**Interactive comment on "Comparison of different evaporation estimates over the African continent" by P. Trambauer et al.**

Anonymous Referee #2

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**Reaction to the interactive comment by Anonymous Referee #2 on: "Comparison of different evaporation estimates over the African continent" by P. Trambauer et al., hessd-10-8421-2013**

We would like to thank this referee for his/her interesting comments and suggestion that contributed to improve our paper and to clarify specific points. Hereby we present the authors reply (AC) to the referee's comments (RC).

*General comments.*

RC: The research starts from the observation that few evapotranspiration intercomparison studies exist, none of them being focussed on the African continent. Indeed, the main novelty of the paper is to provide results for a large panel of regions and climates of the African continent. To reach this purpose, the authors suggest a detailed regions classification in Section 2.2. Furthermore, they consider 3 broad modelling/approaches classes (hydrology, land surface, remote sensing) and they select one or two models in each of them. However, the criteria used for model selection are not explained in the text. Each modelling approach is said 'representative' of its class but the meaning of this representativeness is not explained. Can the output of the selected models be considered as a benchmark of the output of a larger set of existing models belonging to each class? Previous studies have been done at the global scale and should be referred to give at least a partial information on the relative position of the selected models in their specific category (eg . multi model analysis and GEWEX LandFlux results). Furthermore the authors should specify and justify if they expect a larger ET variability between classes than within each class. It is likely that another model selection would have provided different results. Considering the 'remote sensing' class as specific looks arbitrary and meaningless in the sense that remote sensing input could be usable as input in any of the other two classes. Even remote sensing products are based on ET algorithms. Classification should avoid confusion resulting from criteria based on input data and methods.

> AC: Eight products were considered to capture the variance of the evaporation estimates resulting from various sources of uncertainty, e.g. model parameterization, model structure or assumptions made in the model and input data. We chose different types of models so as to have estimates based on very different approaches in the calculation of ET (hydrological models, land surface models, remote sensing product). Well documented, used and cited models were selected. For the hydrological models, we selected PCR-GLOBWB model that is used at a global scale for a variety of purposes: seasonal prediction, quantification of the hydrological effects of climate variability and climate change, to compare changes in terrestrial water storage with observed anomalies in the Earth's gravity field and to relate demand to water availability in the context of water scarcity (see Sperna Weiland et al. (2012), van Beek et al. (2011), Wada et al. (2011), Droogers et al. (2012), Sperna Weiland et al. (2011)). In Mueller et al. (2013) it appears that ERAI is a good representative of the reanalysis products and GLEAM is a good representative of the diagnostic datasets (average products). ERAL is an upgraded land surface model for ERA-Interim reanalysis, and MOD16 is greatly used, has a high spatial resolution and easily accessible online. We therefore believe that the output of the selected models can be considered as an initial benchmark of the output of a larger set of existing models belonging to each class.
>
> The inclusion of other models may indeed modify the resulting dispersion or uncertainty, and it is indeed something that can be done in the future. Moreover, a comparison with the global

benchmark product developed by Mueller et al. (2013) may be recommended. However, we think that through the selection of eight products we can already give an overview of the possible variances or dispersion of the products within the different regions. For example, in the humid Sahel region we can already see that a significant spread between the products can be expected, whereas in humid Southern Africa we expect a low spread between the products. To make this clearer we included references to previous studies done at the global scale and further elaborated the introduction section.

We expect the variability to be larger between classes than within each class. Mueller et al. (2013) completed sensitivity simulations using the same model to compare the influence of uncertainties in precipitation to differing model structures. They found evaporation from simulations with different precipitation to show a smaller range than those from different models using the same forcing. In our study, we also found the estimates of the same model with different precipitation inputs to be closer than those resulting from different models forced with the same precipitation input in some regions. However, we did see the opposite in other regions such as humid Southern Africa.

We are aware that remote sensing could be used as input in any of the other two classes. We hereby referred to "remote sensing" products (could be changed to "satellite-based" products) to those in which their inputs here rely to a large extent on satellite observations.

