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Reed Maxwell
Editor
Hydrology and Earth System Sciences

Lausanne, 03.07.17

Subject : Response to Referee Comments

Dear Reed Maxwell,

Thank you for taking the time to coordinate the review and editing of our work. We apologize for our lengthy reply period and hope it hasn't disrupted your time schedule too much.

I have made the necessary changes to the article according to each of the reviewers and below I have included a point-by-point response to them. This point-by-point response does repeat many of my responses during the review phase. I will enclose both my marked up manuscript and a clean version.

In addition, according to my responses, I make some promises for future publications. These include calculating ground heat flux with the soil temperature measurements from decagon probes, a foot print analysis, an evaporation map, and vegetation class estimations for all pixels. Although this will undoubtedly fall beyond the scope of this review process, I will try to remember to inform you when my "distributed energy balance" calculation paper has been accepted for publication.

As Hans Peter Schmid (2002) describes, foot print analysis over vegetation and over uneven topography is difficult and hard to validate. This could be addressed in comparison with the calculation of evaporation from our distributed meteorological stations that we hope to publish soon. Similarly, an evaporation map of the catchment will fit well in this calculation as well. We could use these two results from this work and measurements in combination with our spatial measurements to determine how evaporation varies spatial and the footprint of our stations. This future publication would be dedicated to the spatial variation in evaporation.

Thank you again.

Natalie Ceperley on behalf of all coauthors

Point by point Replies: (I have indicted my replies with a '>')

<u>Reviewer # 1</u>

1, I find the calculation of net radiation for all the meteorological stations does not really contribute to the paper. If I understand correctly, the measured net radiation is not really used except in validation against the measured ones at the energy balance stations. It is interesting as a stand-alone piece but is not well integrated into this paper. And I find removing this does not change the paper significantly or even make the paper more focused. One supporting evidence for my argument is that none of the related calculations was even mentioned in the abstract and conclusions. Another reason I think this should be removed is that the calculations were not studied deeply. For example, I think the explanation of biases in the calculated net radiation is not thorough. The biases in the net longwave radiation in Figure 3 are so large that I don't think it is due to the wavelength of the instrument. Give these two reasons, I would strong suggest remove this part.

>This is understandable; it arose from a discussion among co-authors. I moved this figure and the discussion surrounding it to the supplementary material.

Minor comments: 1, line 23, page 8: I would not use consistent. Maybe 'smooth'.
> Thank you for this suggestion. This has been changed.

2, line 22-25, page 9: This should go to a place much earlier when the radiative and flux measurements are first discussed (for example in Figure 4).
> This is a good point; it has been moved to the discussion of figure 5 on the previous page.

3, Figure 7 does not reveal much new information and should be removed. On the other hand, the discussion of Figure 8 is rather superficial at this moment. I only see 1 sentence for Figure 8 (line 20, page 9).
> More discussion has been added for figure 8. Figure 7 and related discussion has been added to supplementary material.

4, Figure 10 (section 3.3.1): R2 should be provided in order to claim ?NDVI and soil moisture have the strongest positive correlation with evaporative fraction?.
>A table of R2 values has been added to the figure.

5, Figure 11 has too much non-essential and redundant information. The only helpful information is the middle panel showing the validation of the model. The others can be safely removed. On the other hand, Figure 12 can be combined with the middle panels of Figure 11. By the way, figure 12 is not even mentioned.
> The validation of the model and figure 12 has been combined and discussion has been developed around figure 12.

6, line 9, page 11: should be figure 9, not figure 8.
> Thank you. This has been changed.

Reviewer # 2

> Based on AR2's recommendations, which were quite helpful, I have added some more development and discussion, in particular regarding additional work that has come out from the region.

The easiest way to deal with this point is probably to modify the abstract and develop some aspects of the physical basis of E fluxes, but I encourage the authors to develop

more thoroughly the NDVI-based model (although so far, the EF derived time series seems unrealistically high to me).
> As you recommended, I have made it clear that our fitting of evaporative fraction to NDVI and soil moisture is more of an exploration of the physical basis of evaporation and not a full-scale model, ready for large-scale implementation in the discussion.
> Your comments regarding the title are very helpful and I changed it to "Evaporation from Cultivated and Semi-Wild Sudanian Savanna in West Africa" because based on the floristic composition of the site, we are solidly in the biogeographic / phytosociological zone, and not the sahelian or Sudano-sahelian. Upon request, in future publications, or in supplementary materials, I could provide general botanical inventories that we completed early in our time on the site that support this classification. Semi - arid refers to the highly seasonal precipitation pattern.

L 20: I am not sure that you actually showed evidences that the fact that fluxes above the savanna-forest were higher was due to the number of rocks and trees and tree productivity.
> We did measure higher fluxes and explain it with the tree productivity.

L25: I think a paragraph is missing in the paper, as Figure 12 is not explained, and it is never written in the main text that NDVI only is sufficient to predict EF. This should be also further discussed.
> Thank you for bringing this to my attention. I have reconfigured some of the figures as per the recommendations of the first reviewer and I think that the connections between the figures and the text will be more apparent.

p2.L2: This is not straightforward: it should be sustained by a proper reference or moderated by adding 'for example'. For instance, there could be among-species differences in leaf renewal timing for some trees, not necessarily related to moisture availability.
> You are right. This sentence is meant to be rather general pointing out that there are some evergreen species on our site but most are deciduous. I changed the wording to make it clear that this is a general statement.

P2.L18-25: I would move these equations to section 2.3 (as is done with EF- or move EF equation to the introduction, although this relates more to 'measurements and calculations' than to an introduction).
> This is a good suggestion. I moved the equations to the Flux Calculation
P2.L26-32: consider removing some references. 2-3 references by statement are enough.
> While I think this is usually true, in this case, I want to demonstrate that it is an ubiquitous problem.
P2.L32: Let me suggest a few references that should be carefully studied and probably discussed at the end of the article, because they are located either in similar eco-climatic context, or bounding (either in the south or in the north) the study area. (Brummer et al., 2008; Guyot et al., 2009, 2012, Lohou et al., 2010, 2014, Mamadou et al., 2014, 2016; Velluet et al., 2014)
> Thank you for these references. I will add some discussion at the end of the article.

P3.L6: It is not the evaporative fraction, which is based on the concept of self-preservation, but the method that estimates daily evapotranspiration from evaporative fraction?
> Thank you, this is clarified.
P3.L15: This has been studied in West Africa and for a broad range of eco-climatic contexts by (Lohou et al., 2014)
> Thank you for the additional references. I will incorporate them appropriately.
P3.L19: is 'raised' plateau an appropriate term? I have never heard it.
> you are correct, the "raised" is redundant. I will remove this.
P3.L20: This is not true. I have not checked all the literature, but at least (Guyot et al., 2012; Lohou et al., 2014; Mamadou et al., 2016; Velluet et al., 2014) have studied energy fluxes in the area for different land covers and several seasonal cycles.
> Again, thank you for the additional references. I will incorporate them appropriately. P3. L24-L27: I would move that to the conclusion.
> Thank you for this recommendation.
P4. L 16-17: I am not sure this is relevant here.
> Since I do discuss social perception, I think it is relevant. The ethnic identity is the main way that the village identifies itself and is a primary determinant of land use.

P4. L18: It is not the sudanian area which is defined by alternating wet and dry season, but rather the monsoon climate. My suggestion would be (if you choose to keep sudanian instead of sahelo-sudanian): 'The watershed falls within the sudanian zone of the west-African monsoon climate system, with alternating dry and wet seasons with the rainfall falling. . ..'
> This is a helpful precision, Thank you.

P5.L7-8: This is an important remark: why not using ground T being recorded with the Decagon moisture probes for calculating G Only two depths are enough for a first calculation using the Harmonic method (Guyot et al., 2009). This would allow to be less elusive about the residuals of the energy budget, and to bring more evidence to conclude on higher/lower G under fields/Savanna.
> This is a good suggestion. I will add this in current or future publications.
P6.L6: I really think that individual times series should be shown, because according to Figure 5, they can be much different. At least one for the forest-Savanna cover and another for the field cover, and for the two depths, on a same figure containing H, LE and RN for the two land covers and for the same period. Maybe NDVI too?
> Thank you for the suggestion. I will reorganize some of the figures to have a figure that just has time series.
P6-7: section 2.8; I do agree with Reviewer #1 who proposes to remove this section. It could bring some interesting results, but would need much more developments, which are not the purpose of that paper. This would allow to gain some room for further developments in the text.
> Thank you for this remark, it is helpful to make a final decision.

P8.L10. To me, the NDVI for the forest in the dry season is not as much greener as you would expect from a forest dominated by Vitellaria paradoxa, which only need about a month for leaf renewal. The NDVI pixel must include some significant herbaceous cover. If possible, could you estimate the vegetation classes distribution within the pixel?

> This is a good suggestion, it is clear that all of the pixels are very mixed. I will try to include a vegetation class estimation in this publication or in the planned publication about the spatial variation of evaporation. There is nowhere in the catchment that the forest is dominated by V. paradoxa. V. paradoxa is an agroforestry tree most often found in fields outside of this study area.

P8.L17. These are not average diurnal cycles, but single days samples. For me, all the results and conclusions drawn from this analyze (otherwise very interesting!) are weak due to the under sampling of diurnal cycles. For instance, we could not state from these single days, that 'Net radiation is slightly higher during the wet season (P8.L21)', (although this is probably true). If there is enough data to produce composite diurnal cycles over larger periods, please do. It is very hard to understand why there is such a significant LE flux in April over the field, which should be composed of bare soil according to the text and pictures. I can only suspect that there has been a rain in the previous day(s), - and there has been rain events in April according to Fig.4, and that the single day sample is too particular to be analyzed as a representative day. There may also be some other processes acting, such as lateral subsurface water transfer, and that should be discussed, but I doubt so. Another solution is to provide time series of RN, LE and H (and SM, rainfall, NDVI), as proposed on the comment P6.L6, on a larger plot than Figure 8, and not separated by wind sectors.These results should be discussed in the light of previous results for diurnal cycles obtained in the area (Guyot et al., 2012; Mamadou et al., 2014, 2016), for instance.

> Thank you for the suggestions for data presentation. It is clear that picking representative days can never capture the amount of variation visible. In a previous iteration of the paper, I did have a composite day, but we removed it because it concealed too much information. The scatter plot comparison of the components of the energy balance shows the information the comparison that would be visible on a composite plot, though not the diurnal variation. Figure 9 breaks up these comparisons by individual month. I will reconsider the choice of graphics once I make a time series plot as you suggest.

P8.L25: there is also, for both sites, this interesting feature in the late afternoon that LE> RN and even slightly positive during the night, as noted in (Mamadou et al., 2014, 2016), for instance.

> Thank you for identifying this comparison, I will discuss it more in my improved comparison to other sites.

P8.L31: It was lower over the field (if I am not mistaken).

P8.31: again, the expression 'for all months' does not hold when only two days are compared.

> According to figure 9, which is a composite comparison of all the months individually, shows that the ratio of Rn-ag to Rn-forest in April is less than 1, which means that it is lower over the field.

> Thank you for catching this mistake.

P9.L2: this is an interesting statement, but it needs to be further supported. For in- stance, (Mamadou et al., 2016), for a forested site in similar conditions, noted an early LE peak in the dry season, but also that Soil moisture changed very little from the morning to the afternoon (<0.1mm). They concluded that it was probably a temperature limitation of stomatal opening.

> Thank you for pointing me to this work.

P9.L2-7: this is not supported by a figure. Again, I think that time series of the fluxes should be shown. Also, I think the discussion on limitations should consider here conductances, which can be affected by several processes, such as moisture limitations, but also shading, or stomatal resistances.

> Thank you for the suggestion, I will include this in my revision and consider how to best support it with a figure.

P9.L5. What is the 'absolute maximum'

> Thank you for pointing me to this imprecision and confusion. I will rewrite it.

P9.L11. I am not sure about this conclusion. I think that dynamic aspects should be taken into account, as fields and savanna will not necessarily have equal amounts of RN at the same time. I am not entirely sure on this, and I think that calculating G from temperature probes could help on that.

> This is also a good suggestion, I will qualify it and think about how to support it better (or refute it).

P9.L15-19. I think this is similar to what is found in (Guyot et al., 2009)

> Thank you for identifying this comparison. I'll explore it more in depth.

P9L20-28: This relates to the footprint concept. To my point of view, the footprint should be explicitly calculated for specific periods. But I would understand that it could significantly impact the paper in its current form. At least, wind sectors of Figure 8 should be more discussed; For instance, I do not clearly understand what is the difference between all the time series of, say, the Field panel, how have they been calculated? Also, I may be wrong, but I guess that N-W winds are the Harmattan winds, bringing hot, dry, and dusty air from the Sahara, and S-E winds would be the monsoon inflows, bringing moist air? If so, and as this has significant impact in the resulting energy budget, it could deserve some further insights (see e.g. (Guyot et al., 2012)).

> The wind sector analysis was a strategy to interpret the data based on the wind direction without a foot print analysis. Thank you for pointing out the aspects that are not clear, I will explain it better and further put it in context based on current literature.

P9.L25-27. I agree with Reviewer #1 that Figure 7 does not bring much, thank you for agreeing to move this figure to the appendix. Also, I am not sure that such correlation is an evidence for a causal effect.

P10.L2. Burning practice should be defined in the site description.

> I will. Thank you for the suggestion.

P10.L11-15: thank you for the correlation coefficient added on this figure.

P10.L25: My guess is that there are serious temporal limitations in this approach, and although the correlation coef are not too bad, the approach could probably be improved by considering different time windows. For instance, in the field, there is bare soil in the dry season, and for a little while, only soil evaporation may occur, and there is probably no need to take NDVI into account. On the opposite, once the herbaceous layer has grown, the system may not be water limited anymore, and soil moisture is not needed anymore. During the growing phase only, the equation could probably produce better results.
Also, what soil moisture time series have you used? If this is the catchment averaged one, then the higher regression slope on soil moisture for the field further indicate a higher

moisture-controlled system. If the ultimate goal is to compare it with remote sensing-derived soil moisture, this could easily be added here.

> These are very good suggestions. I would like to refine the model more, however perhaps it is beyond the scope of this paper? I will try to explain my soil moisture time series better in my revision. I did use a catchment averaged soil moisture, which does mean there is some bias, since there were more sensors and better working sensors, in the cultivated field.

P11.L4-10: some statements need to be made clearer (but maybe this is due to my poor english):

'sensible heat flux showed the greatest diff. in November & March': agree for November, although October seems even more different, but the ratio in March is close to 1. Unless the two mentioned surfaces are the two field surfaces (2009: millet, 2010 fallow)? But then it should be June and September. Again, for LE flux: the strong difference between forest and field are in March. I guess you point to the millet and fallow land use? Could you further discuss on why the fallow evapotranspirate less?

> Thank you for these comments, this is helpful to know where I need to go into more depth in my discussion. I'll improve these passages. It should be understandable even to a non-english speaker!

L7-9: I think again Figure 8 is not clear enough, why not having a plot (as suggested above) with the fluxes of forest + field on a similar panel? There could be a panel of Rn, of LE, H, Soil moisture(+precip), and, say, NDVI?

> Thanks for the suggestion. I'll see how I can improve this figure and the time series in general. Perhaps your other suggested figures will also improve this point.

L9: The strongest difference could also be expected in the dry season, no? (see e.g. (Mamadou et al., 2016)) Or please expand on why this is expected.

> I would think this would be the highest difference because one site is still "moist" and the other is dry at this time. I'll see if Mamadou's findings help me explain this in a more relevant and convincing way.

On Rn: (Guyot et al., 2009) described a higher Rn on the dry season over woody cover, because surface temperature was lower, and LWnet higher. This could be discussed (if judged relevant), because there is an opposite behavior here. Although according to Fig.7 LWnet is higher in the forest in the dry season, and there are two tails in the LW-net box plot of Figure 6.

> I'll discuss it in contrast to Guyot's findings. This is very helpful.

P11.L15-16: I am not sure why rock presence should be mentioned here. Plus, they are not the only producers of H fluxes. Maybe an extra sentence could be added? And to clearly show that they are somehow responsible for a good part of H flux, a footprint analysis should be undertaken.Also, according to Figure 1, there is a strong topographic difference close to the forested area. I am not a specialist, but could that affect fluxes in any way?

> Yes you are right. This is why I performed an extra coordinate transform on the data, which goes beyond the normal procedure of data correction. I'll try to pull up some more examples of how rock presence changes the energy balance.

P11.L18: this is not clear to me: are we talking about trees getting water from open waters in the channel? If not, it should be simply stated that upper trees have 'probably' access to shallow groundwater at the origin of the springs.

> Yes, that is a smart way to word it.

P11.L20: what is permanent?

> The spring, I'll clarify.

P11.L20-21: I guess reference to the land cover is missing: this sentence relates to the field, right?

> yes you are right, I'll clarify

P11.L26. According to the picture in Figure 5, the field location is not particularly covered with more vegetation. The LE fluxes there are really high, and I have no explanation for this. On a Large Aperture scintillometer beam pathway, including very mixed cover, and including also a gallery forest preserved for similar reasons (Guyot et al., 2012) had much lower LE fluxes for instance. Same observation for (Brummer et al., 2008) in South West Burkina Faso, at a similar latitude, or (Mamadou et al., 2016) in a fully forested parkland in North Benin. This is very surprising, and I have no explanation.

> I'll look more closely at each of their cases and try to offer a more convincing explanation.

I am also curious, I have looked at the satellites images in google map, and the field location seems to appear in a middle of a much larger forest. What is at the origin of this specific deforestation? (this is not relevant in the review, only personal interest).

> The area all around this site is preserved as hunting reserves and Arly National Park. When people were forced to stop living in the areas as the became reserved, they were granted permission to live and farm only on this small "island" inside of the conserved area. I am sorry I didn't make this history more clear. As a side project during this research, I collected some oral histories of this transition. I hope to publish something from these interviews as well, although it will probably be in a different journal.

P12.L5-8, this should be rewritten according to the references given in the comment P2.L32. There is a site in Burkina Faso in similar climatic context, and sites in Benin are not that far south, and as for the cultivated ones, have probably a rather similar ecological context.

> Thank you again for pointing me to that work.

P12.L11-18: I have read that references to figure 12 have been added, as well as more discussion. Currently there is a strong issue that really needs to be addressed: The EF clearly shows that fluxes are very high, and this should be commented. EF could be compared with the study of (Lohou et al., 2014), which spans different eco-hydrological contexts through the N-S West-African gradient. In your Figure 12, EF does not seem to drop below 0.5, which is exceptionally high. If I roughly take a yearly average value of 0.6, and a yearly average daily value for ETo of say 5mm (Wang et al., 2007), which is probably a lower bound for ETo in this area, this produces about 1100mm or evap-otranspiration yearly, which is much higher than precipitation. Footprint analysis could be undertaken to identify the reason for such high evapotranspiration. This could lead to very promising result.

> Yes, thank you for this precision. Perhaps I will add a table to directly compare our results to others to try to pull out reasons why ours are so different. I will think about adding a footprint analysis in the future.

P12.L23: cultural taboos, or health-related issues (malaria)?

> I am basing this on the best ethnography that I found of gourmantche agricultural practices. I did not study the full motivation behind historical taboos.

P13.L8: Add 'in the field', to make it clearer
> Thank you for this suggestion

Figures: In general, figure captions are too long and should be limited to description and not interpretation, but Figures are of good quality.
> Thank you, I will try to shorten them and put more in the text.
Figure 1: If possible, I would prefer the elevation shown as contour lines to better see the satellite image below. For instance, it is impossible to locate the village. And also, it is not easy to understand what is the dark line S-E / N-W just north of the study area: is it a plateau edge or a riparian area? I would recommend to put contour lines of the whole map, and draw the catchment contours with a proper shape.
Remove 'land locked country'? and 100m of elevation change. . .and the plateau?. If this is important, it should be put in the main text.
> Okay thank you for this, it is also in the main text, so I'll remove it here. I'll try to improve the map.

Figure 2: Figure caption: you could remove the last sentence, which is interpretation
> Okay, I will put it in the text.

Figure 4: soil moisture is exceptionally high in 2011 (known to be a dry year in the area, so I doubt there is any issue with the rain record), could you comment on that?
> This is a good point. I'll try to find an explanation. But if I can't, it is worth pointing out this inconsistency.
Figure 5: thank you for putting in the same figure both photographs and diurnal cycles, this makes a nice figure.
> You are welcome.
Figure 6: Figure caption: you could remove interpretation sentences. I also think there is some confusion in the middle-bottom two description.
> Okay, I'll clarify and move interpretation to the text.

P2.L1: change sudanian to sahelo-sudanian
> As stated, based on the floristic composition of the site, we are solidly in the biogeographic / phytosociological zone, and not the sahelian or Sudano-sahelian. I have added a botanical inventory to support this.

P2.L16: add 'in' before Eq.(1)
> Okay, Thank you.
P3.L7: [. . .]the diurnal cycle 'of' each [. . .]
> Okay, Thank you.

P4. L3: [. . .] were made in 'a' small [. . .]
> Okay, Thank you.
P4. L21 'in the' Guinean zone
> Okay, Thank you.
P6.L9. remove 'infrared'
> Okay, Thank you.
P7.L4. where 'smoothed'
> Thank you, this part was moved to the Supplementary Material
P8.L5. remove first occurrence of 'air'.
> Okay, Thank you.
P8.L21. for the both sites'
> Thank you
P8.L25. Heat instead of heath
> Thank you
P9.L12: remove 'below'
> Thank you
P9.L21: contributed 'to' higher fluxes'
> Thank you
P10.L24: be fitted'
P11.L16: at the end of the 'wet' season'
> Thank you
P12.L27: has protected 'it'?
> Thank you

Open - Reviewer # 3

Major Comment: Firstly, the paper is poorly organized, with much extensive content, though not exhaustive and too much interpretation in the results. While the methodology, in particular the eddy covariance data treatment requires a particular attention to have reliable turbulent fluxes, this was partially presented by the authors and the units of keys variables were omitted. In addition, there was a total confusion in the signification of such variables. For example, the available energy is not the sum of turbulent fluxes (H+LE) but rather the difference between the net radiation and the soil heat flux (Rn-G), see L13, L25, p5; and section 3.2.2.
> I have tried to make my wording and variable reference more precise and detailed.

