

Responses to referee #2' comments on

Inverse modeling of hydrologic parameters using surface flux and runoff observations in the Community Land Model

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We greatly appreciate the constructive comments and suggestions from the anonymous referee, which help us improve the quality of this paper. Our responses to the comments are provided item-by-item as follows.

The paper “Inverse modeling of hydrologic parameters using surface flux and runoff observations in the Community Land Model” analyzed the impacts of different observation, temporal resolution and parameter reduction on parameter optimization results following the previous sensitivity work. These works are important for the CLM community to realize and improve this model in detail. Authors have done amount of simulations. I think there are still some major concerns before it can be accepted for publication.

Major

1. The vegetation parameters such as leaf area index, V_{cMax} are very important to the surface fluxes simulation. Have you considered the effects of these parameters? For example, CLM4 use low V_{cMax} values compared to the measured ones, this will result in low latent heat flux.

Response: *Thanks for the suggestion. The vegetation parameters, especially V_{cmax} and the slope of the stomatal conductance formulation, are significant parameters. In the manuscript, we focused on the hydrological parameters and set the vegetation parameters as defaults. We will consider the effects of these vegetation parameters in our follow-on studies. We added discussions in the revised manuscript regarding the potential importance of vegetation parameters and its implications.*

2. The soil texture also affects the soil evaporation, this also contribute to the fluxes. Compared with the parameters used in your study, are these parameters more sensitive to fluxes or not? I think these vegetation parameters and soil texture should be discussed.

Response: *It is true that soil texture also affects the soil evaporation and fluxes. In this study, the prior distributions for porosity, permeability, specific yield, Clapp and Hornberger exponent, and saturated soil matrix potential parameters are determined from soil texture information based on Cosby et al. (1984). In our previous studies (Hou ete al., 2012; Huang et al., 2013), we have performed global sensitivity analysis over all hydrologic parameters, including the aforementioned ones derived from soil texture. Results from previous studies suggested that the soil texture derived parameters are of secondary importance when LH and runoff are the targets of inversion. Therefore, in this study, we chose three representative sites and focused on significant parameters as suggested in previous studies.*

3. Page 17, second paragraph. The LH in Fig. 4 is better than that of Fig. 10. And the runoff in Fig. 8 is better than Fig. 12. How can you get the conclusion of “Overall, inverse modeling with a reduced set of parameters identified from previous sensitivity analysis shows some small improvements in simulating heat flux compared to using

the posterior results with ten parameters”? With less parameters involved in the optimization, you cannot obtain the improvements, the results are not consistent with your finding. Also in page 17, line 19-21, the conclusion is not consistent you’re your results.

Response: *We agree with your point and have made modifications of the conclusions accordingly. In typical model fitting (e.g., regression), a better fit (i.e., smaller RMSE or high R²) is expected with more explanatory variables/terms. In the inverse studies, we do not expect to obtain smaller RMSEs between the observed and modeled responses using posterior estimates with only subset of parameters. We do want to emphasize that comparable predictions can be obtained using full- or sub-set of parameters, yet the latter setup helps alleviate the non-uniqueness issues of inversion and yield stable results with much faster convergence and therefore is more applicable in practice.*

As for the discussion of impacts of temporal resolution of heat flux observation on inverse modeling, Fig.2 shows that the simulations with reference probability of 1.0, 0.95 and 0.9 are similar when using monthly fluxes; Fig.5 shows that the results are improved only with reference probability of 1.0 and 0.95 when using daily fluxes. Comparing these two figures, the results using monthly fluxes are better than that using daily fluxes. We think the conclusion that “increasing data frequency requires a more stringent acceptance criterion” is consistent with the results. We changed the sentence to “This indicated that using data of higher temporal resolution might require a relatively more stringent acceptance criterion (i.e., higher p_{ra})”.

4. Page 4, “we adopt and compare the performances of two different inversion strategies, including deterministic least-square fitting and a stochastic Bayesian inversion approach integrated with Markov-Chain Monte-Carlo (MCMC) sampling”. But from the paper, I can not find the results of least-square fitting. Right?