RC: The study doesn't consider any validation against in-situ observations. As stated in Section 2.1, the models have mainly been validated for North America. The article mentions that nevertheless the MODIS ET product has in addition been compared in Asia but that it gives poor results compared to observations. As a consequence, model performance in Africa seems largely unknown and neither the models nor their mean behaviour can be considered as a reference. In this way, the comparisons done with EM can only be indicative of the dispersion resulting from the considered models. These aspects should be better reflected in the introduction section.

The objective of the current paper is thus more to discriminate areas where a good consistence can be found between results of the selected models in contrast with regions where models output diverge. However, a simple intercomparison is useless if it doesn't go further in the interpretation of the differences. The objective of the paper should then be extended in this direction. Indeed, the uncertainty in models output varies as a function to uncertainty in 1) model forcing; 2) ET modelling and parameterizations; 3) values of model parameters. The paper investigates part of the common input, but none of the meteorological variables, excepted the precipitation (point 1); it interprets superficially the impact of ET algorithms differences (point 2) and doesn't consider at all parameters values (point 3). Of course, to provide a full answer to all these aspects is challenging and a full in-depth study of all of them is probably out of the scope of a single paper. Anyway, the announced objective of the study stated in the introduction should be more ambitious than simply 'doing an intercomparison'. In particular, the content of the discussion section should be part of the results. Instead, the discussion section should state how the present work contributes to the problematic investigated by the international research community and what are the suggested directions for future work.

AC: We thank the reviewer for the useful comments to focus the objective of the paper. The following paragraph was added to the introduction:
"This comparison can serve as an indirect validation of methods or tools used in operational water resources assessments. In this study we do not intend to evaluate whether one product is better than the others but to discriminate areas where good consistency can be found between the results of the selected models in contrast to regions where model results diverge. We seek to provide a range of uncertainty in the expected actual evaporation values for the defined regions. The understanding of this range can be useful in for example water resources management when estimating the water balance.

As suggested by the reviewer, the content of the discussion was moved to the results, the interpretation was extended, and the discussion now states how the present work contributes to the problem as investigated by the international research community and adds some recommendations.

*Specific comments.*

RC: Introduction: although not available on the studied 2000-2010 period, a new operational ET product is produced by the EUMETSAT LSA-SAF (Ghilain et al., 2011, HESS, 15, 771–786) and should be cited.

AC: We thank the reviewer for pointing this out, and the following paragraph was added in the introduction:
Ghilain et al. (2011) present the instantaneous (MET) and daily (DMET) evaporation products developed in the framework of EUMETSAT's Land Surface Analysis Satellite Application Facility (LSA-SAF). The MET and DMET products became operational in August 2009 and November 2010 respectively, and were satisfactorily validated against ground observations in Europe. The products were compared with models from ECMWF and from the Global Land Data Assimilation System (GLDAS) in Africa and parts of South-America. This comparison showed that the spatial correlation of the products with ECMWF remained very high (85 to 95 %) and was constant throughout the whole year. However, they found that for Northern and Southern Africa their product (LSA SAF MET) exhibited lower estimates than ECMWF and GLDAS, with the difference with the ECMWF product being the largest (EUMETSAT, 2011)."

RC: Overall results: Monthly mean results are investigated over a multi-annual period (2000-2010). Monthly standard deviation of daily product could possibly differ from one method to the other. Without displaying all the results systematically, could you comment on how they compare?

The suggestion of the reviewer is very valid and can provide extra information. We added a paragraph in the discussion as follows:
" Products compared at a monthly time scale certainly result in better outcomes than when the products are compared at a daily time scale. This study focused on the monthly and seasonal comparison, with daily comparisons considered to be beyond the scope of this study. However, monthly standard deviations of daily products differ from one product to the other and from one region to the other. A comparison of the monthly standard deviation of daily products (with the exception of MOD16 that does not provide daily estimates) consistently showed that in all arid and hyper-arid areas (R2, R3, R4, R5, R12, R13, and R21) ERAL has the highest standard deviation, generally followed by ERAI and GLEAM. In these regions the mean values and variability of the standard deviation of PCR-GLOBWB derived products seem to be lower. In other regions, the standard deviations of all the products have roughly the same variability and mean values. Among the four PCR-GLOBWB derived products, the one forced with Penman-Monteith (PCR_PM) showed slightly higher values of standard deviation than the other three products. For every product and every region, a seasonality of the standard deviation can be observed, with the highest standard deviations during the wet seasons."

