison of LE datasets against LandFlux-EVAL benchmark product*

Figure 5 presents the monthly mean scatter plots of LE between the LandFlux-EVAL benchmark product and other products for four sub-regions. The detailed statistics are listed in Table 2. It can be seen that the model performance varies among different LE products with statistical indices values ranging from 0.81 to 0.99 for correlation coefficient (R), and from 2.75 to 26.73 W/m$^2$ for RMSD for all sub-regions. Overall, the HOLAPS appears to yield the closest agreement with the LandFlux-EVAL benchmark product, with R higher than 0.98 and RMSD less than 12.46 W/m$^2$. The relatively poorer performance of the HOLAPS for region 4 explains the slight underestimation of LE when compared with the benchmark dataset (Figure 4). Similarly, the PT$_{SRB-PU}$ and PM$_{SRB-PU}$ also present a lower estimate of LE in region 4 compared to the benchmark dataset. However, the products based on SEBS perform better than in other regions. The possible underlying reasons for these biases are related to the uncertainties of the models and the forcing data. Quantification and reduction of these uncertainties are required in the future studies. Our results suggest that the HOLAPS provides a unique high resolution LE product and thereby can contribute to a better understanding of the water and energy cycles over the TP.

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2015-551, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 2 February 2016




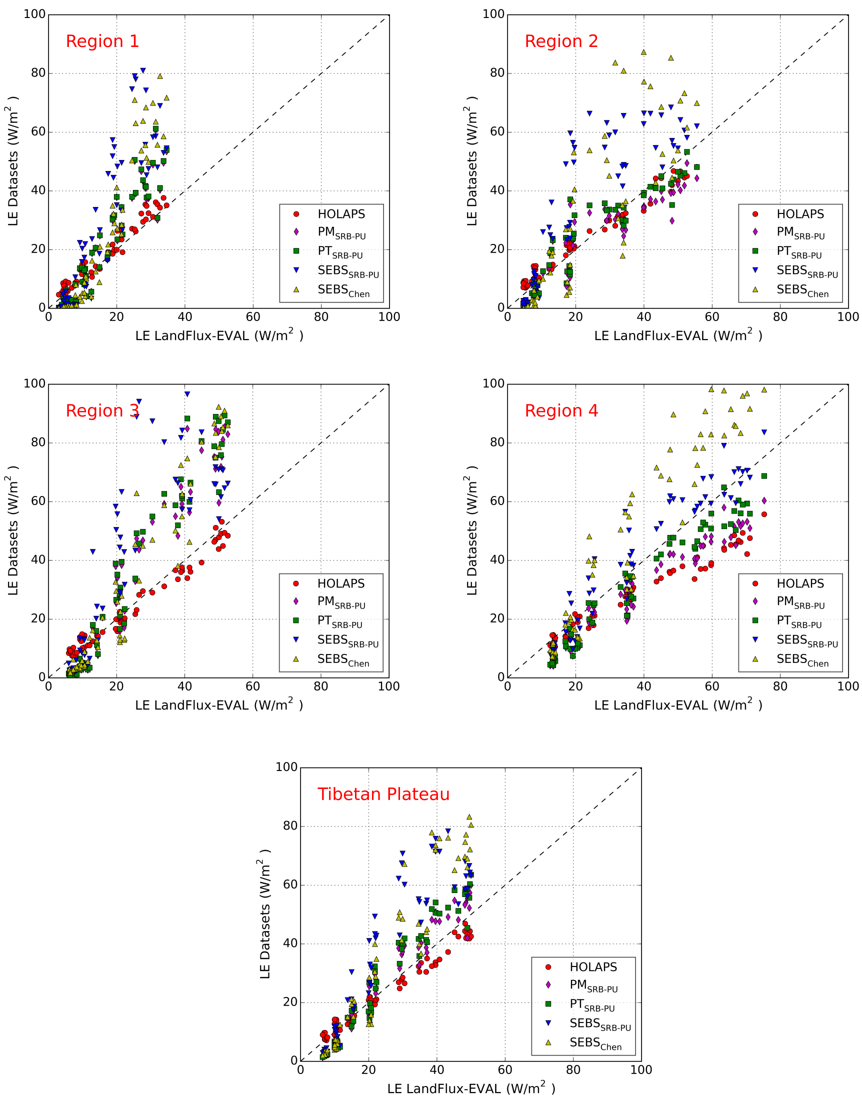


Figure 5: The monthly mean scatter plots of LE between the LandFlux-EVAL benchmark product and other products over the whole TP and its sub-regions.