Secondly, one of the main points of this paper was in the site comparison; however, basic information about the research sites was lacking. Did both sites have similar soil characteristics? The large differences in soil water content may indicate site differences in soil texture.
> I include more information about soil characteristics.

Also, more information is needed about the flux footprint. What was the fetch? Was the vegetation in particular (the rain fed site) within the flux footprint homogenous? The forest site seems to be located in a very complex topography according the map of the site (Figure 6). How this has been taken into account in the analysis of eddy covariance data?

> This was also a comment from AR2. We used a planar tilt correction to correct for the positive average wind speed as described by Oldroyd, H. J., Pardyjak, E. R., Huwald, H. and Parlange, M. B.: Adapting Tilt Corrections and the Governing Flow Equations for Steep, Fully Three-Dimensional, Mountainous Terrain, Bound.-Layer Meteorol., 1,Äì27, 2015.

> While I think a flux footprint would be interesting, I am saving it for a future analysis due to certain constraints that I discuss in my reply to AR2.

These aspects are important for understanding and interpreting the results. Finally, what is the value of the slope?
> I add a calculation of slope for the different wind directions around the EC stations.

Some of the writings throughout the text may be rewritten in more compact and yet concise style without losing the message they want to convey to the readers.
> This is a good comment, I hope that I improved the writing.

Some conclusions are drawn without the support of data.
> I hope that I have improved the writing of conclusions

Abstract L18-20: Which period of the year? I am very surprised with this result!
>
L18-22: I don't agree with this deduction. The presence of rocks and trees cannot, from my point of view, allow you to say that the soil heat flux is higher in the fields. You should take care with this assertion since you don't have any in situ measurements or direct calculation/estimation of this term of the energy balance to reinforce your conclusion.
>
Introduction L15-25: Give the units of all variables the first time that they are used.
>
L14-16: The cited reference Foken, 2008 'The energy balance closure problem: An overview' is not an appropriate reference. T. Foken has never worked on the link between global atmospheric processes and the land surface atmosphere interaction. Please provide an appropriate reference.
> Foken among the other cited references have all discussed the challenges of energy balance closure. Burba, 2013; Domingo et al., 2011; Farhadi, 2012; Federer et al., 2003; Foken, 2008; Foken et al., 2009; GUO et al., 2006; Katul and Parlange, 1992; Krishnan et al., 2012, 2012; Kustas et al., 1994; Parlange and Katul, 1992; Williams et al., 2012
L18: Write LeE is 'latent heat flux' instead of latent energy flux.
> Okay, Thank you.
L29: Replace Evaporation by Evapotranspiration since you were talking about vegetated surface.
> Brutsaert, 1982: evaporation is usually adequate to cover all processes of vaporization - transpiration from vegetation and direct evaporation from the soil are difficult to separate, water that is transpired is also evaporated through the stomata of plants.
L30 -33: It is true that in situ data of energy and water vapor fluxes were limited 'in the past', but today there are a lot of studies which have been conducted in this part of Africa

(Guyot et al, 2009; 2012; Mamadou et al., 2014 and 2016; Velluet et al., 2014; Timouk et al., 2009; Ramier et al., 2009).
>
L12-15, p3: THIS is not general but depends on the region; authors should specify the region in which this result has been obtained.
>
L1 27, section 2.1 there are too much information's which are from my point of view not really essential for the interpretation of fluxes. An example "the village is made up of a majority...". I cannot get the importance of this sentence and elsewhere in the section 2.1.
> Thank you for your perspective. The ethnic groups of the village are relevant because a link is made to traditional land use practices.

L32 p4: Infrared gas analyzers. Open path or closed path? Need to be precized
> Thank you.
L1 p5: Replace eddy correlation by eddy covariance. What is the distance between the two studied sites?
> Okay Thank you.
L10: This is not true!! Sensible and latent heat fluxes cannot be measured at a half hour time step if you really used eddy covariance system to measure the fluctuation. How the sampled data have been then processed? What are the selection criteria? Given the complexity of these measurements, it is very shocking to see that certain details were not presented. Why do you use day light measurements (8am ' 4pm) for the comparison? Give the reason of this choice.
> We measured everything at 10 Hz but only calculated fluxes at a half hour time step. All covariance measurements were calculated exactly as said with the corrections stated. We did not use any software besides our own Matlab code that has been used for many studies and was modified for Burkina Faso. The errors of eddy covariance are much higher at night and at dawn and dusk.
L20: Give the unit of different variables of Eq 4.
> ok
L25: Here instead of using the day light measurements as mentioned in L10, you preferred to use midday average. Why?
>Evaporative fraction is only computed once per day. The logic is exactly the same, but here we calculated when there error increased. There is a whole body of literature on this.
L9, section 2.6: What do you called the incoming shortwave infrared radiation? Is it the incoming shortwave radiation? If yes, make it clearer.
> ok

P7, Give the units of variables of Eq 9 to Eq12.
> ok
L5, p7: Longwave incoming or reflected radiation?
> I am not sure to what you are referring.

L8: Write Ts instead of T s
> I am not sure to what you are referring.

L5: I cannot get the meaning of this sentence.

> I am not sure to what you are referring.

L17: You started by saying that energy balance varied according to the month, i agree and now you compare a single day in April and in July. This is not coherent with the title of the section.
> Yes, I hope it is clearer now.

L23: Write the sensible heat flux
>okay, thank you.

L24-25: In the sentence, 'by July the latent heat has surpassed the sensible heath..'. How do you explain this fact? Replace heath by heat in the sentence.
> This can be explained by moisture availability.

L26-27: What was the magnitude of this residual in the morning? residual is lower over the savanna (which values?) and what about the agricultural field?
> Give magnitudes.

L30: What is the dust season? How was it objectively defined? Although the dust is something common over the region, it should affect also the measurement of the second site. How do you explain the fact that the net radiation was lower over the savanna-forest?
>This has been clarified, Net radiation was lower over the savanna – forest due to differences in albedo that were discussed.

L31-32: I am very surprised with these results. They are contrary to those obtained over the region. . .I would like to see the temporal evolution of H and LE based on half hourly data over the two studied sites.
> Okay I hope that I put them into more context and improved the figures to your liking.
L1-4, p9: I cannot get the meaning of the sentence ?The timing of the peaks of latent energy. . .the peak in the diurnal was after noon?. This sentence may be rewritten in more compact and yet concise way. Replace latent energy by latent heat flux and elsewhere in the paper.
> Okay thank you.
L6- 7: I would like to see the diurnal cycle of the available soil moisture
> I will go into more detail regarding soil moisture, for more detail on the soil texture, please see Ceperley, 2014.

Section 3.2.2: What is the general correlation?
> You are correct, this is not a technical term.
L25: It is normal since the reflected longwave radiation depends on surface temperature (Eq. 9)
> good
Section 3.2.3: it is very surprising that the savanna-forest contributed more sensible heat flux throughout the year than the agricultural land. The convection above the agricultural field should be more than that of the forest because the 'exposed area' and also the presence of vegetation over the forest which should limit this process.

> Yes, I was also surprised.

Section 3.3.1 Could you give the values of coefficient correlation and their associated p-values? It seems that wind speed is also correlated with EF. How have you identified the two dominant variables? How landscape moisture availability can be expressed as both NDVI and soil moisture? Higher levels of soil moisture? Which levels? What is the total net radiation? In the sentence ?Total net radiation does not show a strong influence, suggesting that this is not a radiation limited system?, I do not see the data which support this conclusion.

> I have now added correlations to the figure. Wind speed is less.

L21, replace supposition by hypothesis.

>ok

Section 3.3.2: Give the values of coefficient correlation and their associated p-values of your fit.

>ok These were in the original figure 11. I will now move them to the text.

Section 4.1, L13-16: I am not sure for these explanations. . . L19-20: What allow you to say that the level of water availability is permanent? Show then the water table in dry and wet season?

> I looked at it every day all year. I have pictures. The water level is explored more in depth in my colleages thesis.

L21: Replace latent heat by latent heat flux (and elsewhere in the paper)

>ok

L7-9, p12: I cannot get the meaning of the sentence In table 1: The Li-7500 measures both H2O and CO2 concentrations not 'HO concentration'. It seems that authors only provided the height of sensors above the agricultural field. What is the height of eddy covariance and additional measurements above the savanna-forest?

> Our licor was not calculated for CO2. Thank you for catching the typo with water. The two stations were identical in terms of height from surface.

Figure 4: Environmental parameters at study site (which one?)

> Averaged across all except when other wise noted.

Figure 5: Write in the title Diurnal cycle of the energy balance components. In the title of

> Okay Thank you

Figure 6 : H+LeE is not the total available energy!!!

> Understood though it is the sum of turbulent fluxes which is equal to total available energy.

Figures 11 and 12 are not cited in the paper.

> This has been improved.

Sincerely,

Dr. Natalie Ceperley, University of Lausanne

Evaporation from Cultivated and Semi-Wild Sudanian Savanna in West Africa

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Abstract. Rain-fed farming is the primary livelihood of semi-arid West Africa. Changes in land cover have the potential to affect precipitation, the critical resource for production. Turbulent flux measurements from two eddy-covariance towers and additional observations from a dense network of small, wireless meteorological stations combine to relate land cover (savanna forest and agriculture) to evaporation in a small (3.5 km^2) catchment in Burkina Faso, West Africa. We observe larger sensible and latent heat fluxes over the savanna-forest in the headwater area relative to the agricultural section of the watershed all year. Higher fluxes above the savanna-forest are attributed to the greater number of exposed rocks and trees and the higher productivity of the forest compared to rainfed, hand-farmed agricultural fields. Vegetation cover and soil moisture are found to be primary controls of the evaporative fraction. Satellite derived vegetation index (NDVI) and soil moisture are determined to be good predictors of evaporative fraction, as indicators of the physical basis of evaporation. Our measurements provide an estimator that can be used to derive evaporative fraction when only NDVI is available. Such large-scale estimates of evaporative fraction from remotely sensed data are valuable where ground-based measurements are lacking, which is the case across the African continent and many other semi-arid areas. Evaporative fraction estimates can be combined, for example, with sensible heat from measurements of temperature variance, to provide an estimate of evaporation when only minimal meteorological measurements are available in remote regions of the world. These findings reinforce local cultural beliefs of the importance of forest fragments for climate regulation and may provide support to local decision makers and rural farmers in the maintenance of the forest areas.

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1 Introduction

The sudanian savanna in South-Eastern Burkina Faso is a patchwork of savanna, forest, and scrubland with some patches more representative of the drier Sahel, and others more representative of the more humid Guinean forests. Vegetation is mainly deciduous according to seasonal moisture availability, but spatial variations in topography, water availability, and plant communities result in some variation in greenness and some evergreen species, for example near the springs. Historically, people in this region rely on a mix of hunting and gathering, small scale agriculture, and pastoralism. As land claims and regulations have changed, communities have been forced to rely more on agricultural production as a primary source of food and income, resulting in land conversion for agriculture. Today small-scale rain fed agriculture is the dominant livelihood in large parts of West Africa, despite its high level of dependence on seasonally controlled hydrology. Conversion of the landscape to agriculture involves removing rocks, trees, natural grasses, and tilling the soil (Swanson, 1978). Transformation of forestland to agriculture has been shown by model simulations to alter global circulation, hydrology, and biogeochemistry both in the present and in predictions of the future (Abiodun et al., 2008; Feddema et al., 2005; Mande et al., 2011; Steiner et al., 2009; Sylla et al., 2015; Vitousek, 1997).

Modification of the land surface results in changes to the physical environment, and specifically hydrological fluxes, by altering the components of the surface energy budget (Pielke et al., 2002). The partition of net radiation into sensible heat, evaporation, and soil heat flux drives global atmospheric processes and is controlled by interacting surface and atmospheric conditions (Foken, 2008; Szilagyi and Parlange, 1999).

The energy balance is challenging to close even in areas and regions with extensive datasets and accessibility, and is particularly challenging in areas with complex surfaces (Burba, 2013; Domingo et al., 2011; Farhadi, 2012; Federer et al., 2003; Foken et al., 2009; Guo et al., 2006; Katul and Parlange, 1992; Krishnan et al., 2012, 2012; Kustas et al., 1994; Parlange and Katul, 1992; Williams et al., 2012). Evaporation from vegetated surfaces remains the component of the global distribution of water that is the least frequently measured and thus the least well understood (Brutsaert, 1982; Brutsaert and Parlange, 1992; Burba, 2005; Compaore, 2006; Crago, 1996; Crago and Qualls, 2013), particularly in West Africa, due to limited field observations (Bagayoko et al., 2007; Dolman et al., 1997; Gash et al., 1997; Mande et al., 2011). A connection exists between changes in albedo and the occurrence of drought in West Africa, although the physical processes and direct implications for desertification are debatable (Charney, 1975; Nicholson et al., 1998).

The evaporative fraction, the ratio of latent heat flux to available energy, is useful to estimate total daily evaporation with measurements of a single component of the energy balance and to up-scale surface measurements using remote sensing products (Brutsaert and Sugita, 1992; Compaore, 2006; Porte-Agel et al., 2000; Shuttleworth, 1989; Szilagyi et al., 1998; Szilagyi and Parlange, 1999). Using evaporative fraction to calculate the total daily evaporation is based on the concept of self-preservation in the diurnal evolution of the surface energy budget (Brutsaert and Sugita, 1992; Porte-Agel et al., 2000), stating that the diurnal cycle of each of the energetic fluxes will resemble that of available energy, even if there is variation in the quantity, allowing for exploiting satellite data that are typically only obtainable once a day at best. Remotely sensed

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land surface temperature is currently the primary tool for mapping the surface energy budget over a large area (Bateni and Entekhabi, 2012). Evaporative fraction is constant during day time in fair weather conditions (Gentine et al., 2007) but can be much less constant when moisture circulation rates are high and available soil moisture increases (Lhomme and Elguero, 1999). Seasonal progression of evaporative fraction response to rainfall and moisture availability can depend on surface conditions. For example, it can respond faster in grassland than in woodland (Farah et al., 2004). These variations are not explained by meteorological conditions, including cloudiness alone, but rather change in surface resistance and moisture advection and availability (Farah et al., 2004; Lohou et al., 2010, 2014).

We measured the complete energetic and hydrologic fluxes in two sites of a semi-arid, mixed-use catchment over a year and a half, capturing both the greening and dry-down phases. The land is used as a agroforestry parkland farmed every 2-3 years and a forested area made up of evergreen trees arranged in a gallery forest surrounding a spring and an open wooded savanna (savanna-forest) on a plateau about 100 meters above the surrounding land. These land covers are representative of the surrounding region and capture the range from more to less anthropogenic land uses. The multi-use comparison over multiple seasonal cycles puts this study among the few recent, long-term studies in this region (Bagayoko et al., 2007; Brümmer et al., 2008; Ezzahar et al., 2009; Guichard et al., 2009; Guyot et al., 2009, 2012, Lohou et al., 2010, 2014, Mamadou et al., 2014, 2016; Mauder et al., 2006; Ramier et al., 2009; Timouk et al., 2009; Velluet et al., 2014). We calculate the evaporative fraction over the study period and compare it with land cover and atmospheric controls, in order to provide estimation based on the physical basis of fluxes. Our measurements are significant because they allow calibration and comparison for calculation of the components of the energy budget from lower cost and more easily maintained stations (Nadeau et al., 2009; Simoni et al., 2011) and corresponding data from satellite imagery. This study has implications for development priorities, as it takes place in context where local livelihood can be dramatically affected by slight changes in the water balance and land cover.

2 Measurements and Calculations

2.1 Site Description

Observations were made in a small catchment (3.5 km^2 area) neighboring the village of Tambarga in the commune of Madjoari, in the Gourma Province, in Burkina Faso, West Africa (figure 1). The ephemeral stream defining the catchment (outlet is 11°26'29.7"N 1°12'57.7"E) flows into the Singou River, which joins the Pendjari River and eventually flows into the White Volta of the Volta River Basin, the third largest river basin by area in West Africa, after the Niger and the Senegal. A rocky escarpment defines the catchment with a plateau on average some 100 meters above the lower agricultural fields and the soil is predominantly sandy-loam (Ceperley, 2014). These fields are the "house" farms and are smaller than the main revenue farms. In 2009, they were farmed with short rotation millet and in 2010 they were left fallow. Plowing occasionally uses animal-drawn plows, but is primarily done by hand – this is not intensive agriculture. The open wooded savanna (savanna-forest) on top of the rocky escarpment and rain-fed grain (corn or millet) are the two dominant land covers of the

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catchment according to area. At opposite ends of the catchment, there is a dense gallery forest in the valley that grows near perennial springs and an ephemeral wetland used for rice cultivation near the point considered the outlet of the watershed. The existence of a raised plateau with perennial springs suggests that there may be lateral subsurface water transfer. Farming is the main livelihood in the village and crops include millet, sorghum, cotton, and rice. Agroforestry trees in the fields are common and consist most often of the tree species *Vitellaria paradoxa*, *Sclerocarya birrea*, and *Ficus* sp. (Bordes, 2010, see table 2). Burning mostly occurs between November and January, but occasionally there is a fire in February or March. The village is made up of a majority of people from the Gourmantche ethnic group, though there is a significant population of Peulh, and some migrants of other areas of Burkina Faso or neighboring countries (Ceperley, 2014).

The watershed falls in the sudanian zone of the West African monsoon climate system, defined by alternating wet and dry seasons, with the rain falling between May and September. The natural vegetation is sudanian-wooded savanna, composed of a mix of deciduous woody trees, shrubs, and tall grasses. In addition, due to the variation in topography and water availability, there are gallery forests near streams or rivers that contain many species endemic further south, in the Guinean zone. The surrounding area is a patchwork of hunting reserves and national parks, and thus has a higher level of vegetation cover than most of the country. This watershed is a prime location to study the consequences of land use change from sudanian savanna to agricultural fields, since it contains both open wooded savanna that hasn't been memorably farmed and regularly farmed fields. Agriculture is primarily rainfed and not mechanized corn and millet cultivation. In addition, the surrounding sudanian savanna, which is characterized by fire-selected grasses ranging from 20 centimeters to 1.5 meters in height also includes patches of woody scrub-land, open forests, gallery forests, and riparian stands (Arbonnier, 2004). Inventory of woody species taller than breast height in the two major land covers was inventoried according to Adamou (2005) and is reported in Table 2.

2.2 Field Measurements

Two energy balance stations were installed from May 2009 through September 2010. One was situated in an agricultural field planted with short season millet in 2009 and left fallow in 2010, and the second one measured over the gallery forest when the wind came from the West (90°±45°) and over the open wooded savanna when the wind came from the South (180°±45°). They were equipped with sonic anemometers, infrared open path gas analyzers, net radiometers, and air temperature and humidity sensors (table 1). Eddy-covariance equipment was placed facing two opposite directions (46° and 226°) on the lower station over the field and in the dominant wind direction on the upper station over the gallery forest. The distance between the two measurement points was approximately 1 kilometer and 100 meters of height difference. Nearby the station in the field was a high precision rain gauge measuring at a resolution of 0.1 mm. In addition, a network of up to 12 small meteorological stations (Ingelrest et al., 2010), was distributed across the watershed with sensors to measure incoming solar radiation, wind direction and speed, air temperature and relative humidity, rainfall, soil moisture and temperature, and surface temperature. In this analysis, we use data from May 2009 - October 2010, the 15 months with both

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towers operational, but when possible, we present the longest time series possible for climatic context. We attempted to measure ground heat flux using heat flux plates but ultimately rejected the observations because of irregularities in the land surrounding the plates.

2.3 Flux Calculation

The surface energy budget is written in Eq. (1):

$R_n = L_e E + H + G$, (1)

where $L_e E$ is latent heat flux, H is sensible heat flux, R_n is the net radiation, and G is the soil heat flux, all in Watts per square meter (W m^{-2}).

The sensible heat, is expressed in Eq. (2):

$H = \rho c_p \overline{w'T'}$, (2)

where ρ is the air density (kg m^{-3}), c_p is the specific heat (J kg^{-1} K^{-1}), $w'T'$ is the covariance of fluctuations of vertical wind speed (m s^{-1}) and temperature (K). Latent heat flux, is expressed in Eq. (3):

$L_e = L_e \rho \overline{w'q'}$, (3)

L_e is the latent energy of vaporization (J g^{-1}), and $w'q'$ is covariance of fluctuations of vertical wind speed (m s^{-1}) and humidity (g m^{-3}).

All measurements were taking at 10 Hz, and fluxes of sensible (H) and latent (L_eE) heat were calculated at a half hour time step using the covariance calculations as written above. Only day light measurements, consistently between sunrise and sunset (8 am - 4 pm), corresponding to when energetic fluxes were of significant magnitude, were used for the comparison. The total of turbulent fluxes, H + L_eE, was subtracted from the net radiation, R_n, to give an indicator of ground heat flux (G, see equation 1), any unaccounted for flux transfers, and the error (Brutsaert, 1982; Higgins, 2012).

We used a planar fit correction that effectively tilted measurements of the three components of the wind field perpendicular to the direction of flow, so that the vertical wind was equal to zero over one month averaging periods (Aubinet et al., 2012; Burba, 2005; Oldroyd et al., 2015; Rebmann et al., 2012; Wilczak et al., 2001). We then performed a linear regression using the mean wind vectors to obtain a matrix that we used to adjust wind vectors and stress tensors in a new coordinate system with a z-axis perpendicular to the mean streamline. Finally, we rotated the intermediate winds and stress tensors. The Webb-Pearman-Leuning equation (Foken et al., 2012; Leuning, 2007; Webb et al., 1980) Eq. (4):

$E = (1 + \mu\sigma)(\overline{\omega'\rho'_v}) + \frac{\bar{T}}{\bar{\rho}_v}\overline{\omega'T'}$. (4)

was used to correct for any influence of trace gas concentrations on temperature and humidity fluctuations.

