Anonymous Referee #1

General Comments

This paper has developed DasPy, an open source data assimilation framework based on the Ensemble Kalman filter method by using Python scripting language. The authors have demonstrated their framework for the Community Land model. This is an important work and quite a tremendous undertaking to provide this capability to the data assimilation community. However, the paper is limited in two important fronts: scientific contribution, and computational capability. As it stands, the DasPy program is not a framework but single data assimilation method applied to one land surface model and a standardized observation model, CMEM.

Response: Thanks for the recommendation. We agree that DasPy is not a framework, but a specific land data assimilation system for users who want to use CLM for land data assimilation studies. Here, already a large community exists. We are sorry for the confusion and this will be fixed in the revision. DasPy cannot replace other existing data assimilation systems, such as DART and LIS. DasPy cannot be used efficiently for operational applications, it should be considered as a research tool. We will remove the term “framework” from the title of the paper and the paper and change it to ”system”. In addition, we will provide a clear comparison between DART, LIS and DasPy to show what DasPy can do and what DasPy cannot do. There are 3 observation operators in DasPy: CMEM (for microwave brightness temperature observation), COSMIC (for Cosmic-ray soil moisture observation) and TSF (for land surface temperature observation). It is therefore not true that only CMEM as observation operator is implemented. In addition, the user can select which of these different types of observations can be assimilated.

There are many active research topics in the land data assimilation community, for example concerning the role of the data assimilation algorithm, adaptive error estimation, multivariate/multiscale data assimilation, joint state and parameter/bias estimation and the development of observation operators. We also added a TODO list on DasPy github. DasPy includes now the successful developments made in the past several years. We are also doing further studies and development to enhance the capabilities of DasPy, such as the EnKF integration, joint state and bias estimation, multi-scale data assimilation and implementation of additional observation operators for multivariate data assimilation. However, in order to make these new developments stable much effort is necessary and the basic system need to be presented to the community and published. What we provide in DasPy is already very useful for land data assimilation researchers working with CLM. Currently, there are 3 PhD students who are using DasPy as part of their PhD work: Roland Baatz (r.baatz@fz-juelich.de) is working on cosmic-ray soil moisture probe assimilation for the Rur catchment

using DasPy; Dominik.Rains (Dominik.Rains@UGent.be) is doing multivariate data assimilation at the regional scale including an observation operator for active microwave remote sensing of soil moisture; Meiling Gao (1543114887@qq.com) is assimilating land surface temperature into CLM to study the heat island effect.

CLM provides a complete framework for land surface modeling, and is becoming more and more popular (396 peer reviewed papers - http://www.cesm.ucar.edu/models/cesm1.2/clm/clm_bibliography.htm) and under very active development by NCAR, so we think there will be more potential users for DasPy. Several years of dedicated effort are necessary to develop a stable data assimilation system usually, this is not possible for a PhD study in 3~4 years. However, PhD students could use and modify DasPy without too much effort and avoid unnecessary programming work. This is why we plan to release DasPy at this stage as many researchers need an easy to implement land data assimilation system to solve a specific problem, like soil moisture assimilation to improve the estimation of land surface fluxes in CLM. We agree that DasPy is not a complete solution for all land data assimilation topics. We will add more capabilities to DasPy according to the progress of our studies. In addition, we think that there is some confusion about the objective of DasPy, and therefore we will revise the manuscript to make it clearer, especially for the specific user community of DasPy. In addition, an outlook section will be developed on the planned future development of DasPy.

Scientific contribution:

1. In the data assimilation (DA) community, the assimilation methods are many and varied. DA methods including Ensemble Kalman fitler (EnKF), particle filter, evolutionary data assimilation, etc. Each method is designed to account for model and observation uncertainties in different ways. Even within each approach there are shades of differences. So what the DA community needs from a program like this is an identification of the common DA modules, for example, ensemble generation methods, error estimation methods, etc. This DasPy program does not have this feature, and does not qualify as a framework. DasPy has hard coded modules for only a single DA method, the Local Ensemble Transform Kalman Filter.

   Response: We agree that DasPy is not a framework, but a specific land data assimilation system for the users who want to use CLM to do land data assimilation studies. We will change the title in the revision from “framework” to ”system”. LETKF also suffices for many researchers who want to assimilate multivariate observations to improve the land surface estimation. For example, the famous land data assimilation framework LIS (Land Information System)

developed by NASA only integrated the EnKF as data assimilation algorithm.

On the other hand, DasPy provides 4 different methods to generate ensemble spread: the initial conditions soil parameters, vegetation parameters as well as the atmospheric forcings can be perturbed. These ensemble perturbation methods can be combined. As such, we partly disagree with the comment by the reviewer.

2. The DA community uses several prediction models: different land surface models, different hydrological models, numerous environmental models and weather prediction models. Again, there are commonalities from all these models from a data assimilation viewpoint. These models have state variables, model parameters, forcing variables, etc. A DA framework about how to access and treat these components from any prediction model is needed. The DasPy program does not the capability and the flexibility to treat these model components.
   Response: The objective of DasPy is multivariate data assimilation with the CLM land surface model. This is already a huge research topic and serves a large community. As already explained in the paper, we believe the land surface modelling community needs a tool for doing data assimilation with a land surface model, and it is then of less interest that a framework can also be used for atmospheric modelling. The objective of this development is therefore different from data assimilation frameworks like DART or LIS. This will be clarified in the revised version of the paper.