RC: Potential ET (PET) (section 3.1):

RC: i- introduce PET definition, discuss concept(s) and possible differences among models;

AC: The definition of PET is introduced at the beginning of section 2.3, but this was extended to make it clearer. We also included a description to make the differences among the models clearer.

RC: ii- differences between 3 PET products (Fig 4): what are the most plausible estimations? Why so large differences?

AC: The differences between the Penman-Monteith and Hargreaves PET products are actually quite small and the differences are due to the different formulations of the method and the greater number of input parameters that Penman-Monteith requires, in comparison with the more simplified Hargreaves method. However, if we analyze at much smaller temporal and/or spatial scales the difference is likely to be more visible. The large differences between the MOD16 PET and the Penman-Monteith PET, which are both computed using the Penman-Monteith approach, are a result of the differences in the input data of meteorological and vegetation data (although we did not compare the input data of these two products in this study).

We believe that the most plausible estimations for the potential evaporation could be somewhere in between, with potential evaporation values higher than Penman-Monteith and Hargreaves computed with ERA-Interim, but lower than those of MOD16. We compared the Hargreaves reference potential evaporation (PEr) computed within this study and the Global Potential EvapoTranspiration (Global-PET) dataset (Zomer et al. 2008), which was also computed using the Hargreaves method (selected among five different methods tested) using inputs from the WorldClim database. We observe that the PEr from the Global-PET is in general around 20-30% higher than the one computed in this study. It might be the case that ERA-Interim temperatures for Africa are slightly lower than the one from the WorldClim database. In this comparison radiation does not influence the estimates as extraterrestrial values are used in this formulation. Regarding the MOD16 dataset, little information was found on the validation of potential evaporation, Wang and Zlotnik (2012) found MOD16 to underestimate actual evaporation in wet years and to systematically overestimate potential evaporation across Nebraska. Overestimations of MOD16 PET might be due to biases in LAI values or in the input meteorological data from GMAO, such as overestimation of solar radiation. Zhao et al. (2006) compared three known meteorological datasets: GMAO, ERA-40 from ECMWF and NCEP/NCAR to evaluate the sensitivity of MODIS global terrestrial gross and net primary production (GPP and NPP) to the uncertainties of meteorological inputs. They found that NCEP tends to overestimate surface solar radiation and underestimate both temperature and vapor pressure deficit (VPD), ECMWF has the highest accuracy but its radiation is lower in tropical regions, and the accuracy of GMAO lies in between. Their results show that the biases in the meteorological reanalysis can introduce significant error in the evaporation estimates. This explanation was added in the manuscript.

RC: iii- comment on the possible particular input/parameters used to compute PET; specific parameters used as a function of vegetation types if any;

AC: The particular inputs used to compute PET are:

For Penman-Monteith reference PET:

$R_n$ net radiation at the earth surface [MJ $m^{-2}$ $day^{-1}$],
T mean daily air temperature at 2 m height [°C],
Dew point temperature at 2 m height [°C],
$u_2$ wind speed at 2 m height [m $s^{-1}$],
Surface pressure [Pa].
Crop resistance for reference crop (rc =70 s m-1)

For Hargreaves reference PET:

Extra-terrestrial Radiation
Maximum, minimum and mean daily temperature [°C]

In both cases, to transform to crop-specific PET, specific parameters for each vegetation types are used:

PCR-GLOBWB model uses crop-factors (see answer to Reviewer#1)
MOD16 uses LAI (from MODIS LAI product)

RC: iv- If relevant for the discussion, add when possible a figure with annual or monthly standard deviation based on daily products over the same period and comment it.

AC: We have addressed this above. We have included a paragraph in the discussion on this point, and feel this provides sufficient clarification. Given this clarification we concluded that an additional figure is not necessary.

RC: v- MOD16 PET missing in dry and arid areas: is there a known justification?

AC: MOD16 does not include urban and barren areas since there is no MODIS derived FPAR/LAI for these land cover types (Mu et al. (2011)). This was added in the manuscript.