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2.4 Evaporative Fraction

Evaporative fraction (EF) was calculated for each half hour of data, separately over the savanna-forest and the agricultural area by dividing the latent heat flux by the available energy, which is equivalent to the sum of sensible and latent heat flux. Although the true measure of available energy would be the difference between the net radiation and the ground heat flux, the sum of the turbulent fluxes, H and LE, was deemed more accurate given the rejection of our ground heat flux measurement. The midday average (10 am - 2 pm) was used as the EF for a given day as that is when it was the most stable over the year (figure 3) Eq. (5):

$$Ef = \frac{L_eE}{H+L_eE} \,. \quad (5)$$

2.5 Volumetric Water Content

Volumetric water content (VWC, m^3 m^{-3}) in the soil was monitored at 15 and 30 cm depths in 2009 and at 5 and 20 cm depths thereafter at some of the small meteorological stations representative of the various land covers (Table 1) using a measure of soil dielectric permittivity and converted to VWC (Topp et al., 1980). Measurements were averaged on the half hour time step for comparison with EC measurements and by day for comparison with EF. Gaps in measurement were due to sensor malfunction. A vertical, spatial average of measurements at various depths was used to obtain a continuous record for the watershed.

2.6 Cloud Cover

Cloud cover was calculated by dividing the incoming shortwave radiation (W m^{-2}) measured with a radiometer (table 1) at each small meteorological station by the theoretical incoming radiation (W m^{-2}) calculated with a simple model (Whiteman and Allwine, 1986) for each of the small meteorological stations operating on any given day Eq. (6):

$$CC = \frac{sw_{measured}}{sw_{Whitman\&Allwine}} \,. \quad (6)$$

The cloud cover was calculated independently for all stations and then averaged to give a single value per day.

2.7 Vegetation Index

Normalized difference vegetation index (NDVI) is based on the amount of infrared radiation absorbed, which is related to the amount of photosynthesis taking place. It is considered a measure of the density of chlorophyll. NDVI is a ratio of the near infrared (NIR) to red wavelengths Eq. (7):

$$NDVI = \frac{NIR-Red}{NIR+Red} \,. \quad (7)$$

Seasonal change in NDVI was observed by extraction of the area of interest from the 250-meter resolution West Africa eMODIS 10-day temporally smoothed data (USGS FEWS NET). It has been corrected for molecular scattering, ozone absorption, and aerosols and then smoothed using a least square linear regression (Swets et al., 1999). The NDVI values are

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validated with *in situ* observation and photographs. The pixels that contained our stations were extracted to give a catchment – wide seasonal impression of the vegetation change. All of the pixels that cover our catchment are composed of multiple vegetation types, given the relatively coarse resolution, but they have been sorted by dominant land cover. An inventory of woody species (diameter at breast height, 1.3 m, greater than 10 cm), was performed for 1 hectare of the forest – savanna and the entirety of the agricultural area within the catchment (table 2). Vegetation was classified according chorology and life form (Adomou, 2005).

2.8 Wind Sector Partition

Dominant wind direction for each half hour covariance measurement was used to sort the sensible and latent energy fluxes (Figure 6). Computation of the mean flux according to wind direction allowed for examination of the effect of wind direction, and corresponding land surface, on the flux magnitudes.

3 Results

3.1 Seasonality

A total of 1600 millimeters (mm) of precipitation was measured over the period of intensive monitoring, 2009-2010, 789 mm in 2009 and 811 mm in 2010 and it fell almost entirely during the period from May to October. As seen in figure 2, average monthly air temperature, cloud cover, soil moisture and NDVI followed the seasonal cycle of the rain: temperature was higher in the dry season (November - March) than in the wet season (May - October); cloud cover was lower in the dry season and increased starting in March and April peaking both years in July; soil moisture was highest in the wet season; and vegetation, as shown by NDVI, increased over the course of the wet season, starting in May and peaking in September and declining afterwards as grasses senesced. The high level of seasonality is characteristic of semi arid environments. Separation between the lower and upper parts of the catchment is apparent in the NDVI time series, where the savanna-forest consistently stays more green, with the field only surpassing it due to its delayed senescence in September 2010. Plowing, early season harvests, and late season harvests are visible earlier in some years over only the agricultural land. However, since these are averages over a few potentially mixed pixels, which were composed of multiple crops, the individual behaviors are not visible. The land use differentiation is visible even at 250 m pixel resolution.

3.2 Components of Energy Balance

3.2.1 By day

The average diurnal cycle of the energy balance varied according to diurnal cycles and by month (figure 3). In this figure, we compare a single day in April with a single day in July. April is before the wet season begins, and prior to any vegetation growth in the agricultural field, however, some of the evergreen forest canopy is already visible in the photos. By July, crops

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or fallow are growing in the field and the canopy is greener. This change in vegetation cover and moisture availability is apparent in the diurnal patterns of the energy balance for both sites. Net radiation is slightly higher during the wet season for both land covers, and none of the fluxes are as smooth, which can be explained by the presence of atmospheric humidity and cloud cover. The sensible heat is higher for both land covers in the dry season, however over the savanna-forest there is still latent flux that nearly matches the sensible heat flux even in the dry season. By July, the latent heat flux surpassed the sensible heat flux for both land covers. This can be explained by moisture availability, as the soil moisture content is much higher in both cases. Over the savanna-forest, we can see that the latent heat flux doesn't decline until the late afternoon, suggesting that it is radiation limited and not moisture limited, whereas over the field it peaks closer to midday. The residual, which is a combination of the ground heat flux and any error, is lower over the savanna-forest, and is negative in the afternoon. For the month of April, the noon median residual is 20% of the noon net radiation for the agricultural field and 13% for the savanna forest and for the month of July, it is 31% for the agricultural field and 25% over the savanna forest. The evaporative fraction is correspondingly higher in the rainy season than in the dry season and as we would expect, has a higher value over the savanna-forest in the dry season but over the agricultural field in the wet season.

Net radiation was the most similar component between the two sites, although during the "dust" season of March and April, it was lower over the agricultural field. Sensible heat was greater over the savanna-forest for all months, with the greatest difference in the "hot" period of March through May, which is an important period for the triggering of early convective storms.

There is a scale discrepancy between the eddy covariance measurements and the net radiometer measurements since the latter only senses exchanges directly above and below it whereas the former's range of detection can span a larger area depending on the wind speed. To account for this, we modeled the net radiation at each small station and then compared it to that measured with net radiometers with acceptable results (see supplementary material).

Latent heat flux was also observed to be greater over the savanna-forest compared to the agricultural field. The point in the day when the latent heat flux peaks signals the moment when the system becomes moisture limited; during the early part of the year, the dry season through May, the diurnal cycle of latent heat flux peaked over the agricultural field during the mid morning, from 9 to 10 am, whereas over the savanna-forest, during the same period, the peak in the diurnal was after noon. In general, our data shows that latent heat flux was greatest at early in the diurnal cycle during the dry season, which suggests depletion of all available moisture early in the day.

3.2.2 Over entire study period

Time series of turbulent fluxes, soil moisture, normalized difference vegetation index, and rainfall demonstrate the highly seasonal moisture and energy availability (figure 4). A high correlation exists for net radiation and the sum of turbulent fluxes (figure 5) between the savanna-forest and the field, with more scatter occurring when soil was wetter (blue). However, the sum of the turbulent fluxes is higher over the savanna-forest than over the field. Since there are equal amounts of net radiation, we can deduce that there is a greater ground heat flux in the field. The lack of shading in the field, and the greater

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abundance of trees, with a high level of productivity, and rocks support this observation. Examination of the two components of net radiation - net long wave and net short wave - shows that soil moisture exerts much greater control on net long wave radiation, with the change in net long wave radiation according to changes in soil moisture in the field much more apparent. Although there is more scatter in net shortwave when soil is wetter, it is less uniformly a response to the two land covers. The savanna-forest's net long wave radiation is greater when the soil is dry whereas the agricultural area has greater net long wave when it is wet. Sensible heat over all land covers is greater under dry conditions than wet (blue), but both sensible and latent heat fluxes are greater over the savanna-forest than the agricultural field regardless of soil moisture. Furthermore, in figure 6, we see that each wind sector has a distinct signature of when latent heat flux is greater than sensible heat flux. This variation can be explained because certain features, such as the ephemeral wetland and the gallery forest (shown in the top left of the forest plot, 16- 46 degrees), contributed to higher fluxes that have access to moisture that persists longer into the dry season. Over the agricultural field, there is more scatter whereas over the savanna-forest, there is a minimal level of about -170 W/m^2 for net long-wave radiation. In this case, the tree canopy buffers the bare ground from the radiation loss.

3.2.3 Month by month

Figure 7 shows the two contrasting trends in surface heat fluxes by comparison of the month-by-month ratios between the measurements over the savanna-forest and agricultural land. The savanna-forest contributed more sensible and latent heat flux throughout the year (ratio < 1), but the difference in sensible heat flux between the two sites was greatest at the end of the year, the beginning of the dry season, and the difference latent heat flux between the two sites was greatest at the beginning of the year, after land was cleared by burning. These trends were consistent over the two years of measurement, however there were some months (July and August 2010) when the sensible heat was close to equal in the two sites. The higher level of similarity in sensible heat between the two sites in 2009 can be explained by the crop choice that year; That field was planted with early (60-95 day) maturing pearl millet crop compared to its usual late variety (130-150 days), requiring a unusually late tilling and an unusually early harvesting, resulting in bare ground during the growing season. These differences are also visible in the NDVI (figures 2, 4). Net radiation was more similar than the other fluxes; the greatest difference occurred when there is bare ground in the field, at end of the dry season, suggesting a higher albedo during this time.

3.3 Evaporative Fraction

3.3.1 Correlations with surface and atmospheric conditions

Examination of the relationship between evaporation and the environmental variables that dominate in various models, shows that for our site, soil moisture and vegetation cover have the strongest positive correlation with evaporative fraction (figure 8). Over both the savanna-forest and the field, we see that landscape moisture availability, expressed as both NDVI

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and soil moisture (VWC), exert a strong influence on the evaporative fraction, with higher rates of evaporation occurring at higher levels of soil moisture and vegetation cover, or in other words moisture availability from either plant or soil. Total net radiation does not show a strong influence, suggesting that this is not a radiation-limited system.

Wind speed shows a strong negative correlation with more evaporation occurring at lower wind speeds, contrary to standard evaporation models. Evaporative fraction and the cloud cover exhibit a positive correlation both over the field and the savanna-forest and could be explained by a two part discontinuous function, with a break at 0.4 (Brutsaert, 1982). In a radiation limited system, cloud cover would reduce evaporative fraction, but in this case, since it is positive, we can deduce that cloud cover is an indicator of high rates of evaporation and moisture availability, thus further supporting our hypothesis that this is a moisture limited system.

3.3.2 Explanatory model

The relationship between soil moisture, vegetation index, and evaporative fraction can be fitted with a linear regression (figure 9), Eq. (8):

$$\begin{cases} EF_{agriculture} = 0.41 \cdot NDVI + 1.4 \cdot VWC + 0.27 \\ EF_{Forest-Savana} = 0.48 \cdot NDVI + 0.35 \cdot VWC + 0.34 \end{cases} \quad (8)$$

Evaporative fraction depends on both soil moisture and vegetation index over agriculture, whereas over the savanna-forest it responds more directly to vegetation index, as shown by the direction of the evaporative fraction color gradient. The evaporative fraction is more variable over the agricultural field, explaining the less good fit of the regression (R^2 = 59 %) compared to over the savanna-forest (R^2 = 66 %). Inclusion of net radiation, cloud cover, down-welling radiation, and wind speed in this model did not significantly change the quality of the regression. This further supports our understanding that this is a moisture limitation of the system. This linear regression model provides and estimation that confirms our understanding of the physical basis of fluxes.

4 Discussion

4.1 Energy balance

The most striking observation is that the savanna-forest had consistently higher levels of both sensible and latent heat flux across all months (figures 4, 5). Sensible heat fluxes over the two surfaces showed the greatest difference in November and October (figure 6). Latent heat flux is the most different between the two land uses in August and May, transition times when the access to water in the catchment is not uniform (figure 6). The greatest similarity between the two land covers was during the wet season, May through September. The difference between the energy balance of the two sites was the most accentuated in the transition from the wet to dry season that occurred in the month of October for sensible heat flux and in the early wet season for latent heat flux (figures 4, 5, 7). Because of this observation, we can expect land use changes to have the most impact during these transition periods, due to differences in growth patterns and rooting depths. In particular since

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agricultural crops are planted, their germination and development is determined by agricultural decisions above water and energy availability. The behavior during the growing season from June through August varied so dramatically between 2009 and 2010 because in 2009 short season millet was planted whereas in 2010, it was left fallow. We can imagine that this difference is due to the high growth rates of the agricultural crop through August and the subsequent harvest, where as the fallow crops grow quickly, transpiring the most in July and then stabilizing into August (figure 4). The sensible and latent energy fluxes from the fallow were lower that that of the forest in 2010, whereas when short season millet was growing, they were more similar. By comparing the changes in soil moisture along the diurnal cycle, we see that even in the dry season there is some variation even in the dry season, particularly at shallow depths, thus in contrast to other authors we cannot attribute the early peak purely to stomata behavior during the dry season (Mamadou et al., 2016). In contrast, during the rainy season, it declined, following the cycle of available radiation.

The net radiation was very similar over both land surfaces, with the greatest differences occurring in the dry season. However early in the dry season net radiation was higher over agricultural whereas early in the dry season, it was higher over forest-savanna. This second, counter intuitive finding, is supported by other work in the subregion that found that net radiation was higher over woody vegetation during the dry season and explained the difference because surface tempaerature was lower and net long wave radiation was higher (Guyot et al., 2009). The residual of the energy budget showed fewer clear patterns, but across seasons, it was greater over the field, likely due to larger ground heat flux into the bare soil.

Two contrasting trends explain why the sensible heat fluxes becomes less similar as the year progresses whereas the latent heat fluxes becomes more similar. First, at the start of the year, the agricultural field is covered with bare ground and the rocks are exposed above the forested area, and throughout the growing season, the bare ground is progressively covered with grass whereas on the hill, the rocks remains exposed. At the end of the wet season, the grass senesces and remains until it is burned in late December or January. The contrast of the annual cycles of bare ground and bare rock drives the difference in sensible heat flux. The bare ground has a high level of albedo compared to the rocks, creating a difference in available energy for turbulent fluxes.

Second, at the start of the year, the upper trees have access to water coming from the springs at the base of the rocks. Although the level of water availability and vegetation increases during the wet season and declines during the following dry season, the spring is permanent perhaps due to subsurface lateral water transfer that also produces shallow groundwater that is available to the trees (Mande, 2014). In contrast, the water availability in the field and the corresponding greenness closely follow the annual cycle of precipitation, driving the variation in latent heat. The ephemeral stream stops flowing at the end of December, when the grasses dry up and the latent heat flux returns to being drastically different between the two sites (Mande, 2014)..

Our observations of H and L_eE are higher than fluxes previously measured in the region (Bagayoko et al., 2007; Dolman et al., 1997; Gash et al., 1997; Guichard et al., 2009; Guyot et al., 2009; Mauder et al., 2006; Schüttemeyer et al., 2006; Timouk et al., 2009), which can be explained by its location inside a semi-protected area with regionally relative high amount of vegetation, increasing L_eE, and an abundance of rocks, raising H. Furthermore, annual cycles of ratios between H and L_eE

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vary by wind sector (figure 6), demonstrating that small variations in land-cover, topography, and moisture availability can lead to dramatic differences in evaporation and evaporative fraction. This is consistent with local land management philosophy, which emphasizes the importance of maintaining the gallery forest, and springs therein, as a common moisture reservoir in the dry season and in case of drought. More continuous, long-term measurements during extreme years would reinforce the validity of this local belief. Our results also emphasize that the forest, even though it is primarily an open wooded savanna, has a higher level of productivity than the rain-fed, hand-farmed fields.

Our values of sensible and latent heat flux are most similar to those measured in Ejura, Ghana in 2002 (Schüttemeyer et al., 2006). Ejura is about 500 km from our site, and though quite far and typically placed in a different category of climate, we measure similar values compared to other areas of West Africa (Guyot et al., 2009), perhaps because measurements took place in November, when vegetation there would be most similar to that at our site. Kompienga is the most similar and closest to ours, though overlapping in terms of seasons, but measurements are still lower than ours (Bagayoko et al., 2007).

The scale incongruity between the turbulent flux (sensible and latent) flux measurements and the net radiation may explain our lack of closure, instead of, for example surface heat water storage during floods (Guyot et al., 2009). There is a strong topographic difference close to the forested area, however we are confident that our planar fit correction effectively corrected for the corresponding effect on turbulent fluxes.

The high magnitude of turbulent fluxes can be explained by Tambarga-Madjoari's location in the midst of a natural park and hunting concession as well as our measurement of a gallery forest, which would demonstrate the importance of the nearby vegetation cover. On the whole, our measurements are comparable to those elsewhere in West Africa, given that most of these sites (Mali, Niger) are more sahelian, and thus have less moisture availability, and others (Nigeria, Benin, Ghana) are considerably further south and thus have denser vegetation (White, 1986).

4.2 Evaporative Fraction

The median monthly evaporative fraction in the forest savanna was lowest in April at 0.47, and highest in September at 0.77, and for the agricultural fields, it was also lowest in April at 0.31 and highest September at 0.79. These values are in general higher than previously found in similar environments during the rainy season (Bagayoko et al., 2007; Brümmer et al., 2008; Guyot et al., 2012; Mamadou et al., 2016). In contrast, our site has a lower dry season evaporative fraction than nearby sites, which suggests that moisture cycling during the wet season is more complete, and that there is less storage into the dry season. This is likely due to a combination of vegetation, soil, and topographic characteristics.

We can compare our values of evaporative fraction with other environmental conditions. Over West Africa, the self-preservation concept of the evaporative fraction could be used together with variables such as albedo, temperature at the surface, and a vegetation index to obtain a reasonable estimate of evaporation (Compaore, 2006). A high correlation between mid-day evaporation and the evaporative fraction exists in Kenyan grasslands (Farah et al., 2004). Evaporative fraction might be affected by cloud cover which alters incoming radiation (Brutsaert and Sugita, 1992), however cloudiness is not related to the stability of evaporative fraction in 2005-2006 in Brazil (Santos et al., 2010). Evaporative fraction may also be

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related to other environmental parameters that are increasingly available and reliable which are obtained remotely through satellites, such as soil moisture (Crago, 1996; Hall et al., 1992). One limitation of this approach is that of the temporal scale since evaporative fraction is computed by day but surface conditions and moisture availability can change instantaneously. However it is extremely valuable to be able to estimate evaporative fraction when only NDVI, or other remotely sensed parameters are available. For this reason our estimation of evaporative fraction with a simple model based on the physical basis of fluxes linked to vegetation and soil moisture, is useful (figure 9). This model can be refined with longer and more varied datasets to increase its accuracy and suitability regionally.

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4.3 Social Context

The gallery forest over which we measure fluxes includes two springs that were the main water source for the village at its founding until a generation ago (Ceperley, 2014). Its important role in local history means that special institutions existed in local tradition for its conservation. For example, wetlands, and other areas with abundant water, fall into a gourmantche category for land called “Tinjali” or land that was not farmed because of cultural taboos until recent development projects and the introduction of rice farming (Swanson, 1978). In addition, since it is forested, it is protected because gourmantche believe that trees have spirits, which may prohibit them from being cut or used, and that some are considered good and some bad. So it is reasonable to conclude that the presence of the forest is not only because the water availability provides the habitat, but also because the village has protected it on some level. Additionally, it is reasonable to think that the institutions that protect this forest are not only protecting it, but also the ecosystem services that it preserves. Our work suggests that these ecosystem services include the cycling of moisture into the atmosphere and the eventual generation of rainfall. In this light, gourmantche myth explains that there is a sack of water above the atmosphere that spirits can pierce, bringing rain delivered by clouds (Alves, 2012). If the gods pierced those clouds with “trees” then our research seems to be right on target in terms of validating what traditions have long known. This is an important tool, as land use becomes more and more contested, the validation of local institutions or land uses can ensure the continuation of these practices.

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5 Conclusions

Sensible and latent heat fluxes were higher over a savanna-forest than a semi-cultivated (millet-fallow) field according to our measurements in a sudanian ecosystem of West Africa in 2009 and 2010. The sensible heat and latent heat flux are generally higher over the savanna-forest because of its more permanent water availability and corresponding greenness, higher productivity and the amount of rocky terrain. For example, the diurnal cycle of latent heat flux peaked earlier in the day during the dry season in the agricultural field, suggesting depletion of all available moisture by late morning. These observations of sensible and latent heat flux are higher than fluxes previously measured in the region, potentially due to this site’s location inside of a semi-protected area. Analysis of wind sectors separately revealed that particular sectors, corresponding to the location of particular features, for example over the ephemeral wetland and the gallery forest,

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contributed higher amounts to the flux. Local land management emphasizes the importance of maintaining the gallery forest, and springs therein, as a common humidity reservoir in the dry season and in case of drought. Changes in land cover may even have consequences for local rainfall triggering, causing cascading effects that transform both the energy and water budgets.