Table 2. Statistics of the LE comparisons between the LandFlux-EVAL benchmark product and other products over the whole TP and its sub-regions.

| | HOLAPS | | PM$_{SRB-PU}$ | | PT$_{SRB-PU}$ | | SEBS$_{SRB-PU}$ | | SEBS$_{Chen}$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | R | RMSD (W/m$^2$) | R | RMSD (W/m$^2$) | R | RMSD (W/m$^2$) | R | RMSD (W/m$^2$) | R | RMSD (W/m$^2$) |
| Region1 | 0.98 | 2.75 | 0.95 | 9.68 | 0.95 | 9.91 | 0.9 | 21.5 | 0.96 | 17.71 |
| Region2 | 0.99 | 3.96 | 0.93 | 6.48 | 0.94 | 5.57 | 0.86 | 17.58 | 0.86 | 17.8 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Region3 | 0.99 | 2.94 | 0.97 | 17.07 | 0.97 | 19.06 | 0.81 | 26.73 | 0.97 | 18.97 |
| Region4 | 0.98 | 12.46 | 0.98 | 10.91 | 0.98 | 8.07 | 0.96 | 7.3 | 0.96 | 18.48 |
| Tibetan Plateau | 0.99 | 3.46 | 0.98 | 5.66 | 0.98 | 7.05 | 0.92 | 17.2 | 0.96 | 16.67 |

## 4 Conclusions

This study provides a comprehensive intercomparison of existing LE products over the TP for the period 2001-2005. Comparing the HOLAPS LE to the LandFlux-EVAL benchmark product, similarities can be found regarding the spatial patterns with increased LE from northwest to southeast. The other LE products ($SEBS_{SRB\text{-}PU}$, $SEBS_{Chen}$, $PT_{SRB\text{-}PU}$ and $PM_{SRB\text{-}PU}$) display different spatial patterns, which indicates the equal importance of model structure and forcing data. Nevertheless, all products capture well the seasonal variability with maximum LE in the summer and minimum LE in the winter. Further comparison against LandFlux-EVAL benchmark dataset over the four sub-regions and whole TP reveals that the HOLAPS LE product has the best performance with highest R and lowest RMSD. However it needs to be emphasized that this study only could provide a cross-comparison of the different datasets. Further, more comprehensive validation of these satellite datasets against flux tower measurements is required to evaluate the actual accuracies of the different products. This will be investigated in further studies.

## Acknowledgements

This study uses the LandFlux-EVAL merged benchmark synthesis products of ETH Zurich produced under the aegis of the GEWEX and ILEAPS projects. The $SEBS_{SRB\text{-}PU}$, $PT_{SRB\text{-}PU}$ and $PM_{SRB\text{-}PU}$ LE products were obtained from the Princeton University Terrestrial Hydrology Research Group. This research was supported by the Cluster of Excellence CliSAP (EXC177), University of Hamburg, funded through the German Science Foundation (DFG), and the MPG-CAS postdoc fellowship. In addition, the authors would like to thank Stefan Hagemann for reviewing the first version of the manuscript.

## References

Chen, X.: Observations analysis of energy exchange between the land surface and atmosphere and its application to parameterization method over the Tibetan Plateau, PhD, Institute of Tibetan Plateau Research, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, 2011.

Chen, X., Su, Z., Ma, Y., Yang, K., and Wang, B.: Estimation of surface energy fluxes under complex terrain of Mt. Qomolangma over the Tibetan Plateau, Hydrology and Earth System Sciences, 17,

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2015-551, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 2 February 2016


Hydrology and Earth System Sciences
Open Access
Discussions

1607-1618, 2013.