Actual ET (AET) (section 3.2):

RC: i- Focus on interpretation of the AET results. Discriminate as much as possible between impact of (1) input data, (2) modelling options/parameterizations, (3) parameters and make a link with the different considered regions when relevant;

We revised the results section as suggested by the reviewer and it is now more focused on the interpretation. The interpretation from the discussion section was moved to the results section where appropriate, and this interpretation was extended by, for example, discussing the impact of input precipitation, radiation, and temperature. We also made more specific reference to how the representation of some of the processes (irrigation, interception) and modeling approaches in different models are related to the results.

RC: ii- P. 8437, L 23-26: in view to provide an interpretation, mention clearly in which model versions water bodies are considered and how (by reference to the used algorithms);

AC: PCR-GLOBWB model (PCR-GLOBWB, PCR_PM, PCR_TRMM, and PCR_Irrig) consider water bodies. Crop factors are specified for the fractions: open water, short vegetation and tall vegetation, respectively. Values have been calculated for each 0.5° cell for each month. "For the wetland areas, the maximum crop factor was set to 1.2 [-], the minimum varying with the minimum monthly temperature: for tropical regions, the value was set to 1.0, for temperate regions without frost to 0.6 and for regions with killing frost at 0.3 [-] based on values proposed by Allen et al. (1998) (van Beek, 2008)".

ERAI and ERAL only consider water bodies larger than 3000 $km^2$. For those grid points, only the energy balance is calculated and evaporation given as a free water surface with prescribed temperature (same as the sea surface temperature analysis when not available from 2-meters temperature climatology). In GLEAM "the contribution of lakes and rivers is not modelled, the predicted evaporation therefore refers only to the land fraction of the total surface area of each cell" (Miralles et al. (2011)). MOD 16 also does not consider evaporation of open water. A summarized explanation was added to the manuscript.

RC: iii- P. 8440 – 8443: regional analysis. Summarize the intercomparison results and focus on the interpretation. Move the detailed intercomparison description by region in Annex together with figures 8-9(-10).

We summarized the intercomparison results and focused on the interpretation. The detailed comparison description together with Figure 9 was moved to the Appendix. We thought it was important to keep figure 8 in the results section to ease the explanation. Figure 10 was reduced to show only a few Taylor plots (to reduce the amount of information) and was also kept in the result section.

Discussion/Conclusions:

RC: i- see general comments;

RC: ii- provide insight into the input of the research compared to previously available information mentioned in the introduction part (Vinukollu et al., 2011; Jiménez et al., 2011; Mueller et al., 2011)?

AC: We provided insight into the input of the research compared to previously available information. The last paragraphs of the conclusions was modified as follows:

"In recent years there has been an increasing amount of studies that focus on global evaporation estimates. Several new estimates were developed and validated with flux towers where available (mostly in North America and Europe), or where indirectly validated (e.g. comparison with another product) in other regions of the world. Moreover, recent studies compare several of these estimates at a global scale, largely coming from land surface models. The main contribution of this paper is to present an evaporation analysis focused on the African continent which serves as an indirect validation of methods or tools used in operational water resources assessments. The paper discriminates areas in the continent where a good consistency can be found between the results of the selected models in contrast to regions where model results diverge. It therefore provides a range of uncertainty in the expected actual evaporation values for the defined regions, which may be useful in for example water resources management when estimating the water balance. Africa strongly relies on agriculture and several regions are often hit by severe droughts; evaporation estimates can assist water managers in the estimation of water needed for irrigation. This paper compares different evaporation products for Africa and presents an Actual Evaporation Multiproduct at a 0.5° resolution. This EM integrates satellite based products, evaporation results from land-surface models and from hydrological models forced with different precipitation and potential evaporation data sets, and may serve as a reference data set (benchmark).

In general ERAI and MOD16 do not show good agreement with other products in most parts of Africa, while the other products are more consistent. ERAL is generally quite close to the EM, and the higher values of evaporation in ERAI when compared with ERAL are partly explained by the analysis of soil moisture data assimilation in ERAI. It also appears that in some regions such as in Southern Africa the agreement between the products is very good, which means that the use of any of these products may be equally good. In other regions, such as in the humid Sahel or the Mediterranean the choice of a particular product needs to be studied further as there is a larger difference between the products."

RC: iii- can we rank the results as a function of class belonging (see introduction)?

AC: This is an interesting point. It would be very interesting to rank the results as a function of the class to which the product belongs. However, we think that this can only be done if ground truth data are available to assess which products perform better or worse than the others. See text added in the introduction. We seek to provide an estimate of variance of the products for each region, but we do not have the necessary tools to rank the results.

