Reply to interactive comments on "Estimation of Hourly Land Surface Heat Fluxes over the Tibetan Plateau by the Combined Use of Geostationary and Polar Orbiting Satellites" by Lei Zhong et al.

Anonymous Reviewer #4

High temporal resolution surface heat fluxes are very important for land-atmosphere interactions. In this manuscript, land surface temperature from polar and geostationary satellite are both used and fed into surface energy balance equation. The results are validated with flux tower observations, and finally hourly surface heat fluxes with 5 km spatial resolution are generated over TP based on the developed SEB scheme. Generally, the manuscript is interesting and well written. It can be published with minor revisions.

Author Response: We would like to sincerely thank the reviewer for the thoughtful comments and suggestions. Please see our responses to your comments and suggestions below.

(1) Page 2, Line 30: I think the authors missed an important kind of method (data assimilation method) for surface heat flux estimations based on remotely sensed LST. Some reference are as follows,

Abdolghafoorian, A., Farhadi, L., Bateni, S.M., Margulis, S., Xu, T.R. (2017). Characterizing the effect of vegetation dynamics on the bulk heat transfer coefficient to improve variational estimation of surface turbulent fluxes. J. Hydrometeorol. 18, 321–333.

Bateni, S.M., Entekhabi, D., & Castelli, F. (2013), Mapping evaporation and estimation of surface control of evaporation using remotely sensed land surface temperature from a constellation of satellites, Water Resour. Res., 49, 950-968, doi:10.1002/wrcr.20071.

Crow, W.T., & Kustas, W.P. (2005). Utility of assimilating surface radiometric temperature observations for evaporative fraction and heat transfer coefficient retrieval, Bound-Lay. Meteorol., 115(1), 105-130, doi:10.1007/s10546-004-2121-0.

Xu, T, Bateni, S.M., Liang, S., Entekhabi, D., & Mao, K. (2014). Estimation of surface turbulent heat fluxes via variational assimilation of sequences of land

surface temperatures from Geostationary Operational Environmental Satellites, J. Geophys. Res., 119, 10,780-10,798, doi:10.1002/2014JD021814.

Xu, T.R., He, X.L., Bateni, S.M., Auligne, T., Liu, S.M., Xu, Z.W., Zhou, J., Mao, K.B.(2019). Mapping Regional Turbulent Heat Fluxes via Variational Assimilation of Land Surface Temperature Data from Polar Orbiting Satellites, Remote Sensing of Environment, 221, 444-461, https://doi.org/10.1016/j.rse.2018.11.023.

Author Response: Thank you for your helpful suggestion. We totally agree with you. Land surface temperature and vegetation information from satellites have been used to estimate regional land surface heat fluxes by different assimilation techniques in recent years. All the above references together with the following comments have been added to the revised manuscript. (P3, L9-15)

In recent years, land surface temperature and vegetation index data retrieved from satellites have been successfully assimilated in the variational data assimilation (VDA) frameworks to estimate surface heat fluxes (Crow and Kustas 2005; Bateni et al., 2013; Xu et al., 2014; Abdolghafoorian et al., 2017; Xu et al., 2019). This kind of method does not require any empirical or site-specific relationships and can provide temporally continuous surface heat flux estimates from discrete spaceborne land surface temperature (LST) observations (Xu et al., 2014).

(2) How to derive 5 km and hourly surface heat fluxes with 10 km and 3 hour forcing data?

Author Response: The final resolution of our product should be determined by the lowest resolution of the source data. Thus, the final surface heat flux product should be 10 km. We corrected this mistake in the manuscript after the quick review by one of the reviewers.