Continuous, long-term measurements during drought and moist years are essential to prove the long-term validity of our observations. Additionally, variations in exchanges according to small landscape features could result in enormous underestimation for up-scaling. We recommend using eddy-covariance measurements such as these to improve estimates with more easily maintained and obtained meteorological station and satellite data. The evaporative fraction is dependent on NDVI, which is an important finding for modeling and up-scaling. Efforts focused on preserving hydrologic services need to take anomalies into account and reinforce cultural institutions that protect wetlands and gallery forests.

The development of a simple NDVI based indicator of evaporative fraction is transferable to other semi-arid systems, agroforestry parklands, and open wooded savannas around the globe. Globally, the African continent and often semi-arid environments represent a gap in observations of land atmosphere interactions. This study is an important step in filling this gap and proposing a tool with still greater potential.

Our results point to the necessity for ground measurements for eventual up-scaling from point to regional evaporation measurements in remote and less-studied regions of the globe. We began this work with discussion with community partners and to bring it full circle we conclude this paper by relating it back to the cultural context.

6 Acknowledgements

The Velux and 3rd Millennium foundations funded a large part of this research in addition to support from the young researcher's (KFPE) grant from the Swiss Agency for Development and Cooperation. Alexandre Repetti, Jean-Claude Bolay, and the center for cooperation at EPFL initiated and continued to this project. We would like to thank all of our colleagues, assistants, and students based both in Switzerland in Burkina Faso who helped us with fieldwork. In particular, collaboration with the International Institute of Environment and Water Engineering facilitated this research. We give additional gratitude to the commune of Madjoari, its residents and its government, who hosted us and our equipment for the duration of this project. This manuscript was greatly improved by feedback from reviewers and the scientific community, for that we are greatful. The final analysis was completed with the support of the NSERC discovery grant.

References

Abiodun, B. J., Pal, J. S., Afiesimama, E. A., Gutowski, W. J. and Adedoyin, A.: Simulation of West African monsoon using RegCM3 Part II: impacts of deforestation and desertification, Theor. Appl. Climatol., 93, 245–261, 2008.

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Adomou, A.: Vegetation patterns and environmental gradients in Benin, PhD thesis, Wageningen University, the Netherlands., 2005.

Alves, J. P. G.: Anthropologie et écosystèmes au Niger: humains, lions et esprits de la forêt dans la culture gourmantché., 2012.

Arbonnier, M.: Trees, Shrubs and lianas of West African dry Zones, CIRAD, MNHN., 2004.

Aubinet, M., Feigenwinter, C., Heinesch, B., Laffineur, Q., Papale, D., Reichstein, M., Rinne, J. and Gorsel, E. V.: Nighttime Flux Correction, in Eddy Covariance, edited by M. Aubinet, T. Vesala, and D. Papale, pp. 133–157, Springer Netherlands., 2012.

Bagayoko, F., Yonkeu, S., Elbers, J. and van de Giesen, N.: Energy partitioning over the West African savanna: Multi-year evaporation and surface conductance measurements in Eastern Burkina Faso, J. Hydrol., 334(3–4), 545–559, doi:10.1016/j.jhydrol.2006.10.035, 2007.

Bateni, S. M. and Entekhabi, D.: Relative efficiency of land surface enrgy balance components, Water Resour. Res., 48(W04510), 2012.

Bordes, C.: La Gestion Des Arbres Par Les Paysans: Etude d'une enclave au milieu de reserves forestieres au sud-est du Burkina Faso, Ingenieur, ISTOM., 2010.

Brümmer, C., Falk, U., Papen, H., Szarzynski, J., Wassmann, R. and Brüggemann, N.: Diurnal, seasonal, and interannual variation in carbon dioxide and energy exchange in shrub savanna in Burkina Faso (West Africa), J. Geophys. Res., 113(G2), 1–11, doi:10.1029/2007JG000583, 2008.

Brutsaert, W.: Evaporation into the Atmosphere: Theory, History, and Applications, Kluwer Academic Publishers, Dordrecht, The Netherlands., 1982.

Brutsaert, W. and Parlange, M. B.: The Unstable Surface Layer Above the Forest: Regional Evaporation and Heat Flux, Water Resour. Res., 28(12), 3129–3134, 1992.

Brutsaert, W. and Sugita, M.: Application of Self-Preservation in the Diurnal Evolution of the Surface Energy Budget to Determine Daily Evaporation, J. Geophys. Res., 97(D17), 18377–18382, 1992.

Burba, G.: Eddy Covariance Method for Scientific, Industrial, Agricultural and Regulatory Applications, Li-COR Biosciences., 2005.

Burba, G.: Eddy Covariance Method for Scientific, Industrial, Agricultural and Regulatory Applications: A Field Book on Measuring Ecosystem Gas Exchange and Areal Emission Rates, LI-Cor Biosciences., 2013.

Ceperley, N. C.: Ecohydrology of a Mixed Savanna-Agricultural Catchment in South-East Burkina Faso, West Africa, Swiss Federal Institute of Technology, Lausanne. [online] Available from: http://infoscience.epfl.ch/record/195232/files/EPFL_TH6040.pdf, 2014.

Charney, J. G.: Dynamics of deserts and drought in the Sahel, Q. J. R. Meteorol. Soc., 101(428), 193–202, 1975.

Compaore, H.: The impact of savannah vegetation on the spatial and temporal variation of the actual evapotranspiration in the Volta Basin, Navrongo, Upper East Ghana, Ecol. Dev. Ser., (36), 2006.

Crago, R. D.: Conservation and variability of the evaporative fraction during the daytime, J. Hydrol., 180(1–4), 173–194, doi:10.1016/0022-1694(95)02903-6, 1996.

Crago, R. D. and Qualls, R.: The value of intuitive concepts in evaporation research, Water Resour. Res., 49(May), n/a–n/a, doi:10.1002/wrcr.20420, 2013.

Dolman, A. J., Gash, J. H. C., Goutorbe, J.-P., Kerr, Y., Lebel, T., Prince, S. D. and Stricker, J. N. M.: The role of the land surface in Sahelian climate: HAPEX-Sahel results and future research needs, J. Hydrol., 188–189, 1067–1079, doi:10.1016/S0022-1694(96)03183-6, 1997.

Domingo, F., Serrano-Ortiz, P., Were, A., Villagarcía, L., García, M., Ramírez, D. A., Kowalski, A. S., Moro, M. J., Rey, A. and Oyonarte, C.: Carbon and water exchange in semiarid ecosystems in SE Spain, J. Arid Environ., 75(12), 1271–1281, doi:10.1016/j.jaridenv.2011.06.018, 2011.

Ezzahar, J., Chehbouni, a., Hoedjes, J., Ramier, D., Boulain, N., Boubkraoui, S., Cappelaere, B., Descroix, L., Mougenot, B. and Timouk, F.: Combining scintillometer measurements and an aggregation scheme to estimate area-averaged latent heat flux during the AMMA experiment, J. Hydrol., 375(1–2), 217–226, doi:10.1016/j.jhydrol.2009.01.010, 2009.

Farah, H. O., Bastiaanssen, W. G. M. and Feddes, R. a.: Evaluation of the temporal variability of the evaporative fraction in a tropical watershed, Int. J. Appl. Earth Obs. Geoinformation, 5(2), 129–140, doi:10.1016/j.jag.2004.01.003, 2004.

Farhadi, L.: Estimation of Land Surface Water and Energy Balance Flux Components and Closure Relation Using Conditional Sampling, MIT., 2012.

Feddema, J. J., Oleson, K. W., Bonan, G. B., Mearns, L. O., Buja, L. E., Meehl, G. A. and Washington, W. M.: The importance of land-cover change in simulating future climates., Science, 310(5754), 1674–8, doi:10.1126/science.1118160, 2005.

Federer, C. A.., Vörösmarty, C., Fekete, B. and Olume, V.: Sensitivity of Annual Evaporation to Soil and Root Properties in Two Models of Contrasting Complexity, J. Hydrometeorol., 4(6), 1276–1290, doi:10.1175/1525-7541(2003)004<1276:SOAETS>2.0.CO;2, 2003.

Foken, T.: The energy balance closure problem: An overview, Ecol. Appl., 18(6), 1351–1367, doi:10.1890/06-0922.1, 2008.

Foken, T., Mauder, M., Liebethal, C., Wimmer, F., Beyrich, F., Leps, J.-P., Raasch, S., DeBruin, H. a. R., Meijninger, W. M. L. and Bange, J.: Energy balance closure for the LITFASS-2003 experiment, Theor. Appl. Climatol., 101(1–2), 149–160, doi:10.1007/s00704-009-0216-8, 2009.

Foken, T., Leuning, R., Oncley, S. R., Mauder, M. and Aubinet, M.: Corrections and Data Quality Control, in Eddy Covariance: A Practical Guide to Measurement and Data Analysis, edited by M. et al Aubinet, Springer Atmospheric Sciences., 2012.

Gash, J., Kabat, P., Amadou, M., Bessemoulin, P., Billing, H., Blyth, E., Bruin, H. A. R. D., Verhoef, J. E., Friborg, T., Harrison, G., Holwill, C. J., Lloyd, C. R., Lhomme, J.-P., Moncrieff, J. B., Monteny, B. A., Puech, D., gaard, H. S., Tuzet, A. and Verhoef, A.: The variability of evaporation during the HAPEX-Sahel intensive observation period, J. Hydrol., Hapex-Sahe(1–4), 385–3999, 1997.

Gentine, P., Entekhabi, D., Chehbouni, A., Boulet, G. and Duchemin, B.: Analysis of evaporative fraction diurnal behavior, Agric. For. Meteorol., 143, 13–29, 2007.

Guichard, F., Kergoat, L., Mougin, E., Timouk, F., Baup, F., Hiernaux, P. and Lavenu, F.: Surface thermodynamics and radiative budget in the Sahelian Gourma: Seasonal and diurnal cycles, J. Hydrol., 375(1–2), 161–177, doi:10.1016/j.jhydrol.2008.09.007, 2009.

Guo, Z., Dirmeyer, P. A., Koster, R. D., Sud, Y. C., Bonan, G., Oleson, K. W., Chan, E., Verseghy, D., Cox, P., Gordon, C. T., McGregor, J. L., Kanae, S., Kowalczyk, E., Lawrence, D., Liu, P., Mocko, D., Lu, C.-H., Mitchell, K., Malyshev, S., McAvaney, B., Oki, T., Yamada, T., Pitman, A., Taylor, C. M., Vasic, R. and Xue, Y.: GLACE: The Global Land Atmosphere Coupling Experiment. Part II: Analysis, J. Hydrometeorol., 7(4), 611–625, doi:10.1175/JHM511.1, 2006.

Guyot, A., Cohard, J.-M., Anquetin, S., Galle, S. and Lloyd, C. R.: Combined analysis of energy and water balances to estimate latent heat flux of a sudanian small catchment, J. Hydrol., 375(1–2), 227–240, doi:10.1016/j.jhydrol.2008.12.027, 2009.

Guyot, A., Cohard, J.-M., Anquetin, S. and Galle, S.: Long-term observations of turbulent fluxes over heterogeneous vegetation using scintillometry and additional observations: A contribution to AMMA under Sudano-Sahelian climate, Agric. For. Meteorol., 154–155, 84–98, doi:10.1016/j.agrformet.2011.10.008, 2012.

Hall, F. G., Huemmrich, K. F., Goetz, S. J., Sellers, P. J. and Nickeson, J. E.: Satellite Remote Sensing of Surface Energy Balance â€□ Success , Failures , and Unresolved Issues in FIFE, J. Geophys. Res., 97(D17), 19061–19089, 1992.

Higgins, C. W.: A-posteriori analysis of surface energy budget closure to determine missed energy pathways, Geophys. Res. Lett., 39(19), 1–5, doi:10.1029/2012GL052918, 2012.

Ingelrest, F., Barrenetxea, G., Schaefer, G., Vetterli, M., Couach, O. and Parlange, M.: SensorScope, ACM Trans. Sens. Netw., 6(2), 1–32, doi:10.1145/1689239.1689247, 2010.

Katul, G. G. and Parlange, M. B.: A Penman-Brutsaert Model for Wet Surface Evaporation, Water Resour. Res., 28(1), 121–126, 1992.

Krishnan, P., Meyers, T. P., Scott, R. L., Kennedy, L. and Heuer, M.: Energy exchange and evapotranspiration over two temperate semi-arid grasslands in North America, Agric. For. Meteorol., 153, 31–44, doi:10.1016/j.agrformet.2011.09.017, 2012.

Kustas, W. P., Rango, A. and Uijlenhoet, R.: A simple energy budget algorithm for the snowmelt runoff model, Water Resour. Res., 30(5), 1515–1527, doi:10.1029/94WR00152, 1994.

Leuning, R.: The correct form of the Webb, Pearman and Leuning equation for eddy fluxes of trace gases in steady and non-steady state, horizontally homogeneous flows, Bound.-Layer Meteorol., 123(2), 263–267, 2007.

Lhomme, J.-P. and Elguero, E.: Examination of evaportive fraction diurnal behaviour using a soi-vegetation model coupled with a mixed-layer model, Hydrol. Earth Syst. Sci., 9(2), 259–270, 1999.

Lohou, F., Saïd, F., Lothon, M., Durand, P. and Serça, D.: Impact of Boundary-Layer Processes on Near-Surface Turbulence Within the West African Monsoon, Bound.-Layer Meteorol., 136(1), 1–23, doi:10.1007/s10546-010-9493-0, 2010.

Lohou, F., Kergoat, L., Guichard, F., Boone, a., Cappelaere, B., Cohard, J.-M., Demarty, J., Galle, S., Grippa, M., Peugeot, C., Ramier, D., Taylor, C. M. and Timouk, F.: Surface response to rain events throughout the West African monsoon, Atmospheric Chem. Phys., 14(8), 3883–3898, doi:10.5194/acp-14-3883-2014, 2014.

Mamadou, O., Cohard, J. M., Galle, S., Awanou, C. N., Diedhiou, A., Kounouhewa, B. and Peugeot, C.: Energy fluxes and surface characteristics over a cultivated area in Benin : daily and seasonal dynamics, Hydrol. Earth Syst. Sci., 18, 893–914, doi:10.5194/hess-18-893-2014, 2014.

Mamadou, O., Galle, S., Cohard, J.-M., Peugeot, C., Kounouhewa, B., Biron, R., Hector, B. and Zannou, A. B.: Dynamics of water vapor and energy exchanges above two contrasting Sudanian climate ecosystems in Northern Benin (West Africa): WATER VAPOR AND ENERGY EXCHANGES, J. Geophys. Res. Atmospheres, 121(19), 11,269-11,286, doi:10.1002/2016JD024749, 2016.

Mande, T.: Hydrology of the Sudanian Savannah in West Africa, Burkina Faso, PhD thesis, Swiss Federal Institute of Technology, Lausanne, Lausanne, Switzerland, 17 January. [online] Available from: https://infoscience.epfl.ch/record/195231/files/EPFL_TH6011.pdf, 2014.

Mande, T., Ceperley, N., Barrenetxea, G., Repetti, A. and Niang, D.: Rainfall-Runoff Processes in a Mixed Sudanian Savanna Agriculture Catchment : Use of a distributed sensor network, in Geophysical Research Abstracts, vol. 13, p. 1, Vienna, Austria., 2011.

Mauder, M., Jegede, O. O., Okogbue, E. C., Wimmer, F. and Foken, T.: Surface energy balance measurements at a tropical site in West Africa during the transition from dry to wet season, Theor. Appl. Climatol., 89(3–4), 171–183, doi:10.1007/s00704-006-0252-6, 2006.

Nadeau, D. F., Brutsaert, W., Parlange, M. B., Bou-Zeid, E., Barrenetxea, G., Couach, O., Boldi, M.-O., Selker, J. S. and Vetterli, M.: Estimation of urban sensible heat flux using a dense wireless network of observations, Environ. Fluid Mech., 9(6), 635–653, doi:10.1007/s10652-009-9150-7, 2009.

Nicholson, S. E., Tucker, C. J. and Ba, M. B.: Desertification, drought, and surface vegetation: An example from the West African Sahel, Bull. Am. Meteorol. Soc., 79(5), 815–830, 1998.

Oldroyd, H. J., Pardyjak, E. R., Huwald, H. and Parlange, M. B.: Adapting Tilt Corrections and the Governing Flow Equations for Steep, Fully Three-Dimensional, Mountainous Terrain, Bound.-Layer Meteorol., 1–27, 2015.

Parlange, M. B. and Katul, G. G.: Estimation of the diurnal variation of potential evaporation from a wet bare soil surface, J. Hydrol., 132(1–4), 71–89, doi:10.1016/0022-1694(92)90173-S, 1992.

Pielke, R. A., Marland, G., Betts, R. A., Chase, T. N., Eastman, J. L., Niles, J. O., Niyogi, D. D. S. and Running, S. W.: The influence of land-use change and landscape dynamics on the climate system: relevance to climate-change policy beyond the radiative effect of greenhouse gases., Philos. Transact. A Math. Phys. Eng. Sci., 360(1797), 1705–1719, 2002.

Porte-Agel, F., Parlange, M. B., Cahill, A. T., Gruber, A. and Porte, F.: Mixture of Time Scales in Evaporation : Desorption and Self-Similarity of Energy Fluxes, Agron. J., 92(September-October), 832–836, 2000.

Ramier, D., Boulain, N., Cappelaere, B., Timouk, F., Rabanit, M., Lloyd, C. R., Boubkraoui, S., Métayer, F., Descroix, L. and Wawrzyniak, V.: Towards an understanding of coupled physical and biological processes in the cultivated Sahel – 1. Energy and water, J. Hydrol., 375(1–2), 204–216, doi:10.1016/j.jhydrol.2008.12.002, 2009.

Rebmann, C., Kolle, O., Heinesch, B., Queck, R., Ibrom, A. and Aubinet, M.: Data Acquisition and Flux Calculations, in Eddy Covariance, edited by M. Aubinet, T. Vesala, and D. Papale, pp. 59–83, Springer Netherlands., 2012.

Santos, C. A. C. D., Silva, B. B. D. and Rao, T. V. R.: Analysis of the evaporative fraction using eddy covariance and remote sensing techniques, Rev. Bras. Meteorol., 25(4), 427–436, doi:10.1590/S0102-77862010000400002, 2010.

Schüttemeyer, D., Moene, a. F., Holtslag, a. a. M., Bruin, H. a. R. and Giesen, N. V.: Surface Fluxes and Characteristics of Drying Semi-Arid Terrain in West Africa, Bound.-Layer Meteorol., 118(3), 583–612, doi:10.1007/s10546-005-9028-2, 2006.

Shuttleworth, W. J.: FIFE: the variation in energy partition at surface flux sites, Remote Sens. Large-Scale Glob. Process. IAHS Publ., (186), 1989.

Simoni, S., Padoan, S., Nadeau, D. F., Diebold, M., Porporato, A., Barrenetxea, G., Ingelrest, F., Vetterli, M. and Parlange, M. B.: Hydrologic response of an alpine watershed: Application of a meteorological wireless sensor network to understand streamflow generation, Water Resour. Res., 47(10), doi:10.1029/2011WR010730, 2011.

Steiner, A. L., Pal, J. S., Rauscher, S. A., Bell, J. L., Diffenbaugh, N. S., Boone, A., Sloan, L. C. and Giorgi, F.: Land surface coupling in regional climate simulations of the West African monsoon, Clim. Dyn., 33(869–892), 2009.

Swanson, R. A.: Gourmantche agriculture, Ouagadougou USAID, 1978.

Swets, D. L., Reed, B. C., Rowland, J. D. and Marko, S. E.: A weighted least-squares approach to temporal NDVI smoothing, in Proceedings of the 1999 ASPRS Annual Conference, Portland, Oregon., 1999.

Sylla, M. B., Pal, J. S. and Wang, G.: Impact of land cover characterization on regional climate modeling over West Africa, Clim. Dyn., 2015.

Szilagyi, J. and Parlange, M. B.: Defining Watershed-Scale Evaporation Using a Normalized Difference Vegetation Index, J. Am. Water Resour. Assoc., 35(5), 1245–1255, doi:10.1111/j.1752-1688.1999.tb04211.x, 1999.

Szilagyi, J., Rundquist, D. C., Gosselin, D. C. and Parlange, M. B.: NDVI relationship to monthly evaporation, Geophys. Res. Lett., 25(10), 1753–1756, 1998.

Timouk, F., Kergoat, L., Mougin, E., Lloyd, C. R., Ceschia, E., Cohard, J.-M., Rosnay, P., Hiernaux, P., Demarez, V. and Taylor, C. M.: Response of surface energy balance to water regime and vegetation development in a Sahelian landscape, J. Hydrol., 1–43, 2009.

Topp, G. C., Davis, J. L. and Annan, A. P.: Electromagnetic determination of soil water content: Measurements in coaxial transmission lines, Water Resour. Res., 16(3), 574–582, doi:10.1029/WR016i003p00574, 1980.

Velluet, C., Demarty, J., Cappelaere, B., Braud, I., Issoufou, H. B.-A., Boulain, N., Ramier, D., Mainassara, I., Charvet, G., Boucher, M., Chazarin, J.-P., O?, M., Yahou, H., Maidaji, B., Arpin-Pont, F., Benarrosh, N., Mahamane, A., Nazoumou, Y., Favreau, G. and Seghieri, J.: Building a field- and model-based climatology of local water and energy cycles in the cultivated Sahel - annual budgets and seasonality, Hydrol. Earth Syst. Sci., 18(12), 5001–5024, doi:10.5194/hess-18-5001-2014, 2014.

Vitousek, P. M.: Human Domination of Earth's Ecosystems, Science, 277(5325), 494–499, doi:10.1126/science.277.5325.494, 1997.