RC: iv- section 4.1.2 meaningless in the discussion section at the current stage: similar input (GLOBWB and PM PET) in PCR gives similar output (AET)!!! But reasons of high differences between GLOBWB/PM and MODIS PET should be elucidated because anticipated impact on models like PCR could be high.

AC: Indeed we agree. This was considered when re-writing the discussion. Reasons of differences between the PET products were discussed. In the results section the following paragraph was added:
"Overestimations of MOD16 PET might be due to biases in LAI values or in the input meteorological data from GMAO, such as overestimation of solar radiation. Zhao et al. (2006) compared three known meteorological datasets: GMAO, ERA-40 from ECMWF and NCEP/NCAR to evaluate the sensitivity of MODIS global terrestrial gross and net primary production (GPP and NPP) to the uncertainties of meteorological inputs. They found that NCEP tends to overestimate surface solar radiation and underestimate both temperature and vapor pressure deficit (VPD), ECMWF has the highest accuracy but its radiation is lower in tropical regions, and the accuracy of GMAO lies in between. Their results show that the biases in the meteorological reanalysis can introduce significant error in the evaporation estimates."

Technical corrections.

General:

RC: i- differentiate usage of 'model', 'data', 'product' in the text (e.g. P 8424, L4: revise sentence: (i) remote sensing, (ii) continental-scale hydrological models, (iii) land surface models are not 'complementary data').

AC: In this sentence, "data" was changed to "products". The text was revised for consistency.

RC: ii- Some of numbers and words in the figure are too small. Check that character size used in figures allows text to be readable in the printed version.

AC: In the printed version, figures are expected to be larger (see also comments to Reviewer #1). For example Fig 8-10 are expected to cover a full page of the manuscript and the characters are then readable. We will make sure that figures are readable in the printed version.

RC: iii- enlarge figure 8-10, considering other numbers of columns to improve space usage on the page;

AC: Figures 8-10 were supposed to be printed in a full page of the manuscript, and the number of columns was optimized for this purpose. Figure 9 was moved to an Appendix and Figure 10 was reduced to show only relevant regions.

RC: iv- suppress Figure 10 (Taylor diagrams) if it doesn't add information compared to Figure 9;

AC: Figure 10 was modified to show only specific regions with relevant information. The information of Figure 9 and 10 are quite different. Figure 9 shows boxplots of seasonal evaporation, and Figure 10 shows the statistics (temporal correlation, RMSE and standard deviation) of the time series of monthly evaporation from Jan 2000 to Dec 2010.

Details:

RC: - P 8423, L12: cite FLUXNET;

AC: We added the sentence: "FLUXNET[1] coordinates regional and global analysis of observations ($CO_2$, water and energy fluxes) from micrometeorological tower sites."

RC: - P 8426, L28: provide information about correction of precipitation from October 2009?

AC: This was answered for Reviewer #1:
From September 2009 to December 2010, the mean monthly ERAI precipitation was corrected using a mean bias coefficient based on the climatology of the bias correction coefficients used for the period 1979-2009. While this only corrects for systematic biases, this was the only option available at the time, as a new version of GPCP (version 2.2) was not available. This explanation was added to the meteorological forcing description.

RC: - P 8427, L13: information about quality (Droogers and Allen, 2002)?

AC: The sentence was changed to:
"Droogers and Allen (2002) compared Penman-Monteith and Hargreaves reference evaporation estimates on a global scale **and found very reasonable agreement between the two methods ($R^2$=0.895, RMSD=0.81). They** suggest that the Hargreaves formula should be considered in regions where accurate climate data cannot be expected."

RC: - P 8427, L15-16: also likely less sensitivity to climatic input data, with possibly a reduction of dynamics and accuracy;

AC: We agree with the reviewer. This was added to the manuscript and the paragraph was revised.

RC: - P 8427, L20-22: a proper calibration of the Hargreaves relationship seems important. What about the parameter value selection - and what is its impact - in the current work?