Chen, X., Su, Z., Ma, Y., Liu, S., Yu, Q., and Xu, Z.: Development of a 10-year (2001–2010) 0.1° data set of land-surface energy balance for mainland China, Atmospheric Chemistry and Physics, 14, 13097-13117, 2014.

Cui, X., and Graf, H.-F.: Recent land cover changes on the Tibetan Plateau: a review, Climatic Change, 94, 47-61, 2009.

Fisher, J. B., Tu, K. P., and Baldocchi, D. D.: Global estimates of the land–atmosphere water flux based on monthly AVHRR and ISLSCP-II data, validated at 16 FLUXNET sites, Remote Sensing of Environment, 112, 901-919, 2008.

Frauenfeld, O. W., Zhang, T., and Serreze, M. C.: Climate change and variability using European Centre for Medium-Range Weather Forecasts reanalysis (ERA-40) temperatures on the Tibetan Plateau, Journal of Geophysical Research: Atmospheres, 110, D02101, 2005.

Jiménez, C., Prigent, C., Mueller, B., Seneviratne, S. I., McCabe, M. F., Wood, E. F., Rossow, W. B., Balsamo, G., Betts, A. K., Dirmeyer, P. A., Fisher, J. B., Jung, M., Kanamitsu, M., Reichle, R. H., Reichstein, M., Rodell, M., Sheffield, J., Tu, K., and Wang, K.: Global intercomparison of 12 land surface heat flux estimates, Journal of Geophysical Research: Atmospheres, 116, D02102, 2011.

Jung, M., Reichstein, M., and Bondeau, A.: Towards global empirical upscaling of FLUXNET eddy covariance observations: validation of a model tree ensemble approach using a biosphere model, Biogeosciences, 6, 2001-2013, 2009.

Jung, M., Reichstein, M., Ciais, P., Seneviratne, S. I., Sheffield, J., Goulden, M. L., Bonan, G., Cescatti, A., Chen, J., de Jeu, R., Dolman, A. J., Eugster, W., Gerten, D., Gianelle, D., Gobron, N., Heinke, J., Kimball, J., Law, B. E., Montagnani, L., Mu, Q., Mueller, B., Oleson, K., Papale, D., Richardson, A. D., Roupsard, O., Running, S., Tomelleri, E., Viovy, N., Weber, U., Williams, C., Wood, E., Zaehle, S., and Zhang, K.: Recent decline in the global land evapotranspiration trend due to limited moisture supply, Nature, 467, 951-954, 2010.

Loew, A., Peng, J., and Borsche, M.: High resolution land surface fluxes from satellite data (HOLAPS v1.0): evaluation and uncertainty assessment, Geoscientific Model Development Discussions, 8, 10783-10841, 2015.

Ma, Y., Kang, S., Zhu, L., Xu, B., Tian, L., and Yao, T.: ROOF OF THE WORLD: Tibetan Observation and Research Platform, Bulletin of the American Meteorological Society, 89, 1487-1492, 2008.

Ma, Y., Zhu, Z., Zhong, L., Wang, B., Han, C., Wang, Z., Wang, Y., Lu, L., Amatya, P. M., Ma, W., and Hu, Z.: Combining MODIS, AVHRR and in situ data for evapotranspiration estimation over heterogeneous landscape of the Tibetan Plateau, Atmospheric Chemistry and Physics, 14, 1507-1515, 2014.

Michel, D., Jiménez, C., Miralles, D. G., Jung, M., Hirschi, M., Ershadi, A., Martens, B., McCabe, M.

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2015-551, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 2 February 2016


Hydrology and Earth System Sciences
Open Access
Discussions

F., Fisher, J. B., Mu, Q., Seneviratne, S. I., Wood, E. F., and Fernández-Prieto, D.: The WACMOS-ET project – Part 1: Tower-scale evaluation of four remote sensing-based evapotranspiration algorithms, Hydrology and Earth System Sciences Discussions, 12, 10739-10787, 2015.