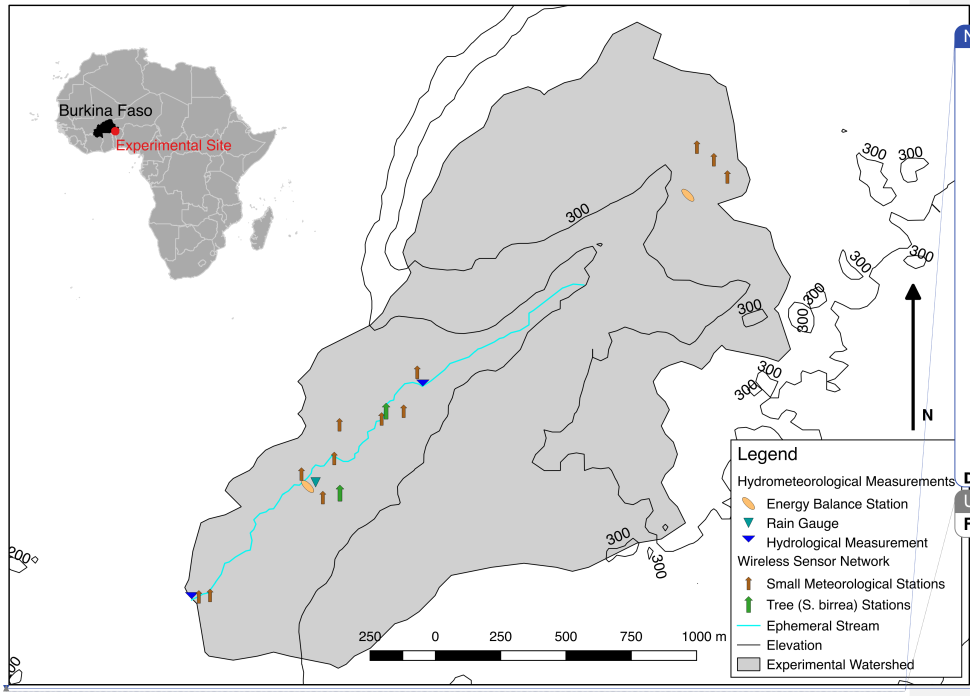
Webb, E., Pearman, G. and Leuning, R.: Correction of flux measurements for density effects due to heat and water vapour transfer, Q. J. R. Meteorol. Soc., 106(447), 85–100, 1980.

White, F.: la vegetation de l'Afrique: Memoire accompagnant la carte de vegetation de l'Afrique., 1986.

Whiteman, C. D. and Allwine, K. J.: Extraterrestrial solar radiation on inclined surfaces, Environ. Softw., 1(3), 164–169, 1986.

Wilczak, J. M., Oncley, S. P. and Stage, S. A.: Sonic anemometer tilt correction algorithms, Bound.-Layer Meteorol., 99(1), 127–150, 2001.

Williams, C. a., Reichstein, M., Buchmann, N., Baldocchi, D., Beer, C., Schwalm, C., Wohlfahrt, G., Hasler, N., Bernhofer, C., Foken, T., Papale, D., Schymanski, S. and Schaefer, K.: Climate and vegetation controls on the surface water balance: Synthesis of evapotranspiration measured across a global network of flux towers, Water Resour. Res., 48(6), W06523, doi:10.1029/2011WR011586, 2012.



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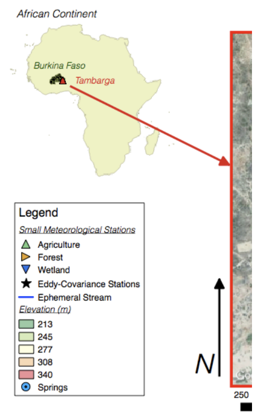

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Figure 1: Map of Experimental Watershed. The site is located next to the village of Tambarga, in the southeastern corner of Burkina Faso, West Africa. Energy balance stations, small meteorological stations, including those near agroforestry trees, and hydrologic monitoring stations are shown. Springs are located at the source of the ephemeral stream, at the base of the rocky escarpment.

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Instrument	Measurement	Height/Depth	Number	Interval	Time Span
CSAT-3 Sonic Anemometer (Campbell Scientific, Logan, UT, USA)	3D Wind Speed and Direction, Air Temperature	2.2 m	3	20 Hz, proc. 30 min.	May 2009 - October 2010
Li- 7500 Infrared Gas Analyser (LICOR, Lincoln, NE, USA)	H_2O Concentration	2.2 m	3	20 Hz, proc. 30 min.	May 2009 - October 2010
CNR2 Radiometer (Kipp & Zonen, Delft, The Netherlands)	SW LW Radiation	2.1 m	2	1 min.	October 2009 - October 2010
HMP450 (Campbell Scientific, Logan, UT, USA) with Radiation Shield	Air Temperature, Air Humidity	2.25 m	2	1 min.	May 2009 - October 2010
Pluviometer 3029 (Précis Mécanique, Bezons, Cedex, France)	Precipitation	1 m	1	0.1 mm	May 2009 - January 2015
Davis Instruments (Hayward, CA, USA)	Precipitation	.02 m	12	1 min.	May 2009 - January 2015
Davis Instruments (Hayward, CA, USA)	Shortwave Solar Radiation, Incoming	1.8m	12	1 min.	May 2009 - January 2015
Infrared thermometer TN901 (Zytemp, Taiwan, R.O.C.)	Surface Temperature	1.1 m	12	1 min.	May 2009 - January 2015
SHT7 (Sensiron AG, Staefa ZH, Switzerland)	Air Temperature & Humidity	1.7 m	12	1 min.	May 2009 - January 2015
5TM, 5TE, ECTM (Decagon, Pullman, WA, USA)	Soil Humidity	5-30 cm	~ 24 (varied)	1 min.	May 2009 - January 2015

Table 1: Inventory of Instruments used for Energy Balance Analysis: The name of the sensor or instrument is followed by the measurement it performs, the height and depth of each sensor, the total number used, and the interval of measurement. The heights were identical at both measurement points.

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Inventory of woody vegetation in Forest / Savanna (1 ha.)			
Acacia macrostachya	Leg.-Mim.	mph	S
Burkea africana	Leg.-Caes.	mph	SZ
Combretum nigricans	Combretaceae	mph	S
Daniella oliveria	Leg.-Caes.	MPh	SZ
Detarium microcarpum	Leg.-Caes.	mph	S
Gardenia erubecens	Rubiaceae	nph	S
Grewia flavescens	Tiliaceae	Lmph	GC
Guiera senegalensis	Combretaceae	nph	SZ
Hymenocardia acida	Euphorbiaceae	mph	SZ
Lannea acida	Anacardiaceae	mPh	S
Parkia biglobosa	Leg.-Mim.	mPh	S
Prosopis africana	Leg.-Mim.	mPh	S
Pteleopsis subrosa	Combretaceae	mph	SZ
Pterocarpus erinaceus	Leg.-Pap.	mPh	S
Sclerocarya birria	Anacardiaceae	mph	S
Sterculia setigera	Sterculiaceae	mph	S
Strychnos spinosa	Loganiaceae	LmPh	PAL
Terminalia avicennioides	Combretaceae	mph	S
Terminalia laxiflora	Combretaceae	mPh	S
Terminalia schimperiana (glaucenscens)	Combretaceae	mph	S
Terminalia mollis	Combretaceae	mph	PRA
Vitellaria paradoxa	Sapotaceae	mPh	S
Ximenia americana	Olacaceae	nph	Pt

Inventory of woody vegetation in Agricultural Fields			
Acacia sieberiana	Leg.-Mim.	mph	SZ
Bombax costatum	Bobacaceae	mph	S
Detarium microcarpum	Leg.-Caes.	mph	S
Ficus sp.	Moraceae	MPh	
Lannea sp.	Anacardiaceae	mPh	S / SZ
Piliostigma reticulatum	Leg.-Caes.	mph	SG
Sclerocarya birrea	Anacardiaceae	mph	S
Terminalia schimperiana (glaucenscens)	Combretaceae	mph	S
Terminalia laxiflora	Combretaceae	mPh	S
Terminalia mollis	Combretaceae	mph	PRA
Ziziphrus mauritaniana	Thamnaeceae	mph	PAL

Chorology		No.	
S	Sudanian	19	
SZ	Sudano-Zambezian	6	
GC	Guieo-Congolian	1	
PAL	Paleotropical	1	

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Pt	Pantropical	1
SG	Sudano/Guinean transition	1
PRA	Pluriregional African	1

Abbreviations	
Leg.-Caes.	Leguminosae.-Caesalpinioideae
Leg.-Mim.	Leguminosae-Mimosoideae
Leg.-Pap.	Leguminosae-Papilionoideae

Life Forms		
mph	microphanerophyte	2 - 8 m
MPh	megaphanerophyte	> 30 m
nph	nanophanerophyte	0.5-2 m
L	Liana	
mPh	mesophanerophyte	8-30 m

Table 2: Inventory of species found in both agricultural field site and forest savanna site.

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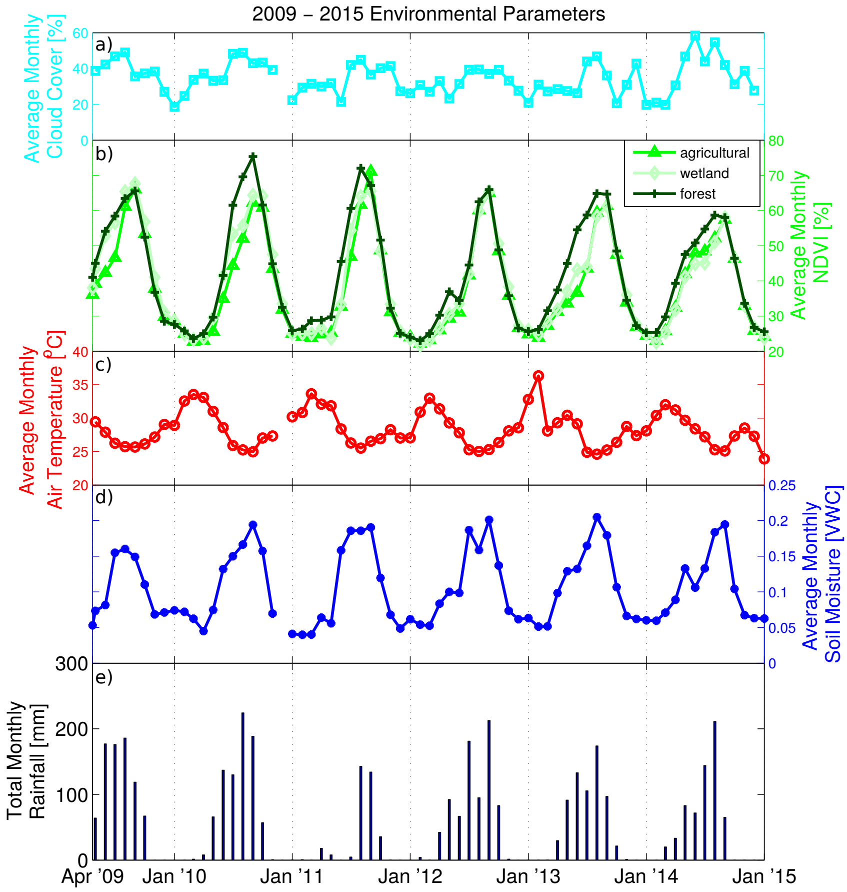

Figure 2: Environmental Parameters at Study Site for Monitoring Period (2009 - 2015): a) Cloud cover measured with shortwave radiometers and averaged over all stations; b) Average NDVI from MODIS satellite data (250 meter resolution, 10-day composite) averaged over each landcover of pixels containing stations; c) Monthly average air temperature (red line), also averaged for all stations; d) Volumetric soil moisture averaged over all stations and all land covers between 5 and 30 cm depth (blue line); And e) monthly rainfall (missing bars indicate lack of rain).

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Diurnal cycle of Energy Balance Components

	April 2010	July 2010	
Agricultural Field			Agricultural Field
Savanna- Forest			Savanna-Forest

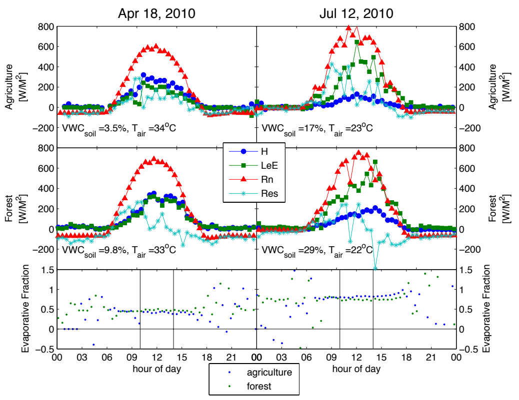

Figure 3: Diurnal Cycle of the Energy Balance. The upper four photographs correspond to the four subplots - the date of the photograph is the same month as the representative plot of diurnal energy budget. Note that April (left) is the dry season and the atmosphere was very hazy, in part due to fires. July is the start of the rainy or wet season (right). The energy budget is made up of the sensible heat (H, blue), latent heat (LeE, green), net radiation (R_n, red) on the y-axis (W/m2) over the savanna-forest (middle row) and agricultural land (top row) according to time of day (x-axis, 24 hours). The residual of the energy budget is also shown in turquoise. The final row shows the half hour calculation of evaporative fraction. Daily averages were taken between 10 and 14 hours, shown with the vertical lines, with the savanna-forest in green and agriculture in blue.

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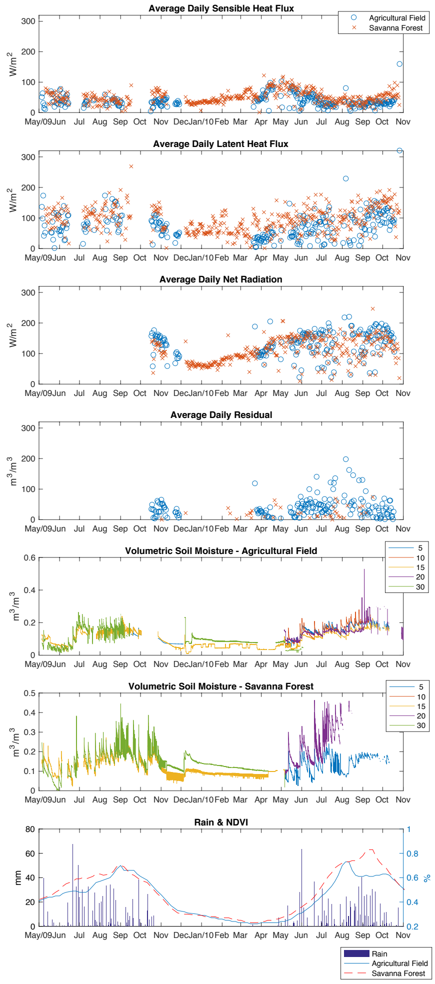

Average Daily Sensible Heat Flux
Agricultural Field
Savanna Forest
W/m2
Average Daily Latent Heat Flux
Average Daily Net Radiation
Average Daily Residual
Volumetric Soil Moisture - Agricultural Field
Volumetric Soil Moisture - Savanna Forest
Rain & NDVI
Rain

Figure 4: Time Series of Average Daily Sensible Heat Flux (1), Average Daily Latent Heat Flux (2), Average Daily Net Radiation (3), Average Daily Residual (4), Volumetric Soil Moisture in the Agricultural Field (5), Volumetric Soil Moisture in the Savanna Forest (6), Daily Rain and NDVI (7). Plots 1 – 4 show the data from the energy balance stations over Agricultural Field (blue circles) and Savanna Forest (red crosses) in Watts per square meter. Plots 5 – 6 show the Volumetric Soil Moisture at 5 different depths over the same time period. Finally, plot 7 shows the NDVI for the pixels containing the energy balance station in the field (blue dashed) and in the savanna forest (red, solid). The rain in mm is shown as a bar graph.

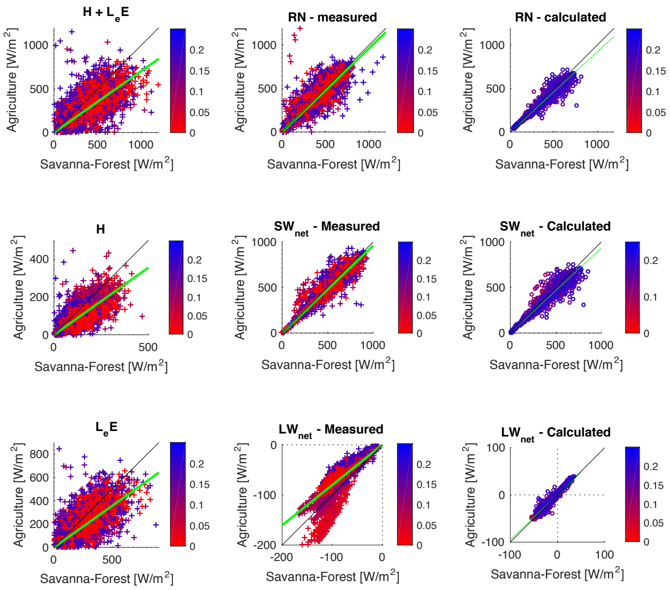

Figure 5: Comparison between fluxes measured over the savanna-forest and the field. In each plot, colour indicates soil volumetric water content, red is dry and blue is wet. The least square regression lines are shown in green and the 1:1 lines are in black. Measurements over the savanna-forest are on the x-axis and those over agriculture are on the y-axis. All fits were significant (p<0.005). The middle column shows the components of net radiation calculated with the net radiometers. The right shows the components of net radiation calculated using parameters measured at the small meteorological stations: Ta, incoming SW, Ts, etc.

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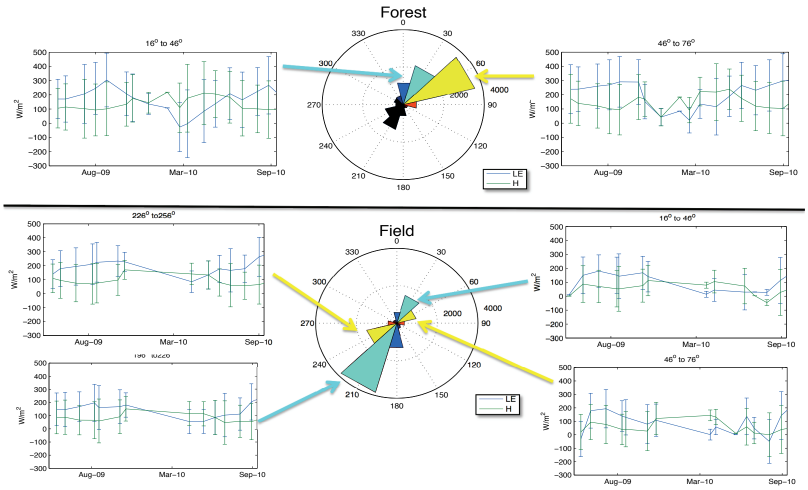

Figure 6: Two dominant wind sectors for each eddy-covariance set up are plotted: Above the two over the savanna field and below the 4 over the agricultural field. Mean latent heat flux for each month with standard deviations is shown in blue and sensible heat in green. Note that for some months there was no data.

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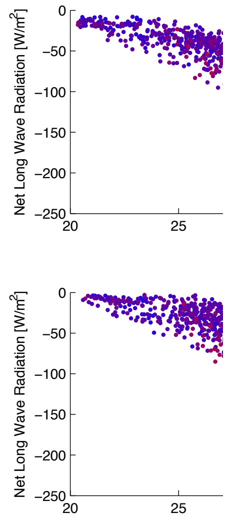

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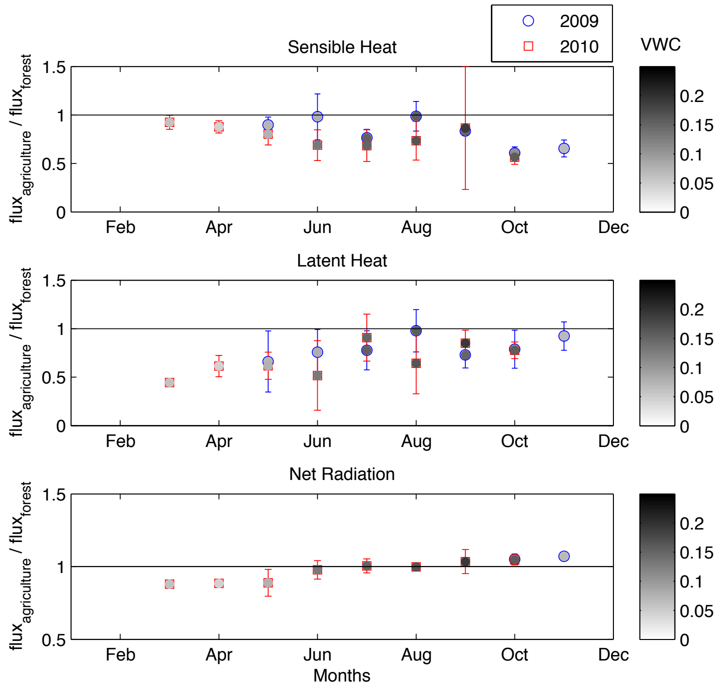

Figure 7: Examination of ratio of the daily fluxes by month and year. The ratios between flux measurements over the field and savanna-forest is shown according to month (x - axis) and year (in colour: blue is 2009 and red is 2010). The soil moisture value is shown with shading. Error bars show the standard deviation around the average of daily ratios. Points below the 1 line indicate when the savanna-forest flux is higher than the agricultural field flux. It is important to note that the field was farmed in 2009 until the end of July but left fallow in 2010.