It should also be noted that the forcing dataset of ITPCAS has a spatial resolution of 10 km and a temporal resolution of 3 hours. For the temporal resolution, a linear statistical downscaling method was used to derive hourly meteorological forcing data based on the original 3-hour forcing data and in situ measurements in this study. The general idea is to establish an empirical relationship between each 3-hour measurement. Then, this relationship is applied to meteorological forcing data (P5, L17-21). For example, T_{a00}, T_{a01} and T_{a03} represent the in situ air temperature measurements from six stations at 00 h, 01 h and 03 h, respectively. Thus, $T_{a00} = [a_1, a_2, a_3, a_4, a_5, a_6]$, $T_{a01} = [b_1, b_2, b_3, b_4, b_5, b_6]$, and $T_{a03} = [c_1, c_2, c_3, c_4, c_5, c_6]$, Then, the linear equation $T_{a01} = k_1 T_{a00} + k_2 T_{a03}$ can be solved. According to the meteorological forcing data at 00h and 03h, the plateau scale T_a at 01h can be achieved by the following formula.

$$\begin{pmatrix} b_{11} & \cdots & b_{1n} \\ \vdots & \ddots & \vdots \\ b_{m1} & \cdots & b_{mn} \end{pmatrix} = k_1 \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{pmatrix} + k_2 \begin{pmatrix} c_{11} & \cdots & c_{1n} \\ \vdots & \ddots & \vdots \\ c_{m1} & \cdots & c_{mn} \end{pmatrix}$$

where a, b and c represent meteorological forcing data at 00 h, 01 h and 03 h, respectively; and m and n represent total rows and columns, respectively, of the grid data. The meteorological forcing data at other times can be similarly determined.

(3) In equation 5, sensible heat flux is represented as Hs, while it is H in equation 11. They should be the same in one manuscript.

Author Response: This item has been corrected to keep the same format. (P7)

(4) What is the time period of this study? as well as validation results in Table 3.

Author Response: The time period for all meteorological data and satellite data covers the whole year of 2008. This information has been added in section 2. (P5, L9-10)

(5) Figure2: the 'ITPCAS' is a name of institute, not data. It should be changed into 'Meteorological data' or something else.

Author Response: 'ITPCAS' in Figure 2 has been replaced with 'Meteorological forcing data'. (P20)

(6) Figure 3: the estimated G0 has a big bias against ground measurements. This is because G0 is parameterized with Rn. G0 and Rn do not have the same diurnal variation shape. The G0 peak values are usually later than Rn. However, the parameterization did not consider this. The authors may discuss this in the manuscript.

Author Response: Thank you for this insightful comment. We discuss the large bias in estimated soil heat flux as follows. (P8, L7-12)

It should be noted that some bias exists between the estimated soil heat flux and ground measurements because soil heat flux is parameterized with net radiation flux (equation (8)). However, soil heat flux and net radiation flux do not have the same diurnal variation shape. The soil heat flux peak values are usually later than the net radiation flux peak values, which was not taken into account in the parameterization. Thus, development of a better parameterization scheme for soil heat flux is needed.

(7) Figure 4: usually, the observations were drawn by open cycles, and estimations are drawn by solid lines.

Author Response: Figure 4 (now Figure 5) has been redrawn according to your suggestion. (P23)

(8) Why Rn is underestimated from June to Aug. at BJ site in figure 4? Why H (LE) is underestimated (overestimated) from Jan. to May? The authors should give some explanations.

Author Response: As shown by the surface radiation balance equation (equation (6)), the downward short radiation is the main incoming energy. A comparison was made between the forcing data and in situ downward radiation at BJ station. From June to August, the monthly diurnal MB was -4.87 Wm^{-2}, which explains why the derived net radiation flux was underestimated by the SEBS model from June to August. This phenomenon was also found in the study by Yang et al. (2010). As for the time period from January to May, the underestimation of sensible heat flux was mainly caused by the negative bias of the land-atmosphere air temperature difference. The MB for the land-atmosphere difference could be -5.69 K from January to May. As there is a complementary relationship between sensible heat flux and latent heat flux, the corresponding latent heat flux tends to be overestimated. This discussion has been added to the revised manuscript. (P10, L8-18)

(9) Figure 5: the authors give two days of diurnal cycles over TP. The results are from which day and which year? It should be noted on figure 5. In addition, why you choose these two days?

Author Response: It should be noted here that the diurnal cycles of land surface heat flux are based on the annual mean of 2008. The top panels are sensible heat flux, and the bottom panels are latent heat flux. We have added this information in the figure caption. (P24)