Response: *We used the PEST (the least-square fitting) to do the inversion with the defaults as initial values, and found that simulations of heat flux and runoff using the calibrated parameters show little improvement. Therefore, we did not show the results since it is not central to this paper. We removed the sentence to avoid confusion.*

5. Can you discuss more about: impact of optimized parameters using fluxes on the runoff or the impacts of optimized parameters using runoff on the fluxes? It is interesting that whether you could get contrary conclusion or not. If the findings are contrary, which observation can be used in the calibration?

Response: *This is an important point. The LH flux can be measured by flux tower*

which represents a typically small area, while the runoff is a composite response of a drainage basin which is a large area. These are among the many factors that result in different parameter sensitivity (and therefore identifiability) patterns for different types of observables (e.g., LH flux vs runoff). We think that unless CLM can perfectly describe the energy flux and runoff processes, it is expected that optimized parameters from Type1 data (the historic or training periods) are better for Type1 simulations (the predicting or testing periods) than optimized parameters from Type2 data. Another reason that we did not perform the test is that only energy flux observations are available at the flux tower sites, and only runoff data are available at the MOPEX basins.

Minor

1. CLM is used to model the runoff. Usually the land surface model is not good choice in the runoff simulation for a small basin. Can you explain more about this? Whether it is reasonable or not?

Response: *That is one of the motivations of our study – to improve the runoff simulations through runoff parameter calibration. CLM4 is among one of the few land surface models that include runoff generation parameterizations. However, due to its typical applications as the land component of the community Earth system model for global simulations at coarse scales, the potential of improving runoff simulations in CLM4 has only been evaluated in a limited number of studies (e.g., Li et al, 2011; Huang et al., 2013). However, these studies clearly demonstrated that it is possible to improve runoff simulations in CLM4 through calibration. Therefore, this study constitutes our first attempt toward such a calibration and the result is satisfactory. The calibration tells us whether model errors are more related to poor choices of parameter values or limitations in model structure (i.e., systematic overestimate/underestimate persists after calibration). Our study shows that the inversion method can significantly improve the runoff simulations using the CLM model. Improving the model structure is another important aspect. We will explore this in our follow-on studies.*

2. Page 12, line 26. “the posterior estimates of parameters all significantly improve the heat flux simulation in summer”, I think the improvement is not significant in summer from Fig. 2.

Response: *From July to August, the simulations with reference acceptance probability of 1.0 and 0.95 in Fig.2 capture the variability of heat fluxes, while the result with default parameters is very poor. Therefore, we think the improvement is significant.*

- Page 13, line 1, what is “Gaussian probabilities of misfits between calculated and observed responses”, please add more explanations.

Response: *The Gaussian probabilities are calculated using Eq.2 in the manuscript. The likelihood of parameter sets is the product of the Gaussian probabilities.*

- Page 14, last paragraph, there are no results to support this section. Because you don’t provide the daily results of US-MOz. Same as Page 15, the last paragraph.

Response: *In the manuscript, we described the results and did not show the figures due to page limits. Figures R1-R4 show the results using daily data at the US-MOz site and one MOPEX site.*