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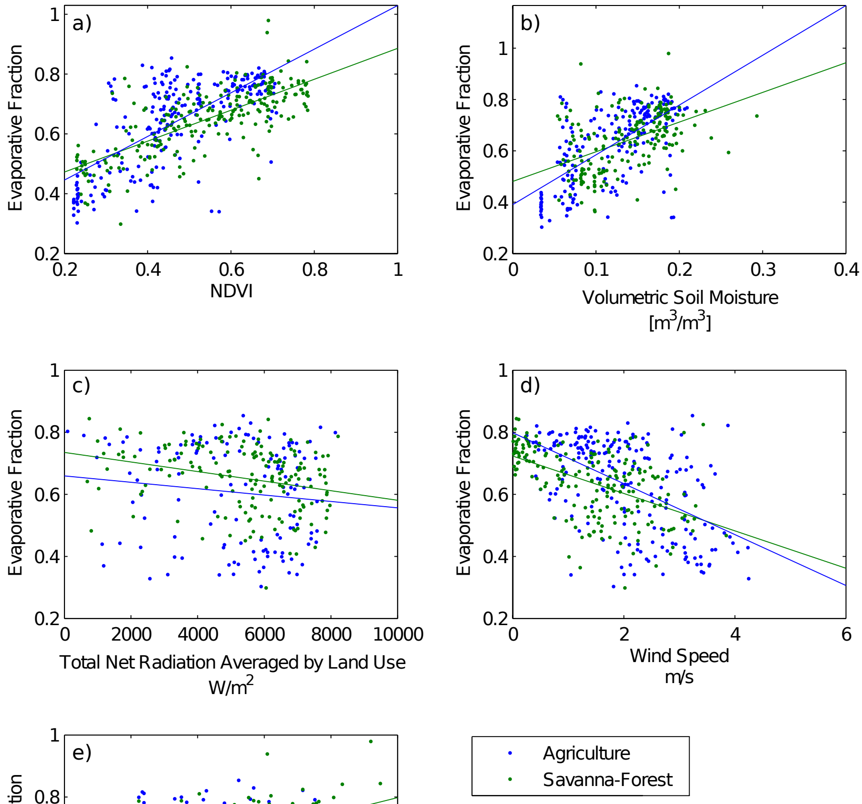
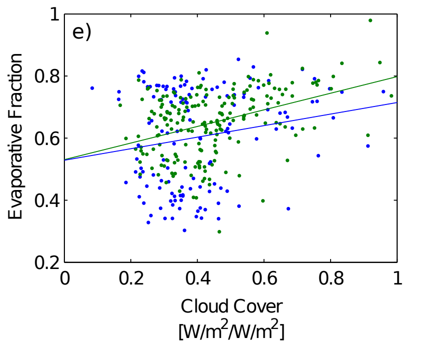
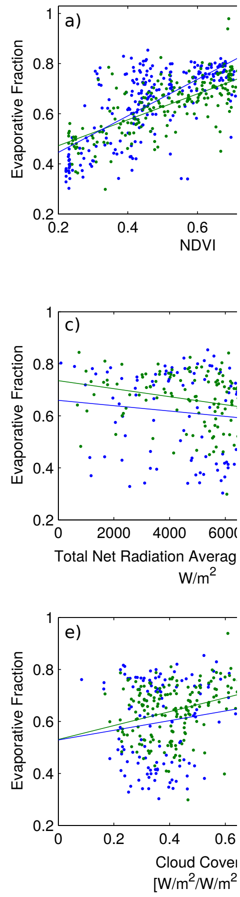




	Evaporative Fraction	
	Agriculture	Savanna-Forest
Vegetation (NDVI)	69.76	74.71
Soil Water content	64.63	48.33
Net Radiation	-6.88	-13.33
Wind Speed	-51.85	-43.07
Cloud Cover	19.17	38.94



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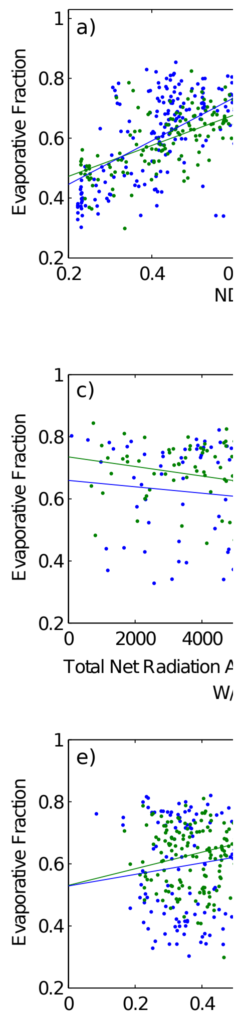
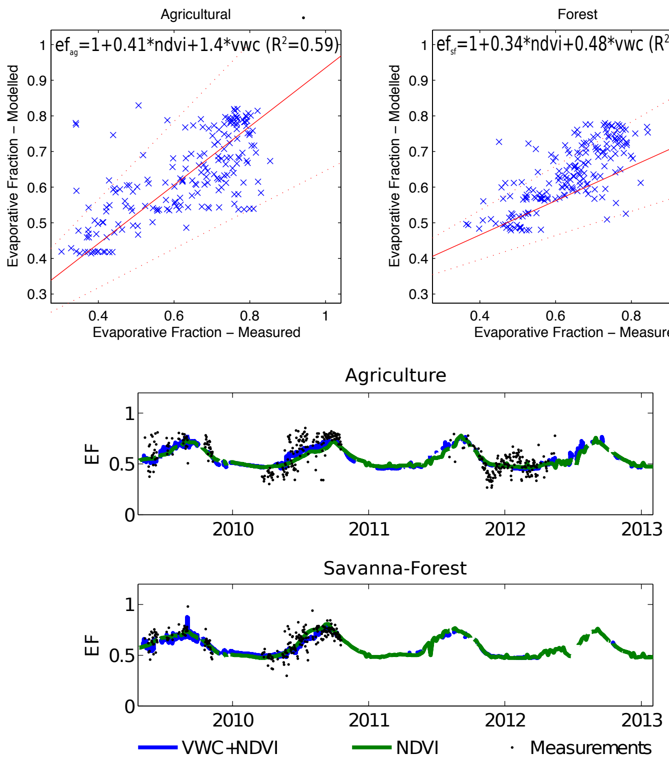


Figure 8: Daily evaporative fraction over study period for the agricultural field (blue) and the savanna-forest (green) compared with the observed a) NDVI, b) VWC, c) wind speed, d) net radiation, and e) cloud cover. In all cases, environmental variables are from the average of stations with the same landcover with the energy balance station. These plots show a better correlation with NDVI and VWC (top row), suggesting moisture, not radiation, limited system. The least squared regression lines are shown for each plot. Correlations between variables are in the table.



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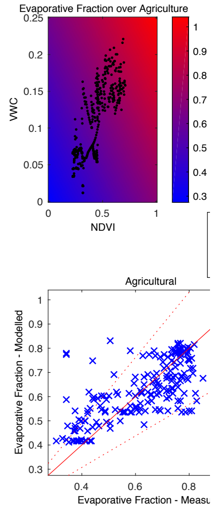

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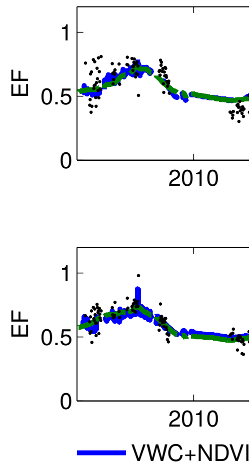

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Figure 9: Further Examination of relationship between Soil Moisture, Vegetation Index, and Evaporative Fraction. Upper plots show quality of fit of linear regression model relating soil volumetric water content, vegetation index, and evaporative fraction over agriculture (left) and over savanna-forest (right). The 1:1 line is in red and the 95% confidence interval is shown with dotted lines for the range of available soil and vegetation. Lower plots shows evaporative fraction over the field (above) and the savanna-forest (below). Measured data points are in black (points), calculated evaporative fraction based on soil moisture and NDVI is shown in blue and NDVI alone is shown in green.

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Supplementary Material

S1.1 Net Radiation

To account for any scale discrepancies between the small meteorological stations and the energy balance stations, net radiation was calculated at each small station (Brutsaert, 1982). Net shortwave radiation was calculated using the measured incoming shortwave radiation (table 1) and albedo (α) Eq. (S1):

$sw_n = (1 - \alpha) \cdot sw_i$. (S1)

Albedo was measured using solar radiometers facing up and down for 155 days between October 2011 and November 2012. Since albedo is heavily correlated with soil moisture and vegetation cover, a linear regression model of albedo based on soil moisture and NDVI was used to estimate albedo when it was not measured. When either soil moisture or NDVI was not available, a linear model based just on the other, available metric was used. Gaps were filled with a linear interpolation and data missing at the beginning of the observation were filled using a linear interpolation based on average albedo for the day of the year (between April 22-25, 2009). All estimated albedo values were smoothed using a 10-day moving average filter. Albedo fell within the acceptable range for the vegetation covers (Figure S1). Long wave radiation was calculated as the sum of long wave upwelling radiation, Eq. (S2):

$Rl_u = \varepsilon_s \sigma T_s^4$. (S2)

where ε_s is the surface emissivity, taken to have an average value (0.97), σ is the Stefan Boltzmann constant, and T_s is the measured surface temperature, and the incoming long wave radiation, which is taken as a fraction of clear sky incoming long wave radiation, Eq. (S3):

$Rl_i = Rl_{ic}(1 + a m_c^b)$, (S3)

where Eq. (S4):

$Rl_{ic} = \varepsilon_{ac} \sigma T_a^4$. (S4)

and m_c is the measured cloud cover (6), a and b are constants, ε_{ac} is the atmospheric emissivity during clear sky conditions, and T_a is the measured air temperature. The atmospheric emissivity is Eq. (S5):

$\varepsilon_{ac} = a'(\frac{e_a}{T_a})^{\frac{1}{7}}$. (S5)

where e_a is the vapor pressure near the surface, determined with the measured relative humidity and air temperature and a' is calculated with a Beta function and air temperature and averages 1.24 at our site as it does for average meteorological conditions (Brutsaert, 1982). Comparison to the measured net radiation at the energy balance station (figure S2) shows some discrepancies. These may be due to the difference in wavelengths measured by the solar radiation sensors at the small meteorological stations, which use a silicon photodiode detector to detect radiation at wavelengths of 300 to 1100 nanometers. Whereas the pyranometer measures from 300 to 2800 nm and the pyrogeometer from 4.5 to 42 µm. The spectral response of the individual sensors was not available at this time, but estimation using standard spectra (ASTM G173-03 Reference Spectra) integrated over the two different short wave ranges indicates that the solar radiation sensors measure

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61.78% of the energy that the pyranometers measure. These differences would be further exaggerated by the geometry of the sensor (180° for sw_i and 150° for sw_u from the pyranometer versus the solar radiation sensor which is less than 100% for the full 180°) especially in dusk and dawn conditions. Additionally, the effect of albedo varies according to cloudiness and sun altitude. Most of the radiation emitted by the earth and atmosphere is between 4 and 100 μm and measurements are often flawed because instruments themselves emit radiation of comparable wavelengths and intensity to the long wave radiation that we want to measure. Thus our comparison is reasonable because it is of a similar order of magnitude, further fine-tuning the calculation will be done in a subsequent work.

References

Brutsaert, W.: Evaporation into the Atmosphere: Theory, History, and Applications, Kluwer Academic Publishers, Dordrecht, The Netherlands., 1982.

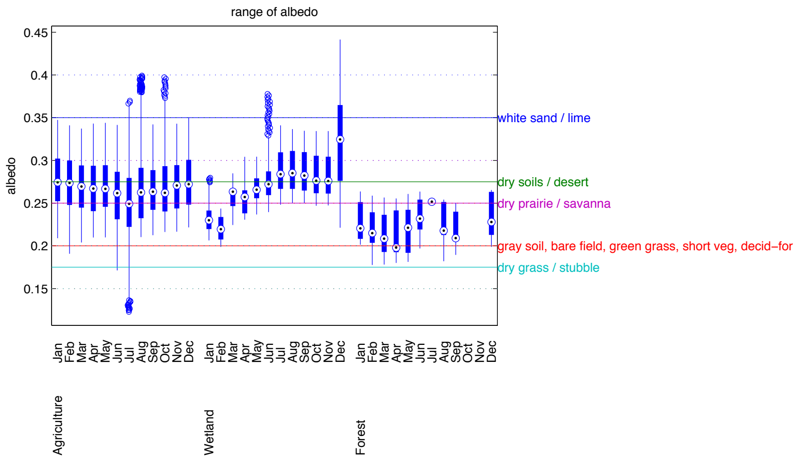

Figure S1: Distribution of albedo by landcover (Agricultural, Wetland, and Forest) and by month for the study period. The central dot is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the most extreme data points not considered outliers, and outliers are plotted individually. Average values for various land-covers listed by Brutsaert (1982) are drawn and labelled to the right. Ranges for these are shown in dotted lines. Our values mostly range between those of bare field or green grass and dry soils and desert, with dry prairie or savanna making a good mid value.

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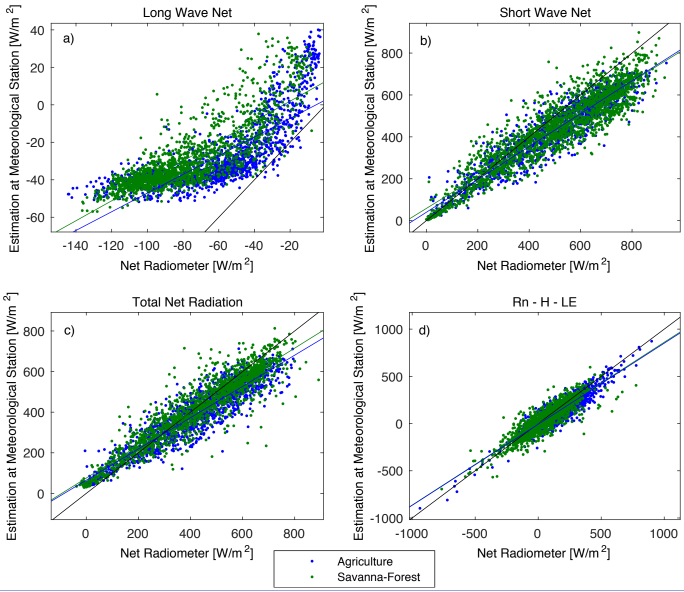

	Agriculture	Savanna-Forest
a) LW_{net}	0.58	0.50
b) SW_{net}	0.76	0.78
c) R_n	0.80	0.77
R_n -H- L_eE	0.86	0.86

Figure S2: Comparison of measurements and calculations on a half hour scale of (a) net short wave, (b) net long wave, and (c) total radiation and the residual (not shown, correlation in table) after subtracting the measured turbulent fluxes. In all cases the slope is less than 1, which means that the measurements are greater than the calculation. The slopes of the regression lines are in the accompanying table. In each plot, measurements over the agricultural field are shown in blue and over the savanna-forest are shown in green. Black lines show the one to one line and coloured lines show the least squared regression lines.

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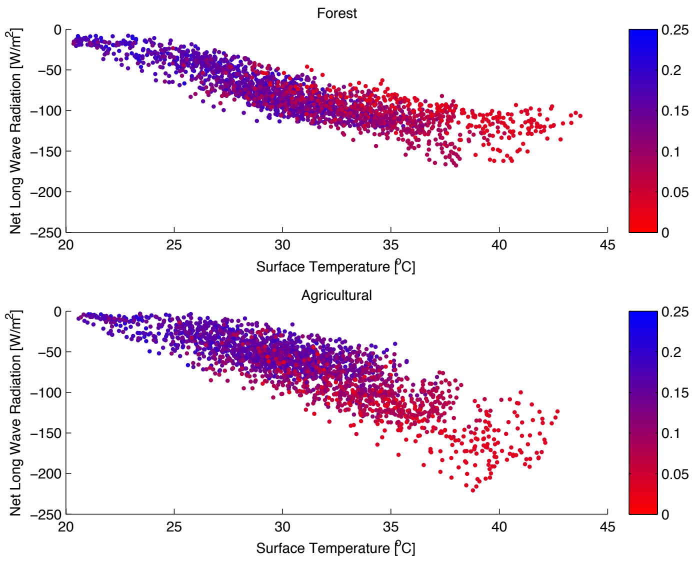

Figure S3: Net Long-wave Radiation Response to Soil Moisture and Surface Temperature. Surface temperature and net long wave radiation had a strong negative correlation with each other and also with volumetric soil water content, shown by the colour. The pattern of this correlation varied by land cover, savanna-forest above and agriculture below.

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(Abiodun et al., 2008; Feddema et al., 2005; Mande et al., 2011; Steiner et al., 2009; Sylla et al., 2015; Vitousek, 1997)(Abiodun et al., 2008; Feddema et al., 2005; Mande et al., 2011; Steiner et al., 2009; Sylla et al., 2015; Vitousek, 1997)

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(Foken, 2008; Szilagyi and Parlange, 1999)(Foken, 2008; Szilagyi and Parlange, 1999)

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The surface energy budget is written Eq. (1):

$R_n = L_e E + H + G,$ (1)

where $L_e E$ is latent energy flux, H is sensible heat flux, R_n is the net radiation, and G is the soil heat flux. The sensible heat, Eq. (2):

$H = \rho c_p \overline{w'T'}$, (2)

and latent heat, Eq. (3):

$L_e = L_e \rho \overline{w'q'}$, (3)

fluxes can be obtained from eddy covariance and the using the above equations, where ρ is the air density, c_p is the specific heat, $w'T'$ is the covariance of fluctuations of vertical wind speed and temperature, L_e is the latent energy of vaporization, and $w'q'$ is covariance of fluctuations of vertical wind speed and humidity.

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(1):

$R_n = L_eE + H + G$, (1)

where L_eE is latent energy flux, H is sensible heat flux, R_n is the net radiation, and G is the soil heat flux.

The sensible heat, Eq. (2):

$H = \rho c_p \overline{w'T'}$, (2)

and latent heat, Eq. (3):

$$L_e = L_e \rho \overline{w'q'}$$

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(1):

$R_n = L_eE + H + G$, (1)

where L_eE is latent energy flux, H is sensible heat flux, R_n is the net radiation, and G is the soil heat flux.

The sensible heat, Eq. (2):

$H = \rho c_p \overline{w'T'}$, (2)

and latent heat, Eq. (3):

$$L_e = L_e \rho \overline{w'q'}$$

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(Burba, 2013; Domingo et al., 2011; Farhadi, 2012; Federer et al., 2003; Foken et al., 2009; GUO et al., 2006; Katul and Parlange, 1992; Krishnan et al., 2012, 2012; Kustas et al., 1994; Parlange and Katul, 1992; Williams et al., 2012)(Burba, 2013; Domingo et al., 2011; Farhadi, 2012; Federer et al., 2003; Foken et al., 2009; GUO et al., 2006; Katul and Parlange, 1992; Krishnan et al., 2012, 2012; Kustas et al., 1994; Parlange and Katul, 1992; Williams et al., 2012)

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(Brutsaert, 1982; Brutsaert and Parlange, 1992; Burba, 2005; Compaore, 2006; Crago, 1996; Crago and Qualls, 2013)(Brutsaert, 1982; Brutsaert and Parlange, 1992; Burba, 2005; Compaore, 2006; Crago, 1996; Crago and Qualls, 2013)

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(Bagayoko et al., 2007; Dolman et al., 1997; Gash et al., 1997; Mande et al., 2011)(Bagayoko et al., 2007; Dolman et al., 1997; Gash et al., 1997; Mande et al., 2011)

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(Charney, 1975; Nicholson et al., 1998)(Charney, 1975; Nicholson et al., 1998)

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(Brutsaert and Sugita, 1992; Compaore, 2006; Porte-Agel et al., 2000; Shuttleworth, 1989; Szilagyi et al., 1998; Szilagyi and Parlange, 1999)(Brutsaert and Sugita, 1992; Compaore, 2006; Porte-Agel et al., 2000; Shuttleworth, 1989; Szilagyi et al., 1998; Szilagyi and Parlange, 1999)

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(Brutsaert and Sugita, 1992; Porte-Agel et al., 2000)(Brutsaert and Sugita, 1992; Porte-Agel et al., 2000)

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(Bateni and Entekhabi, 2012)(Bateni and Entekhabi, 2012)

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(Gentine et al., 2007)(Gentine et al., 2007)

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(Lhomme and Elguero, 1999)(Lhomme and Elguero, 1999)

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(Farah et al., 2004; Lohou et al., 2010, 2014)

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(Farah et al., 2004).

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(Farah et al., 2004).

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(Bagayoko et al., 2007; Ezzahar et al., 2009; Guyot et al., 2009; Mauder et al., 2006)(Bagayoko et al., 2007; Ezzahar et al., 2009; Guyot et al., 2009; Mauder et al., 2006)

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(Nadeau et al., 2009; Simoni et al., 2011)(Nadeau et al., 2009; Simoni et al., 2011)

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Our results point to the necessity for ground measurements for eventual up-scaling from point to regional evaporation measurements in remote and less-studied regions of the globe. We began this work with discussion with community partners and to bring it full circle we conclude this paper by relating it back to the cultural context.

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The surface energy budget is written in Eq. (1):

$R_n = L_e E + H + G,$ (1)

where $L_e E$ is latent energyheat flux, H is sensible heat flux, R_n is the net radiation, and G is the soil heat flux, all in Watts per square meter (W m^{-2}).

The sensible heat, is expressed in Eq. (2):

$H = \rho c_p \overline{w'T'}$, (2)

where ρ is the air density (kg m^{-3}), c_p is the specific heat (J kg^{-1} K^{-1}), $w'T'$ is the covariance of fluctuations of vertical wind speed (m s^{-1}) and temperature (K). Land latent heat flux, is expressed in Eq. (3):

$L_e = L_e \rho \overline{w'q'}$, (3)

fluxes can be obtained from eddy covariance and the using the above equations, where ρ is the air density, c_p is the specific heat, $w'T'$ is the covariance of fluctuations of vertical wind speed and temperature, L_e is the latent energy of vaporization (J g^{-1}), and $w'q'$ is covariance of fluctuations of vertical wind speed (m s^{-1}) and humidity (g m^{-3}).