Miralles, D. G., Holmes, T. R. H., De Jeu, R. A. M., Gash, J. H., Meesters, A. G. C. A., and Dolman, A. J.: Global land-surface evaporation estimated from satellite-based observations, Hydrology and Earth System Sciences, 15, 453-469, 2011.

Miralles, D. G., Jiménez, C., Jung, M., Michel, D., Ershadi, A., McCabe, M. F., Hirschi, M., Martens, B., Dolman, A. J., Fisher, J. B., Mu, Q., Seneviratne, S. I., Wood, E. F., and Fernaìndez-Prieto, D.: The WACMOS-ET project – Part 2: Evaluation of global terrestrial evaporation data sets, Hydrology and Earth System Sciences Discussions, 12, 10651-10700, 2015.

Mueller, B., Seneviratne, S. I., Jimenez, C., Corti, T., Hirschi, M., Balsamo, G., Ciais, P., Dirmeyer, P., Fisher, J. B., Guo, Z., Jung, M., Maignan, F., McCabe, M. F., Reichle, R., Reichstein, M., Rodell, M., Sheffield, J., Teuling, A. J., Wang, K., Wood, E. F., and Zhang, Y.: Evaluation of global observations-based evapotranspiration datasets and IPCC AR4 simulations, Geophysical Research Letters, 38, L06402, 2011.

Mueller, B., Hirschi, M., Jimenez, C., Ciais, P., Dirmeyer, P. A., Dolman, A. J., Fisher, J. B., Jung, M., Ludwig, F., Maignan, F., Miralles, D. G., McCabe, M. F., Reichstein, M., Sheffield, J., Wang, K., Wood, E. F., Zhang, Y., and Seneviratne, S. I.: Benchmark products for land evapotranspiration: LandFlux-EVAL multi-data set synthesis, Hydrology and Earth System Sciences, 17, 3707-3720, 2013.

Peng, J., Liu, Y., Zhao, X., and Loew, A.: Estimation of evapotranspiration from MODIS TOA radiances in the Poyang Lake basin, China, Hydrology and Earth System Sciences, 17, 1431-1444, 2013.

Qiu, J.: China: the third pole, Nature News, 454, 393-396, 2008.

Sellers, P., Dickinson, R., Randall, D., Betts, A., Hall, F., Berry, J., Collatz, G., Denning, A., Mooney, H., and Nobre, C.: Modeling the exchanges of energy, water, and carbon between continents and the atmosphere, Science, 275, 502-509, 1997.

Shi, Q., and Liang, S.: Characterizing the surface radiation budget over the Tibetan Plateau with ground-measured, reanalysis, and remote sensing data sets: 1. Methodology, Journal of Geophysical Research: Atmospheres, 118, 9642-9657, 2013.

Vinukollu, R. K., Meynadier, R., Sheffield, J., and Wood, E. F.: Multi-model, multi-sensor estimates of global evapotranspiration: climatology, uncertainties and trends, Hydrological Processes, 25, 3993-4010, 2011.

Yang, K., Wu, H., Qin, J., Lin, C., Tang, W., and Chen, Y.: Recent climate changes over the Tibetan Plateau and their impacts on energy and water cycle: A review, Global and Planetary Change, 112, 79-91, 2014.

Hydrol. Earth Syst. Sci. Discuss., doi:10.5194/hess-2015-551, 2016
Manuscript under review for journal Hydrol. Earth Syst. Sci.
Published: 2 February 2016


Hydrology and Earth System Sciences
Open Access
Discussions

You, Q., Fraedrich, K., Min, J., Kang, S., Zhu, X., Pepin, N., and Zhang, L.: Observed surface wind speed in the Tibetan Plateau since 1980 and its physical causes, International Journal of Climatology, 34, 1873-1882, 2014.

Zhang, Y., Liu, C., Tang, Y., and Yang, Y.: Trends in pan evaporation and reference and actual evapotranspiration across the Tibetan Plateau, Journal of Geophysical Research: Atmospheres, 112, D12110, 2007.