3. Error estimation. There are several approaches to error estimation in the DA community. Numerous error estimation methods for prediction model, observation, state variables, forcing variables, model parameters, etc. At least an identification of the commonly used ones from the literature is needed from a paper like this.
   Response: We agree that the error estimation is very important in data assimilation and it is an active study area. We will extend the literature discussion with an overview of the error estimation methods for prediction model, observations, forcings and model parameters. In DasPy we only provide the functions we validated in our past studies which are methodologies to perturb the forcings, soil and vegetation parameters, initial conditions and observations. In addition, the user can adjust the error level for each of these cases. In the paper we will also give further background on the included sources of uncertainty in DasPy.

4. Update procedure. Again, commonly used updating strategies from the literature need to be identified and be included into a program like DasPy.

Response: We believe that the reviewer refers to the updating by the data assimilation algorithm but it is not completely clear to us. As indicated before, in DasPy only LETKF is implemented and we suggest that users read the cited reference papers for LETKF for more details. However, in the nearby future also updating according to EnKF will be released. As indicated before, also a well-known data assimilation framework like LIS has only one data assimilation algorithm implemented.

5. One sound contribution the authors' made in this paper is the inclusion of the CMEM model. The CMEM is a standardized observation model in the land surface DA community. Yet, its inclusion into DasPy is not standardized from a DA standpoint. Different DA strategies for handling observation model, and its assimilation

   Response: First we would like to re-stress that multiple observation operators are implemented in combination with CLM. Not only CMEM (for microwave brightness temperature observations), but also COSMIC (for Cosmic-ray soil moisture observation) and TSF (for land surface temperature observations). It is unclear to us why the reviewer thinks that the implementation is not standard from the DA-viewpoint. No further explanation is provided by the reviewer.

Computational capability:

6. The authors' choice of scientific language of Python is very sound and their use of modules such as numpy and matplotlib is very good. What make modules like numpy and matplotlib so popular is their modularity, they provide tools independent of the problem at hand, allowing flexibility for users to adapt these modules to different problems. Yet, this DasPy lacks modularity and the flexibility to adapt to different assimilation problems.

   Response: We agree that the modularity of numpy and matplotlib is very good. numpy or matplotlib have thousands of functions and the users can choose which module needs to be imported before calculation. If we understand this comment correctly, the question might be related to the long discussion on process oriented language versus object oriented language". As mentioned on the Wikipedia: "The OOP paradigm has been criticized for a number of reasons, including not meeting its stated goals of reusability and modularity, and for overemphasizing one aspect of software design and modeling (data/objects) at the expense of other important aspects (computation/algorithms)". We think that modularity is not very important for a scientific code, and we should focus more on the capability of DasPy. If DasPy works correctly from the scientific point of view and if it is useful for the community, then it is possible to further develop it towards a

software framework in the future. The software design only can be done correctly when we know the specific software requirements. However, we usually do not know this yet during research, and it becomes clear after more experience was gained on the scientific topic.

7. The DasPy is very limited to only one DA method, the Local Ensemble Transform Kalman Filter. Even the modules developed for this one DA method are not transferrable to other shades of EnKF. No inclusion of different ensemble generation approaches, different error estimation methodologies, etc. The modules need be independent so that they can be plug-and-played into another approach.
   Response: This reviewer comment is a repetition of the former comments 1), 3) and 6). Therefore, we refer to the answers provided before. Here it is important to highlight that the statements by the reviewer are not completely correct: DasPy offers for example different ways to generate the ensemble. Forcings and/or soil and vegetation parameters and/or initial conditions can be perturbed, and different variances and covariances can be defined for the ensemble generation. We will add different data assimilation methods and more choices of ensemble generation methods as options in the revision.

8. Computationally, what the DA community needs from a program like DasPy is a standardized collection of modules so that users can pick and choose specific tools they need to address their problem. At this stage, the DasPy program is simply a specialized application of one DA method for a specific problem. DasPy is hardly extensible to other problems, e.g. streamflow, weather prediction, etc. Even with soil moisture, there are still lots to be desired. Assimilation with calibrated ensemble of model parameter values, for example.
   Response: As explained before, it is not our goal to provide a general data assimilation framework. As motivated also in the paper, we believe that a specific data assimilation system for land surface modelling is needed and helpful for the land surface modelling community. In addition, some of the points the reviewer mentions are already included in DasPy. DasPy can calibrate an ensemble of model parameter values. We also admit that even for land surface modelling many further improvements are possible and needed. For large problems, like streamflow assimilation, coupling to an atmospheric model for weather prediction, we think it is better to use other data assimilation tools like DART or LIS. We supply here a code that is interesting for land surface modelers of CLM because it allows data assimilation in an easy way for their model. For the future new extensions will be provided. The outlook section of the paper lists planned extensions and associated software releases.