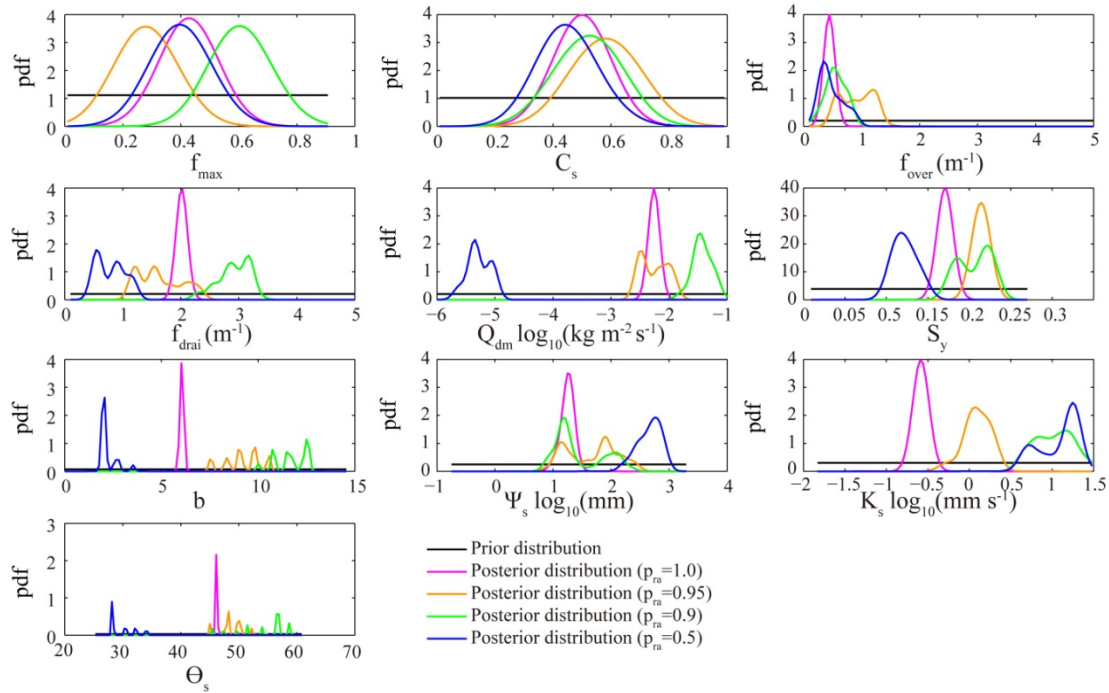


Figure R1. Posterior distribution of the parameters with four reference acceptance probabilities using daily heat flux data at the US-MOz site.

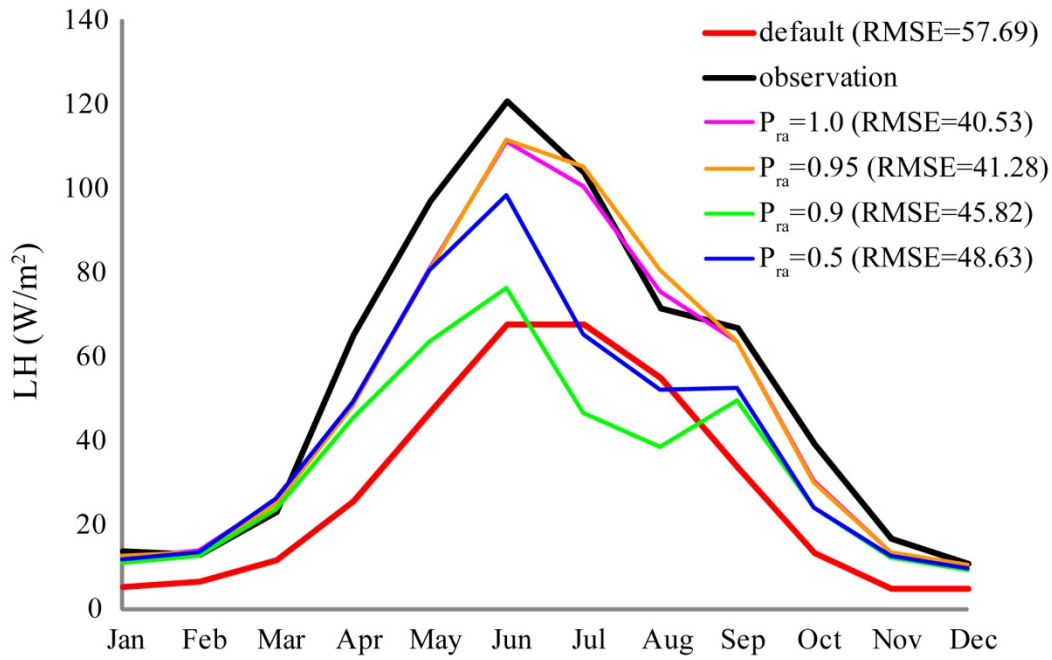


Figure R2. Simulated heat fluxes using the posterior estimates of parameters at the US-MOz site.