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fluxes can be obtained from eddy covariance and the using the above equations, where ρ is the air density, c_p is the specific heat, $w'T'$ is the covariance of fluctuations of vertical wind speed and temperature,

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(Brutsaert, 1982; Higgins, 2012)(Brutsaert, 1982; Higgins, 2012)

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(Aubinet et al., 2012; Burba, 2005; Oldroyd et al., 2015; Rebmann et al., 2012; Wilczak et al., 2001)(Aubinet et al., 2012; Burba, 2005; Oldroyd et al., 2015; Rebmann et al., 2012; Wilczak et al., 2001)

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(Foken et al., 2012; Leuning, 2007; Webb et al., 1980)(Foken et al., 2012; Leuning, 2007; Webb et al., 1980)

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2.8 Net Radiation

To account for any scale discrepancies between the small meteorological stations and the energy balance stations, net radiation was calculated at each small station (Brutsaert, 1982). Net shortwave radiation was calculated using the measured incoming shortwave radiation (table 1) and albedo (α) Eq. (8):

$sw_n = (1 - \alpha) \cdot sw_i$. (8)

Albedo was measured using solar radiometers facing up and down for 155 days between October 2011 and November 2012. Since albedo is heavily correlated with soil moisture and vegetation cover, a linear regression model of albedo based on soil moisture and NDVI was used to estimate albedo when it was not measured. When either soil moisture or NDVI was not available, a linear model based just on the other, available metric was used. Gaps were filled with a linear interpolation and data missing at the beginning of the observation were filled using a linear interpolation based on average albedo for the day of the year (between April 22-25, 2009). All estimate albedo values were smooth using a 10-day moving average filter. Albedo fell within the acceptable range for the vegetation covers (Figure 2). Long wave radiation was calculated as the sum of long wave upwelling radiation, Eq. (9):

$Rl_u = \varepsilon_s \sigma T_s^4$. (9)

where ε_s is the surface emissivity, taken to have an average value (0.97), σ is the Stefan Boltzmann constant, and T_s is the measured surface temperature, and the incoming long wave radiation, which is taken as a fraction of clear sky incoming long wave radiation, Eq. (10):

$Rl_i = Rl_{ic}(1 + am_c^b)$, (10)

where Eq. (11):

$Rl_{ic} = \varepsilon_{ac} \sigma T_a^4$. (11)

and m_c is the measured cloud cover (6), a and b are constants, ε_{ac} is the atmospheric emissivity during clear sky conditions, and T_a is the measured air temperature. The atmospheric emissivity is Eq. (12):

$\varepsilon_{ac} = a'(\frac{e_a}{T_a})^{\frac{1}{7}}$. (12)

where e_a is the vapor pressure near the surface, determined with the measured relative humidity and air temperature and a' is calculated with a Beta function and air temperature and averages 1.24 at our site as it does for average meteorological conditions (Brutsaert, 1982). Comparison to the measured net radiation at the energy balance station (figure 3) shows some discrepancies. These may be due to the difference in wave lengths measured by the solar radiation sensors at the small meteorological stations, which use a silicon photodiode detector to detect radiation at wavelengths of 300 to 1100 nanometers. Whereas the pyranometer measures from 300 to 2800 nm and the pyrogeometer from 4.5 to 42 μm. The spectral response of the individual sensors was not available at this time, but estimation using standard spectra (ASTM G173-03 Reference Spectra) integrated over the two different short wave ranges indicates that the solar radiation sensors measure 61.78% of the energy that the pyranometers measure. These differences would be further exaggerated by the geometry of the sensor (180° for sw_i and 150° for sw_u from the pyranometer versus the solar radiation sensor which is less than 100% for the full 180°) especially in dusk and dawn conditions. Additionally, the effect of albedo varies according to cloudiness and sun altitude. Most of the radiation emitted by the earth and atmosphere is between 4 and 100 µm and measurements are often flawed because instruments themselves emit radiation of comparable wavelengths and intensity to the long wave radiation that we want to measure. Thus our comparison is reasonable because it is of a similar order of magnitude, further fine-tuning the calculation will be done in a subsequent work.

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There is a scale discrepancy between the eddy covariance measurements and the net radiometer measurements since the latter only senses exchanges directly above and below it whereas the former's range of detection can span a larger area depending on the wind speed. To account for this, we modeled the net radiation at each small station and then compared it to that measured with net radiometers with acceptable results (figure 3).

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Further examination reveals that surface temperature and net long wave radiation have a strong negative correlation (figure 7see supplementary material) that is controlled by variations in soil moisture.

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This might be explained by Tambarga-Madjoari's location in the midst of a natural park and hunting concession as well as our measurement of a gallery forest, which would demonstrate the importance of the nearby vegetation cover. On the whole, our measurements are comparable to those elsewhere in West Africa, given that most of these sites (Mali, Niger) are more sahelian, and thus have less moisture availability, and others (Nigeria, Benin, Ghana) are considerably further south and thus have denser vegetation (White, 1986)(White, 1986).

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(Brutsaert and Sugita, 1992)(Brutsaert and Sugita, 1992)

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Abiodun, B. J., Pal, J. S., Afiesimama, E. A., Gutowski, W. J. and Adedoyin, A.: Simulation of West African monsoon using RegCM3 Part II: impacts of deforestation and desertification, Theor. Appl. Climatol., 93, 245–261, 2008.

Alves, J. P. G.: Anthropologie et écosystèmes au Niger: humains, lions et esprits de la forêt dans la culture gourmantché., 2012.

Arbonnier, M.: Trees, Shrubs and lianas of West African dry Zones, CIRAD, MNHN., 2004.

Aubinet, M., Feigenwinter, C., Heinesch, B., Laffineur, Q., Papale, D., Reichstein, M., Rinne, J. and Gorsel, E. V.: Nighttime Flux Correction, in Eddy Covariance, edited by M. Aubinet, T. Vesala, and D. Papale, pp. 133–157, Springer Netherlands., 2012.

Bagayoko, F., Yonkeu, S., Elbers, J. and van de Giesen, N.: Energy partitioning over the West African savanna: Multi-year evaporation and surface conductance measurements in Eastern Burkina Faso, J. Hydrol., 334(3–4), 545–559, doi:10.1016/j.jhydrol.2006.10.035, 2007.

Bateni, S. M. and Entekhabi, D.: Relative efficiency of land surface energy balance components, Water Resour. Res., 48(W04510), 2012.

Bordes, C.: La Gestion Des Arbres Par Les Paysans: Etude d'une enclave au milieu de reserves forestieres au sud-est du Burkina Faso, Ingenieur, ISTOM., 2010.

Brutsaert, W.: Evaporation into the Atmosphere: Theory, History, and Applications, Kluwer Academic Publishers, Dordrecht, The Netherlands., 1982.

Brutsaert, W. and Parlange, M. B.: The Unstable Surface Layer Above the Forest: Regional Evaporation and Heat Flux, Water Resour. Res., 28(12), 3129–3134, 1992.

Brutsaert, W. and Sugita, M.: Application of Self-Preservation in the Diurnal Evolution of the Surface Energy Budget to Determine Daily Evaporation, J. Geophys. Res., 97(D17), 18377–18382, 1992.

Burba, G.: Eddy Covariance Method for Scientific, Industrial, Agricultural and Regulatory Applications, Li-COR Biosciences., 2005.

Burba, G.: Eddy Covariance Method for Scientific, Industrial, Agricultural and Regulatory Applications: A Field Book on Measuring Ecosystem Gas Exchange and Areal Emission Rates, LI-Cor Biosciences., 2013.

Ceperley, N. C.: Ecohydrology of a Mixed Savanna-Agricultural Catchment in South-East Burkina Faso, West Africa, Swiss Federal Institute of Technology, Lausanne. [online] Available from: http://infoscience.epfl.ch/record/195232/files/EPFL_TH6040.pdf, 2014.

Charney, J. G.: Dynamics of deserts and drought in the Sahel, Q. J. R. Meteorol. Soc., 101(428), 193–202, 1975.

Compaore, H.: The impact of savannah vegetation on the spatial and temporal variation of the actual evapotranspiration in the Volta Basin, Navrongo, Upper East Ghana, Ecol. Dev. Ser., (36), 2006.

Crago, R. D.: Conservation and variability of the evaporative fraction during the daytime, J. Hydrol., 180(1–4), 173–194, doi:10.1016/0022-1694(95)02903-6, 1996.

Crago, R. D. and Qualls, R.: The value of intuitive concepts in evaporation research, Water Resour. Res., 49(May), n/a–n/a, doi:10.1002/wrcr.20420, 2013.

Dolman, A. J., Gash, J. H. C., Goutorbe, J.-P., Kerr, Y., Lebel, T., Prince, S. D. and Stricker, J. N. M.: The role of the land surface in Sahelian climate: HAPEX-Sahel results and future research needs, J. Hydrol., 188–189, 1067–1079, doi:10.1016/S0022-1694(96)03183-6, 1997.

Domingo, F., Serrano-Ortiz, P., Were, A., Villagarcía, L., García, M., Ramírez, D. a., Kowalski, a S., Moro, M. J., Rey, a. and Oyonarte, C.: Carbon and water exchange in semiarid ecosystems in SE Spain, J. Arid Environ., 75(12), 1271–1281, doi:10.1016/j.jaridenv.2011.06.018, 2011.

Ezzahar, J., Chehbouni, A., Hoedjes, J., Ramier, D., Boulain, N., Boubkraoui, S., Cappelaere, B., Descroix, L., Mougenot, B. and Timouk, F.: Combining scintillometer measurements and an aggregation scheme to estimate area-averaged latent heat flux during the AMMA experiment, J. Hydrol., 375(1–2), 217–226, doi:10.1016/j.jhydrol.2009.01.010, 2009.

Farah, H. O., Bastiaanssen, W. G. M. and Feddes, R. A.: Evaluation of the temporal variability of the evaporative fraction in a tropical watershed, Int. J. Appl. Earth Obs. Geoinformation, 5(2), 129–140, doi:10.1016/j.jag.2004.01.003, 2004.

Farhadi, L.: Estimation of Land Surface Water and Energy Balance Flux Components and Closure Relation Using Conditional Sampling, MIT., 2012.

Feddema, J. J., Oleson, K. W., Bonan, G. B., Mearns, L. O., Buja, L. E., Meehl, G. A. and Washington, W. M.: The importance of land-cover change in simulating future climates., Science, 310(5754), 1674–8, doi:10.1126/science.1118160, 2005.

Federer, C. a., Vörösmarty, C., Fekete, B. and Olume, V.: Sensitivity of Annual Evaporation to Soil and Root Properties in Two Models of Contrasting Complexity, J. Hydrometeorol., 4(6), 1276–1290, doi:10.1175/1525-7541(2003)004<1276:SOAETS>2.0.CO;2, 2003.

Foken, T.: The energy balance closure problem: An overview, Ecol. Appl., 18(6), 1351–1367, doi:10.1890/06-0922.1, 2008.

Foken, T., Mauder, M., Liebethal, C., Wimmer, F., Beyrich, F., Leps, J.-P., Raasch, S., DeBruin, H. A. R., Meijninger, W. M. L. and Bange, J.: Energy balance closure for the LITFASS-2003 experiment, Theor. Appl. Climatol., 101(1–2), 149–160, doi:10.1007/s00704-009-0216-8, 2009.

Foken, T., Leuning, R., Oncley, S. R., Mauder, M. and Aubinet, M.: Corrections and Data Quality Control, in Eddy Covariance: A Practical Guide to Measurement and Data Analysis, edited by M. et al Aubinet, Springer Atmospheric Sciences., 2012.

Gash, J., Kabat, P., Amadou, M., Bessemoulin, P., Billing, H., Blyth, E., Bruin, H. A. R. D., Verhoef, J. E., Friborg, T., Harrison, G., Holwill, C. J., Lloyd, C. R., Lhomme, J.-P., Moncrieff, J. B., Monteny, B. A., Puech, D., gaard, H. S., Tuzet, A. and Verhoef, A.: The variability of evaporation during the HAPEX-Sahel intensive observation period, J. Hydrol., Hapex-Sahe(1–4), 385–3999, 1997.

Gentine, P., Entekhabi, D., Chehbouni, A., Boulet, G. and Duchemin, B.: Analysis of evaporative fraction diurnal behavior, Agric. For. Meteorol., 143, 13–29, 2007.

Guichard, F., Kergoat, L., Mougin, E., Timouk, F., Baup, F., Hiernaux, P. and Lavenu, F.: Surface thermodynamics and radiative budget in the Sahelian Gourma: Seasonal and diurnal cycles, J. Hydrol., 375(1–2), 161–177, doi:10.1016/j.jhydrol.2008.09.007, 2009.

Guo, Z., Dirmeyer, P. A., Koster, R. D., Bonan, G., Edmond Chan, D., Cox, P., Gordon, C. T., Kanae, S., Kowalczyk, E., Lawrence, D., Liu, I., Cheng-Hsu, Lu, A., Malyshev, S., McAvaney, B., McGregor, J. L., Mitchell, K., Mocko, D., Oki, T., Keith, W., Oleson, C., Pitman, A., Sud, Y. C., Taylor, C. M., Verseghy, D., Vasic, R., Xue, Y. and Yamada, T.: GLACE : The Global Land – Atmosphere Coupling Experiment. Part II : Analysis, Am. Meteorlogical Soc., 7, 611–625, 2006.

Guyot, A., Cohard, J.-M., Anquetin, S., Galle, S. and Lloyd, C. R.: Combined analysis of energy and water balances to estimate latent heat flux of a sudanian small catchment, J. Hydrol., 375(1–2), 227–240, doi:10.1016/j.jhydrol.2008.12.027, 2009.

Hall, F. G., Huemmrich, K. F., Goetz, S. J., Sellers, P. J. and Nickeson, J. E.: Satellite Remote Sensing of Surface Energy Balance: Success, Failures, and Unresolved Issues in FIFE, J. Geophys. Res., 97(D17), 19061–19089, 1992.

Higgins, C. W.: A-posteriori analysis of surface energy budget closure to determine missed energy pathways, Geophys. Res. Lett., 39(19), 1–5, doi:10.1029/2012GL052918, 2012.

Ingelrest, F., Barrenetxea, G., Schaefer, G., Vetterli, M., Couach, O. and Parlange, M.: SensorScope, ACM Trans. Sens. Netw., 6(2), 1–32, doi:10.1145/1689239.1689247, 2010.

Katul, G. G. and Parlange, M. B.: A Penman-Brutsaert Model for Wet Surface Evaporation, Water Resour. Res., 28(1), 121–126, 1992.

Krishnan, P., Meyers, T. P., Scott, R. L., Kennedy, L. and Heuer, M.: Energy exchange and evapotranspiration over two temperate semi-arid grasslands in North America, Agric. For. Meteorol., 153, 31–44, doi:10.1016/j.agrformet.2011.09.017, 2012.

Kustas, W. P., Rango, A. and Uijlenhoet, R.: A simple energy budget algorithm for the snowmelt runoff model, Water Resour. Res., 30(5), 1515–1527, doi:10.1029/94WR00152, 1994.

Leuning, R.: The correct form of the Webb, Pearman and Leuning equation for eddy fluxes of trace gases in steady and non-steady state, horizontally homogeneous flows, Bound.-Layer Meteorol., 123(2), 263–267, 2007.

Lhomme, J.-P. and Elguero, E.: Examination of evaporative fraction diurnal behaviour using a soil-vegetation model coupled with a mixed-layer model, Hydrol. Earth Syst. Sci., 9(2), 259–270, 1999.

Mande, T., Ceperley, N., Barrenetxea, G., Repetti, A. and Niang, D.: Rainfall-Runoff Processes in a Mixed Sudanian Savanna Agriculture Catchment : Use of a distributed sensor network, in Geophysical Research Abstracts, vol. 13, p. 1, Vienna, Austria, 2011.

Mauder, M., Jegede, O. O., Okogbue, E. C., Wimmer, F. and Foken, T.: Surface energy balance measurements at a tropical site in West Africa during the transition from dry to wet season, Theor. Appl. Climatol., 89(3–4), 171–183, doi:10.1007/s00704-006-0252-6, 2006.

Nadeau, D. F., Brutsaert, W., Parlange, M. B., Bou-Zeid, E., Barrenetxea, G., Couach, O., Boldi, M.-O., Selker, J. S. and Vetterli, M.: Estimation of urban sensible heat flux using a dense wireless network of observations, Environ. Fluid Mech., 9(6), 635–653, doi:10.1007/s10652-009-9150-7, 2009.

Nicholson, S. E., Tucker, C. J. and Ba, M. B.: Desertification, drought, and surface vegetation: An example from the West African Sahel, Bull. Am. Meteorol. Soc., 79(5), 815–830, 1998.

Oldroyd, H. J., Pardyjak, E. R., Huwald, H. and Parlange, M. B.: Adapting Tilt Corrections and the Governing Flow Equations for Steep, Fully Three-Dimensional, Mountainous Terrain, Bound.-Layer Meteorol., 1–27, 2015.

Parlange, M. B. and Katul, G. G.: Estimation of the diurnal variation of potential evaporation from a wet bare soil surface, J. Hydrol., 132(1–4), 71–89, doi:10.1016/0022-1694(92)90173-S, 1992.

Pielke, R. A., Marland, G., Betts, R. A., Chase, T. N., Eastman, J. L., Niles, J. O., Niyogi, D. D. S. and Running, S. W.: The influence of land-use change and landscape dynamics on the climate system: relevance to climate-change policy beyond the radiative effect of greenhouse gases., Philos. Transact. A Math. Phys. Eng. Sci., 360(1797), 1705–1719, 2002.

Porte-Agel, F., Parlange, M. B., Cahill, A. T., Gruber, A. and Porte, F.: Mixture of Time Scales in Evaporation : Desorption and Self-Similarity of Energy Fluxes, Agron. J., 92(September-October), 832–836, 2000.

Rebmann, C., Kolle, O., Heinesch, B., Queck, R., Ibrom, A. and Aubinet, M.: Data Acquisition and Flux Calculations, in Eddy Covariance, edited by M. Aubinet, T. Vesala, and D. Papale, pp. 59–83, Springer Netherlands., 2012.

Santos, C. A. C. D., Silva, B. B. D. and Rao, T. V. R.: Analysis of the evaporative fraction using eddy covariance and remote sensing techniques, Rev. Bras. Meteorol., 25(4), 427–436, doi:10.1590/S0102-77862010000400002, 2010.

Schüttemeyer, D., Moene, A. F., Holtslag, A. A. M., Bruin, H. A. R. and van de Giesen, N.: Surface Fluxes and Characteristics of Drying Semi-Arid Terrain in West Africa, Bound.-Layer Meteorol., 118(3), 583–612, doi:10.1007/s10546-005-9028-2, 2006.

Shuttleworth, W. J.: FIFE: the variation in energy partition at surface flux sites, Remote Sens. Large-Scale Glob. Process. IAHS Publ., (186), 1989.

Simoni, S., Padoan, S., Nadeau, D. F., Diebold, M., Porporato, A., Barrenetxea, G., Ingelrest, F., Vetterli, M. and Parlange, M. B.: Hydrologic response of an alpine watershed: Application of a meteorological wireless sensor network to understand streamflow generation, Water Resour. Res., 47(10), doi:10.1029/2011WR010730, 2011.

Steiner, A. L., Pal, J. S., Rauscher, S. A., Bell, J. L., Diffenbaugh, N. S., Boone, A., Sloan, L. C. and Giorgi, F.: Land surface coupling in regional climate simulations of the West African monsoon, Clim. Dyn., 33(869–892), 2009.

Swanson, R. A.: Gourmantche agriculture, Ouagadougou USAID, 1978.

Swets, D. L., Reed, B. C., Rowland, J. D. and Marko, S. E.: A weighted least-squares approach to temporal NDVI smoothing, in Proceedings of the 1999 ASPRS Annual Conference, Portland, Oregon, 1999.

Sylla, M. B., Pal, J. S. and Wang, G.: Impact of land cover characterization on regional climate modelling over West Africa, Clim. Dyn., 2015.

Szilagyi, J. and Parlange, M. B.: Defining Watershed-Scale Evaporation Using a Normalized Difference Vegetation Index, J. Am. Water Resour. Assoc., 35(5), 1245–1255, doi:10.1111/j.1752-1688.1999.tb04211.x, 1999.

Szilagyi, J., Rundquist, D. C., Gosselin, D. C. and Parlange, M. B.: NDVI relationship to monthly evaporation, Geophys. Res. Lett., 25(10), 1753–1756, 1998.

Timouk, F., Kergoat, L., Mougin, E., Lloyd, C. R., Ceschia, E., Cohard, J.-M., Rosnay, P., Hiernaux, P., Demarez, V. and Taylor, C. M.: Response of surface energy balance to water regime and vegetation development in a Sahelian landscape, J. Hydrol., 1–43, 2009.

Topp, G. C., Davis, J. L. and Annan, A. P.: Electromagnetic determination of soil water content: Measurements in coaxial transmission lines, Water Resour. Res., 16(3), 574–582, doi:10.1029/WR016i003p00574, 1980.

Vitousek, P. M.: Human Domination of Earth's Ecosystems, Science, 277(5325), 494–499, doi:10.1126/science.277.5325.494, 1997.

Webb, E., Pearman, G. and Leuning, R.: Correction of flux measurements for density effects due to heat and water vapour transfer, Q. J. R. Meteorol. Soc., 106(447), 85–100, 1980.

White, F.: la vegetation de l'Afrique: Memoire accompagnant la carte de vegetation de l'Afrique., 1986.

Whiteman, C. D. and Allwine, K. J.: Extraterrestrial solar radiation on inclined surfaces, Environ. Softw., 1(3), 164–169, 1986.

Wilczak, J. M., Oncley, S. P. and Stage, S. A.: Sonic anemometer tilt correction algorithms, Bound.-Layer Meteorol., 99(1), 127–150, 2001.