[1] http://fluxnet.ornl.gov/

AC: In this work we chose to stick to the original parameter value of 0.0023. As it can be observed from the results, Hargreaves PET with this parameter of 0.0023 is comparable with Penman-Monteith PET throughout the continent. We did the exercise of computing Hargreaves with a parameter increment to 0.0031 (considering the results of Sperna Weiland et al. (2012)) and found Hargreaves PET to consistently be some 30% higher than Penman-Monteith PET.

RC: - P 8432, L20: ‘several satellite-sensor products’: which?

AC: The satellites used are the ones mentioned in the manuscript in the sentences above. To make it clearer, the sentence: "The GLEAM methodology uses ... to estimate global daily evaporation" was changed to "GLEAM uses a modified Priestley and Taylor (PT) model in combination with an evaporative stress module and a Gash analytical model of rainfall interception to combine the above-mentioned satellite-observable variables and estimate evaporation".

RC: - P 8433, L7-16: multiple references to ‘Zomer et al. (2008)’; perhaps some of them are unnecessary;

AC: We agree that some of the references are redundant and two of the references were removed.

RC: - P 8433, L23-24: ‘area-majority technique’: provide details;

AC: The sentence was changed as follows:
"()... area majority technique, in which the pixel value that is common to majority of the input pixels (because each pixel has equal area) is assigned to the output pixel."

RC: - P 8434, L 22: change the title ‘Comparison of evaporation products’ to ‘Methods for comparison of evaporation products’;

AC: In this study we compared different evaporation products which were derived using different methods and in some cases different input data. We think that our title reflects that, but we are willing to change the title if something more appropriate arises. However we do not quite agree with the title proposed by the reviewer as we are not proposing a method for the comparison, rather we are comparing different product using standard statistics and visualization.

RC: - P 8438, L 16: “We defined”: how ?

AC: The sentence was changed to:
"We defined the seasons in the continent as dry and wet (from available literature (see Sylla et al. (2010) and Jacovides et al. (2003)), and the wet seasons for each region are indicated with a grey shadow in Fig 8."

RC: - P 8439, L 23: ‘assimilation increments’: can you comment on its seasonal variation?

AC: See also reply to Reviewer #1.
As shown in Fig. 11, the soil moisture increments are mainly positive in most of Africa. In those regions, the increments tend to be always positive, with different seasonal variations, but with maximum values close to the rainy season. This was added in page 8439:
"Drusch et. al. (2008) provides a detailed evaluation of the soil moisture analysis scheme used in ERAI pointing to some of the limitations (root zone soil moisture acts as a ”sink” variable, in which errors are allowed to accumulate) and presenting a new surface analysis scheme that is currently operational at ECMWF. "

RC: - P 8440, L 12: MOD16 poor consistency: can you give an interpretation?

AC: By poor consistency we mean that the product is more dissimilar to all the other products and the EM. Already the PET comparison of MOD16 with the other estimates showed high differences especially in arid and semi-arid areas. An interannual variability analysis of the PET estimates shows that the highest differences between MOD16 PET and the other products occur during the dry season. During this season MOD16 evaporation remains higher than the EM, whereas in the wet seasons MOD16 ET is actually lower than the EM even though the PET is still higher. This can be due to the representation of canopy intercepted evaporation. For example in MOD16, evaporation from canopy is restricted by the relative humidity, if the relative humidity is less than 70% there is no evaporation from interception (Mu et al., 2011)

RC: - P 8458-8459: Combine Fig 4 and 5 in a single figure (can be with 3 columns and 2 rows labelled a to f).

AC: Done.

Overall, the paper is well written and easily understandable. It could still be improved by reviewing phrasing, by avoiding some repetitions, and by looking to simplifications when possible.

The paper was carefully reviewed, and where appropriate changes have been made.

The following references were added:


Droogers, P., Immerzeel, W. W., Terink, W., Hoogeveen, J., Bierkens, M. F. P., van Beek, L. P. H., and Debele, B.: Water resources trends in Middle East and North Africa towards 2050, Hydrol. Earth Syst. Sci., 16, 3101-3114, doi: 10.5194/hess-16-3101-2012, 2012.

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Zhao, M., Running, S. W., and Nemani, R. R.: Sensitivity of Moderate Resolution Imaging Spectroradiometer (MODIS) terrestrial primary production to the accuracy of meteorological reanalyses, J. Geophys. Res., 111, G01002, doi: 10.1029/2004jg000004, 2006.