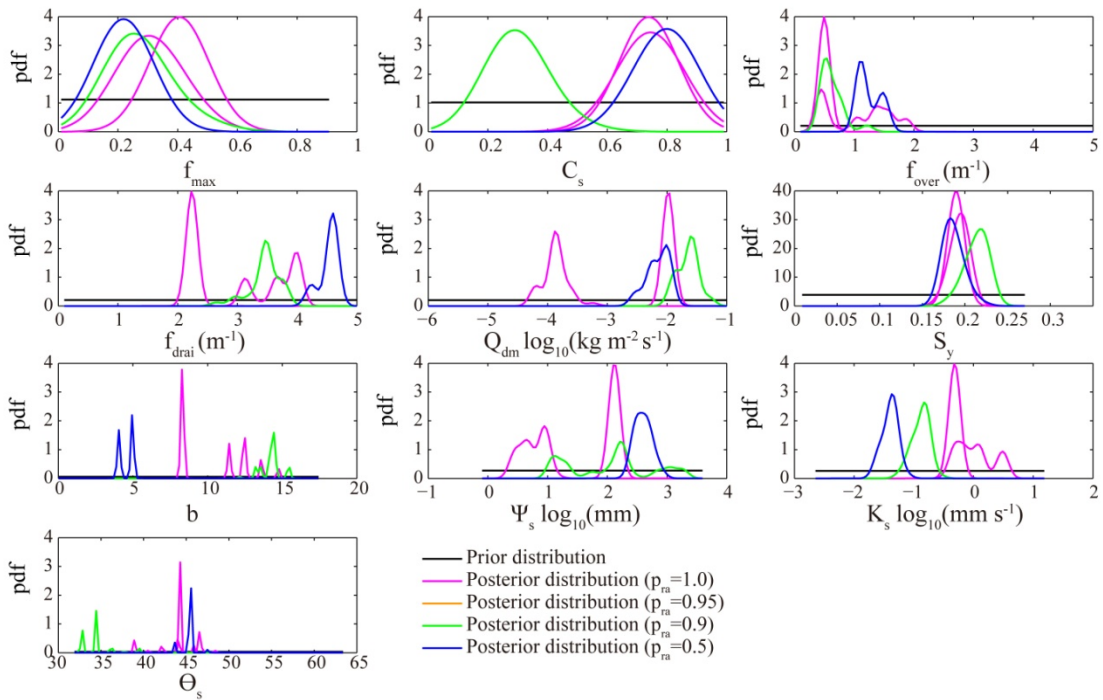


Figure R3. Posterior distribution of the parameters with four reference acceptance probabilities using daily runoff data at the MOPEX basin.

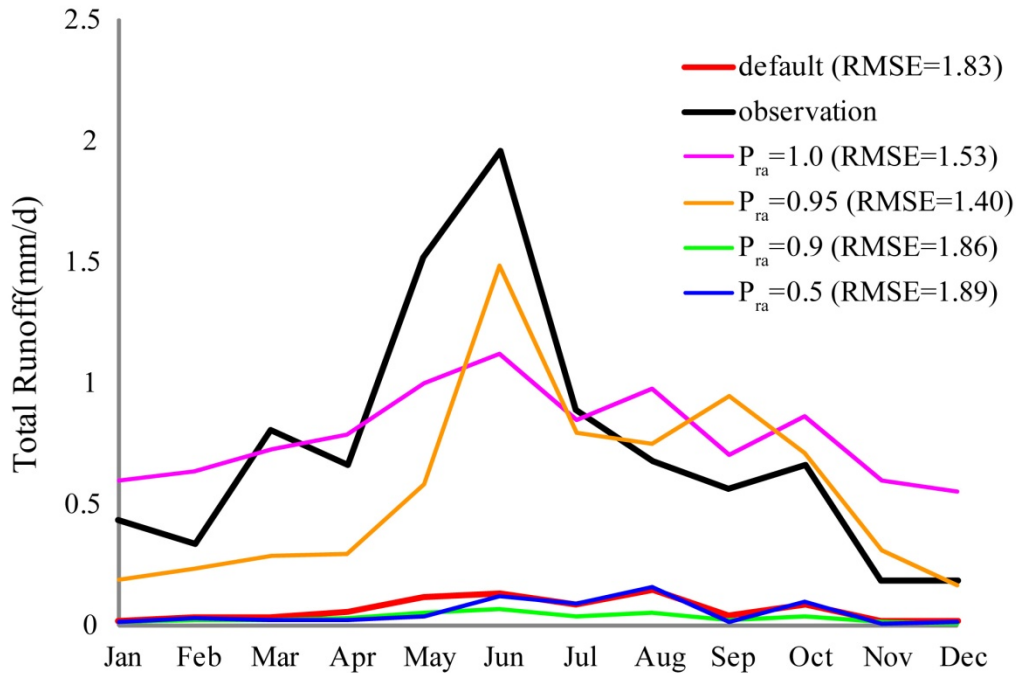


Figure R4. Simulated runoff using the posterior estimates of parameters at the MOPEX basin.

5. What is the reason of large fluctuations in Fig. 8 with optimized parameters? Can you explain?

Response: We can see from Figure 15 that the simulated runoff has more daily variability than the observed runoff in late summer and early fall. This leads to larger simulated monthly runoff than observed. Generally the model does not capture the large daily runoff peaks in the summer from rainfall events. Hence the excess soil moisture leads to larger runoff in late summer and early fall when rainfall events are less frequent and the observed runoff is basically very low. This suggests some systematic biases in the model parameterizations that cannot be fully addressed by parameter calibration. However, we cannot exclude the possibility of errors in either the external forcing or observational heat fluxes. For example, representative of averages on the 1/8 degree grid, the atmospheric forcing data may underestimate rainfall intensity for heavy precipitation events and vice versa, leading to underestimation of runoff peaks in the summer and accumulation of soil moisture for runoff generation in subsequent periods.

6. I think it is better to measure the runoff performance using NSE, not RMSE.

Response: Thanks for the suggestion. NSE, R2, RMSE, and many other measures are all reasonable statistical measures of goodness of fit, particularly in regression or

deterministic inversion studies. We also acknowledge that how to choose an appropriate objective functions has been a topic of studies in the hydrologic calibration literature (e.g., Sorooshian and Dracup, 1980; Sorooshian, 1981; Parada et al., 2003). However, the differences between the measures are not the focus of this study, especially since we are using Bayesian inversion, where the likelihoods are evaluated in the forms of probabilistic distributions that in fact do not have one-to-one correspondence to a single RMSE or NSE.

7. I suggest to add the daily results of US-MOz, because you cite these results many times.

Response: *Please refer to Figure R2 in our response to Minor-comment #4.*

8. Page 20, line 22, I think the surface heat flux could have large day-to-day variability due the change of soil moisture condition

Response: *We agree that there is day-to-day variability in heat fluxes and in runoff. During wet seasons, though, variation in precipitation could be higher than temperature, which might result in more variability in runoff than in heat flux, compared to other seasons.*

References:

- Cosby, B. J., G. M. Hornberger, R. B. Clapp, and T. R. Ginn (1984), *A Statistical Exploration of the Relationships of Soil Moisture Characteristics to the Physical Properties of Soils*, *Water Resour. Res.*, 20(6), 682-690.
- Hou, Z., Huang, M., Leung, L. R., Lin, G., and Ricciuto, D. M.: *Sensitivity of surface flux simulations to hydrologic parameters based on an uncertainty quantification framework applied to the Community Land Model*, *J. Geophys. Res.*, 117, D15108, 10.1029/2012jd017521, 2012.
- Huang, M, Hou, Z., Leung, L. R., Ke, Y., Liu, Y., Fang, Z., and Sun, Y., 2013. *Uncertainty Analysis of Runoff Simulations and Parameter Identifiability in the Community Land Model – Evidence from MOPEX Basins*, *J. Hydromet.*, 10.1175/JHM-D-12-0138.1.
- Li H, M Huang, M Wigmosta, Y Ke, A Coleman, and LR Leung. 2011. *Evaluating Runoff Simulations from the Community Land Model 4.0 Using Observations from Flux Towers and a Mountainous Watershed*. *J Geophys. Res.*, Vol. 116, D24120, 19 PP, doi:10.1029/2011JD016276.
- Parada, L. M., J. P. Fram, and X. Liang, 2003. *Multi-resolution calibration methodology for hydrologic models: Applications to a sub-humid catchment" in Advances in Calibration of Watershed Models*, Q. Duan, H. Gupta, S. Sorooshian, A. Rousseau,

and R. Turcotte, Eds., Water Science and Application Series, 6, American Geophysical Union, 197-211, 2003.