Williams, C. A., Reichstein, M., Buchmann, N., Baldocchi, D., Beer, C., Schwalm, C., Wohlfahrt, G., Hasler, N., Bernhofer, C., Foken, T., Papale, D., Schymanski, S. and Schaefer, K.: Climate and vegetation controls on the surface water balance: Synthesis of evapotranspiration measured across a global network of flux towers, Water Resour. Res., 48(6), W06523, doi:10.1029/2011WR011586, 2012.

Abiodun, B. J., Pal, J. S., Afiesimama, E. A., Gutowski, W. J. and Adedoyin, A.: Simulation of West African monsoon using RegCM3 Part II: impacts of deforestation and desertification, Theor. Appl. Climatol., 93, 245–261, 2008.

Adomou, A.: Vegetation patterns and environmental gradients in Benin, PhD thesis, Wageningen University, the Netherlands., 2005.

Alves, J. P. G.: Anthropologie et écosystèmes au Niger: humains, lions et esprits de la forêt dans la culture gourmantché., 2012.

Arbonnier, M.: Trees, Shrubs and lianas of West African dry Zones, CIRAD, MNHN., 2004.

Aubinet, M., Feigenwinter, C., Heinesch, B., Laffineur, Q., Papale, D., Reichstein, M., Rinne, J. and Gorsel, E. V.: Nighttime Flux Correction, in Eddy Covariance, edited by M. Aubinet, T. Vesala, and D. Papale, pp. 133–157, Springer Netherlands., 2012.

Bagayoko, F., Yonkeu, S., Elbers, J. and van de Giesen, N.: Energy partitioning over the West African savanna: Multi-year evaporation and surface conductance measurements in Eastern Burkina Faso, J. Hydrol., 334(3–4), 545–559, doi:10.1016/j.jhydrol.2006.10.035, 2007.

Bateni, S. M. and Entekhabi, D.: Relative efficiency of land surface enrgy balance components, Water Resour. Res., 48(W04510), 2012.

Bordes, C.: La Gestion Des Arbres Par Les Paysans: Etude d'une enclave au milieu de reserves forestieres au sud-est du Burkina Faso, Ingenieur, ISTOM., 2010.

Brümmer, C., Falk, U., Papen, H., Szarzynski, J., Wassmann, R. and Brüggemann, N.: Diurnal, seasonal, and interannual variation in carbon dioxide and energy exchange in shrub savanna in Burkina Faso (West Africa), J. Geophys. Res., 113(G2), 1–11, doi:10.1029/2007JG000583, 2008.

Brutsaert, W.: Evaporation into the Atmosphere: Theory, History, and Applications, Kluwer Academic Publishers, Dordrecht, The Netherlands., 1982.

Brutsaert, W. and Parlange, M. B.: The Unstable Surface Layer Above the Forest: Regional Evaporation and Heat Flux, Water Resour. Res., 28(12), 3129–3134, 1992.

Brutsaert, W. and Sugita, M.: Application of Self-Preservation in the Diurnal Evolution of the Surface Energy Budget to Determine Daily Evaporation, J. Geophys. Res., 97(D17), 18377–18382, 1992.

Burba, G.: Eddy Covariance Method for Scientific, Industrial, Agricultural and Regulatory Applications, Li-COR Biosciences., 2005.

Burba, G.: Eddy Covariance Method for Scientific, Industrial, Agricultural and Regulatory Applications: A Field Book on Measuring Ecosystem Gas Exchange and Areal Emission Rates, LI-Cor Biosciences., 2013.

Ceperley, N. C.: Ecohydrology of a Mixed Savanna-Agricultural Catchment in South-East Burkina Faso, West Africa, Swiss Federal Institute of Technology, Lausanne. [online] Available from: http://infoscience.epfl.ch/record/195232/files/EPFL_TH6040.pdf, 2014.

Charney, J. G.: Dynamics of deserts and drought in the Sahel, Q. J. R. Meteorol. Soc., 101(428), 193–202, 1975.

Compaore, H.: The impact of savannah vegetation on the spatial and temporal variation of the actual evapotranspiration in the Volta Basin, Navrongo, Upper East Ghana, Ecol. Dev. Ser., (36), 2006.

Crago, R. D.: Conservation and variability of the evaporative fraction during the daytime, J. Hydrol., 180(1–4), 173–194, doi:10.1016/0022-1694(95)02903-6, 1996.

Crago, R. D. and Qualls, R.: The value of intuitive concepts in evaporation research, Water Resour. Res., 49(May), n/a–n/a, doi:10.1002/wrcr.20420, 2013.

Dolman, A. J., Gash, J. H. C., Goutorbe, J.-P., Kerr, Y., Lebel, T., Prince, S. D. and Stricker, J. N. M.: The role of the land surface in Sahelian climate: HAPEX-Sahel results and future research needs, J. Hydrol., 188–189, 1067–1079, doi:10.1016/S0022-1694(96)03183-6, 1997.

Domingo, F., Serrano-Ortiz, P., Were, a., Villagarcía, L., García, M., Ramírez, D. a., Kowalski, a S., Moro, M. J., Rey, a. and Oyonarte, C.: Carbon and water exchange in semiarid ecosystems in SE Spain, J. Arid Environ., 75(12), 1271–1281, doi:10.1016/j.jaridenv.2011.06.018, 2011.

Ezzahar, J., Chehbouni, a., Hoedjes, J., Ramier, D., Boulain, N., Boubkraoui, S., Cappelaere, B., Descroix, L., Mougenot, B. and Timouk, F.: Combining scintillometer measurements and an aggregation scheme to estimate area-averaged latent heat flux during the AMMA experiment, J. Hydrol., 375(1–2), 217–226, doi:10.1016/j.jhydrol.2009.01.010, 2009.

Farah, H. O., Bastiaanssen, W. G. M. and Feddes, R. a.: Evaluation of the temporal variability of the evaporative fraction in a tropical watershed, Int. J. Appl. Earth Obs. Geoinformation, 5(2), 129–140, doi:10.1016/j.jag.2004.01.003, 2004.

Farhadi, L.: Estimation of Land Surface Water and Energy Balance Flux Components and Closure Relation Using Conditional Sampling, MIT., 2012.

Feddema, J. J., Oleson, K. W., Bonan, G. B., Mearns, L. O., Buja, L. E., Meehl, G. A. and Washington, W. M.: The importance of land-cover change in simulating future climates., Science, 310(5754), 1674–8, doi:10.1126/science.1118160, 2005.

Federer, C. a., Vörösmarty, C., Fekete, B. and Olume, V.: Sensitivity of Annual Evaporation to Soil and Root Properties in Two Models of Contrasting Complexity, J. Hydrometeorol., 4(6), 1276–1290, doi:10.1175/1525-7541(2003)004<1276:SOAETS>2.0.CO;2, 2003.

Foken, T.: The energy balance closure problem: An overview, Ecol. Appl., 18(6), 1351–1367, doi:10.1890/06-0922.1, 2008.

Foken, T., Mauder, M., Liebethal, C., Wimmer, F., Beyrich, F., Leps, J.-P., Raasch, S., DeBruin, H. a. R., Meijninger, W. M. L. and Bange, J.: Energy balance closure for the LITFASS-2003 experiment, Theor. Appl. Climatol., 101(1–2), 149–160, doi:10.1007/s00704-009-0216-8, 2009.

Foken, T., Leuning, R., Oncley, S. R., Mauder, M. and Aubinet, M.: Corrections and Data Quality Control, in Eddy Covariance: A Practical Guide to Measurement and Data Analysis, edited by M. et al Aubinet, Springer Atmospheric Sciences., 2012.

Gash, J., Kabat, P., Amadou, M., Bessemoulin, P., Billing, H., Blyth, E., Bruin, H. A. R. D., Verhoef, J. E., Friborg, T., Harrison, G., Holwill, C. J., Lloyd, C. R., Lhomme, J.-P., Moncrieff, J. B., Monteny, B. A., Puech, D., gaard, H. S., Tuzet, A. and Verhoef, A.: The variability of evaporation during the HAPEX-Sahel intensive observation period, J. Hydrol., Hapex-Sahe(1–4), 385–3999, 1997.

Gentine, P., Entekhabi, D., Chehbouni, A., Boulet, G. and Duchemin, B.: Analysis of evaporative fraction diurnal behavior, Agric. For. Meteorol., 143, 13–29, 2007.

Guichard, F., Kergoat, L., Mougin, E., Timouk, F., Baup, F., Hiernaux, P. and Lavenu, F.: Surface thermodynamics and radiative budget in the Sahelian Gourma: Seasonal and diurnal cycles, J. Hydrol., 375(1–2), 161–177, doi:10.1016/j.jhydrol.2008.09.007, 2009.

GUO, Z., DIRMEYER, P. A., KOSTER, R. D., BONAN, G., EDMOND CHAN, D., COX, P., GORDON, C. T., KANAE, S., KOWALCZYK, E., LAWRENCE, D., LIU, I., CHENG-HSU, LU, A., MALYSHEV, S., MCAVANEY, B., MCGREGOR, J. L., MITCHELL, K., MOCKO, D., OKI, T., KEITH W. OLESON, C., PITMAN, A., SUD, Y. C., TAYLOR, C. M., VERSEGHY, D., VASIC, R., XUE, Y. and YAMADA, T.: GLACE : The Global Land – Atmosphere Coupling Experiment . Part II : Analysis, Am. Meteorlogical Soc., 7, 611–625, 2006.

Guyot, A., Cohard, J.-M., Anquetin, S., Galle, S. and Lloyd, C. R.: Combined analysis of energy and water balances to estimate latent heat flux of a sudanian small catchment, J. Hydrol., 375(1–2), 227–240, doi:10.1016/j.jhydrol.2008.12.027, 2009.

Guyot, A., Cohard, J.-M., Anquetin, S. and Galle, S.: Long-term observations of turbulent fluxes over heterogeneous vegetation using scintillometry and additional observations: A contribution to AMMA under

Sudano-Sahelian climate, Agric. For. Meteorol., 154–155, 84–98, doi:10.1016/j.agrformet.2011.10.008, 2012.

Hall, F. G., Huemmrich, K. F., Goetz, S. J., Sellers, P. J. and Nickeson, J. E.: Satellite Remote Sensing of Surface Energy Balance â€™ Success , Failures , and Unresolved Issues in FIFE, J. Geophys. Res., 97(D17), 19061–19089, 1992.

Higgins, C. W.: A-posteriori analysis of surface energy budget closure to determine missed energy pathways, Geophys. Res. Lett., 39(19), 1–5, doi:10.1029/2012GL052918, 2012.

Ingelrest, F., Barrenetxea, G., Schaefer, G., Vetterli, M., Couach, O. and Parlange, M.: SensorScope, ACM Trans. Sens. Netw., 6(2), 1–32, doi:10.1145/1689239.1689247, 2010.

Katul, G. G. and Parlange, M. B.: A Penman-Brutsaert Model for Wet Surface Evaporation, Water Resour. Res., 28(1), 121–126, 1992.

Krishnan, P., Meyers, T. P., Scott, R. L., Kennedy, L. and Heuer, M.: Energy exchange and evapotranspiration over two temperate semi-arid grasslands in North America, Agric. For. Meteorol., 153, 31–44, doi:10.1016/j.agrformet.2011.09.017, 2012.

Kustas, W. P., Rango, A. and Uijlenhoet, R.: A simple energy budget algorithm for the snowmelt runoff model, Water Resour. Res., 30(5), 1515–1527, doi:10.1029/94WR00152, 1994.

Leuning, R.: The correct form of the Webb, Pearman and Leuning equation for eddy fluxes of trace gases in steady and non-steady state, horizontally homogeneous flows, Bound.-Layer Meteorol., 123(2), 263–267, 2007.

Lhomme, J.-P. and Elguero, E.: Examination of evaportive fraction diurnal behaviour using a soi-vegetation model coupled with a mixed-layer model, Hydrol. Earth Syst. Sci., 9(2), 259–270, 1999.

Lohou, F., Saïd, F., Lothon, M., Durand, P. and Serça, D.: Impact of Boundary-Layer Processes on Near-Surface Turbulence Within the West African Monsoon, Bound.-Layer Meteorol., 136(1), 1–23, doi:10.1007/s10546-010-9493-0, 2010.

Lohou, F., Kergoat, L., Guichard, F., Boone, a., Cappelaere, B., Cohard, J.-M., Demarty, J., Galle, S., Grippa, M., Peugeot, C., Ramier, D., Taylor, C. M. and Timouk, F.: Surface response to rain events throughout the West African monsoon, Atmospheric Chem. Phys., 14(8), 3883–3898, doi:10.5194/acp-14-3883-2014, 2014.

Mamadou, O., Galle, S., Cohard, J.-M., Peugeot, C., Kounouhewa, B., Biron, R., Hector, B. and Zannou, A. B.: Dynamics of water vapor and energy exchanges above two contrasting Sudanian climate ecosystems in Northern Benin (West Africa): WATER VAPOR AND ENERGY EXCHANGES, J. Geophys. Res. Atmospheres, 121(19), 11,269-11,286, doi:10.1002/2016JD024749, 2016.

Mande, T., Ceperley, N., Barrenetxea, G., Repetti, A. and Niang, D.: Rainfall-Runoff Processes in a Mixed Sudanian Savanna Agriculture Catchment : Use of a distributed sensor network, in Geophysical Research Abstracts, vol. 13, p. 1, Vienna, Austria., 2011.

Mauder, M., Jegede, O. O., Okogbue, E. C., Wimmer, F. and Foken, T.: Surface energy balance measurements at a tropical site in West Africa during the transition from dry to wet season, Theor. Appl. Climatol., 89(3–4), 171–183, doi:10.1007/s00704-006-0252-6, 2006.

Nadeau, D. F., Brutsaert, W., Parlange, M. B., Bou-Zeid, E., Barrenetxea, G., Couach, O., Boldi, M.-O., Selker, J. S. and Vetterli, M.: Estimation of urban sensible heat flux using a dense wireless network of observations, Environ. Fluid Mech., 9(6), 635–653, doi:10.1007/s10652-009-9150-7, 2009.

Nicholson, S. E., Tucker, C. J. and Ba, M. B.: Desertification, drought, and surface vegetation: An example from the West African Sahel, Bull. Am. Meteorol. Soc., 79(5), 815–830, 1998.

Oldroyd, H. J., Pardyjak, E. R., Huwald, H. and Parlange, M. B.: Adapting Tilt Corrections and the Governing Flow Equations for Steep, Fully Three-Dimensional, Mountainous Terrain, Bound.-Layer Meteorol., 1–27, 2015.

Parlange, M. B. and Katul, G. G.: Estimation of the diurnal variation of potential evaporation from a wet bare soil surface, J. Hydrol., 132(1–4), 71–89, doi:10.1016/0022-1694(92)90173-S, 1992.

Pielke, R. A., Marland, G., Betts, R. A., Chase, T. N., Eastman, J. L., Niles, J. O., Niyogi, D. D. S. and Running, S. W.: The influence of land-use change and landscape dynamics on the climate system: relevance to climate-change policy beyond the radiative effect of greenhouse gases., Philos. Transact. A Math. Phys. Eng. Sci., 360(1797), 1705–1719, 2002.

Porte-Agel, F., Parlange, M. B., Cahill, A. T., Gruber, A. and Porte, F.: Mixture of Time Scales in Evaporation : Desorption and Self-Similarity of Energy Fluxes, Agron. J., 92(September-October), 832–836, 2000.

Rebmann, C., Kolle, O., Heinesch, B., Queck, R., Ibrom, A. and Aubinet, M.: Data Acquisition and Flux Calculations, in Eddy Covariance, edited by M. Aubinet, T. Vesala, and D. Papale, pp. 59–83, Springer Netherlands., 2012.

Santos, C. A. C. D., Silva, B. B. D. and Rao, T. V. R.: Analysis of the evaporative fraction using eddy covariance and remote sensing techniques, Rev. Bras. Meteorol., 25(4), 427–436, doi:10.1590/S0102-77862010000400002, 2010.

Schüttemeyer, D., Moene, a. F., Holtslag, a. a. M., Bruin, H. a. R. and Giesen, N. V.: Surface Fluxes and Characteristics of Drying Semi-Arid Terrain in West Africa, Bound.-Layer Meteorol., 118(3), 583–612, doi:10.1007/s10546-005-9028-2, 2006.

Shuttleworth, W. J.: FIFE: the variation in energy partition at surface flux sites, Remote Sens. Large-Scale Glob. Process. IAHS Publ., (186), 1989.

Simoni, S., Padoan, S., Nadeau, D. F., Diebold, M., Porporato, A., Barrenetxea, G., Ingelrest, F., Vetterli, M. and Parlange, M. B.: Hydrologic response of an alpine watershed: Application of a meteorological wireless sensor network to understand streamflow generation, Water Resour. Res., 47(10), doi:10.1029/2011WR010730, 2011.

Steiner, A. L., Pal, J. S., Rauscher, S. A., Bell, J. L., Diffenbaugh, N. S., Boone, A., Sloan, L. C. and Giorgi, F.: Land surface coupling in regional climate simulations of the West African monsoon, Clim. Dyn., 33(869–892), 2009.

Swanson, R. A.: Gourmantche agriculture, Ouagadougou USAID, 1978.

Swets, D. L., Reed, B. C., Rowland, J. D. and Marko, S. E.: A weighted least-squares approach to temporal NDVI smoothing, in Proceedings of the 1999 ASPRS Annual Conference, Portland, Oregon., 1999.

Sylla, M. B., Pal, J. S. and Wang, G.: Impact of land cover characterization on regional climate modeling over West Africa, Clim. Dyn., 2015.

Szilagyi, J. and Parlange, M. B.: Defining Watershed-Scale Evaporation Using a Normalized Difference Vegetation Index, J. Am. Water Resour. Assoc., 35(5), 1245–1255, doi:10.1111/j.1752-1688.1999.tb04211.x, 1999.

Szilagyi, J., Rundquist, D. C., Gosselin, D. C. and Parlange, M. B.: NDVI relationship to monthly evaporation, Geophys. Res. Lett., 25(10), 1753–1756, 1998.

Timouk, F., Kergoat, L., Mougin, E., Lloyd, C. R., Ceschia, E., Cohard, J.-M., Rosnay, P., Hiernaux, P., Demarez, V. and Taylor, C. M.: Response of surface energy balance to water regime and vegetation development in a Sahelian landscape, J. Hydrol., 1–43, 2009.

Topp, G. C., Davis, J. L. and Annan, A. P.: Electromagnetic determination of soil water content: Measurements in coaxial transmission lines, Water Resour. Res., 16(3), 574–582, doi:10.1029/WR016i003p00574, 1980.

Vitousek, P. M.: Human Domination of Earth's Ecosystems, Science, 277(5325), 494–499, doi:10.1126/science.277.5325.494, 1997.

Webb, E., Pearman, G. and Leuning, R.: Correction of flux measurements for density effects due to heat and water vapour transfer, Q. J. R. Meteorol. Soc., 106(447), 85–100, 1980.

White, F.: la vegetation de l'Afrique: Memoire accompagnant la carte de vegetation de l'Afrique., 1986.

Whiteman, C. D. and Allwine, K. J.: Extraterrestrial solar radiation on inclined surfaces, Environ. Softw., 1(3), 164–169, 1986.

Wilczak, J. M., Oncley, S. P. and Stage, S. A.: Sonic anemometer tilt correction algorithms, Bound.-Layer Meteorol., 99(1), 127–150, 2001.

Williams, C. a., Reichstein, M., Buchmann, N., Baldocchi, D., Beer, C., Schwalm, C., Wohlfahrt, G., Hasler, N., Bernhofer, C., Foken, T., Papale, D., Schymanski, S. and Schaefer, K.: Climate and vegetation controls on the surface water balance: Synthesis of evapotranspiration measured across a global network of flux towers, Water Resour. Res., 48(6), W06523, doi:10.1029/2011WR011586, 2012.

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Classification based on Chorology and Life Form is based on Raunkiaer (1934), Schnell (1971), and Keay & Hepper (1954-1972) via Adomou (2005).

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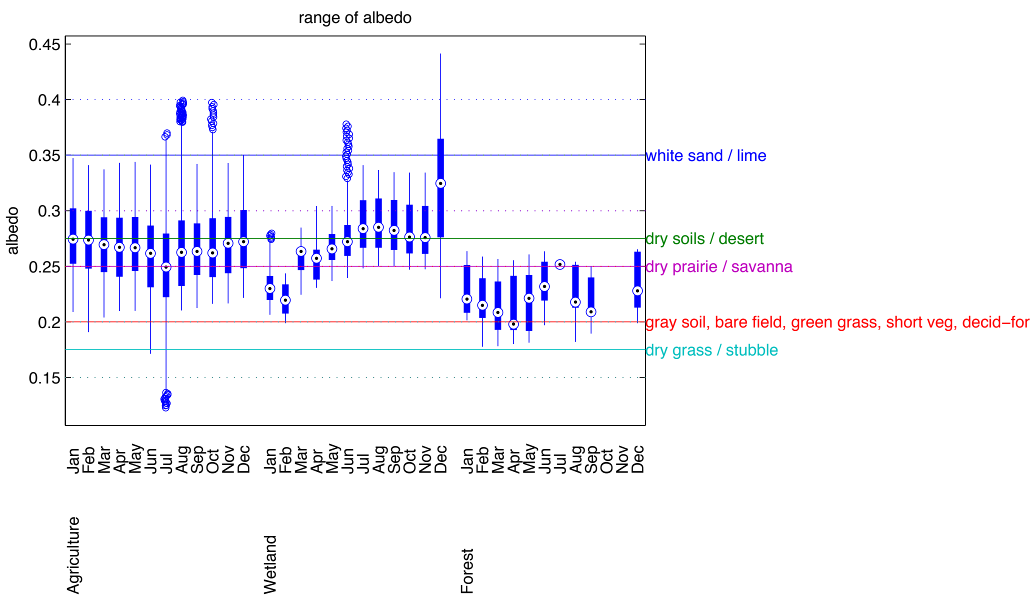
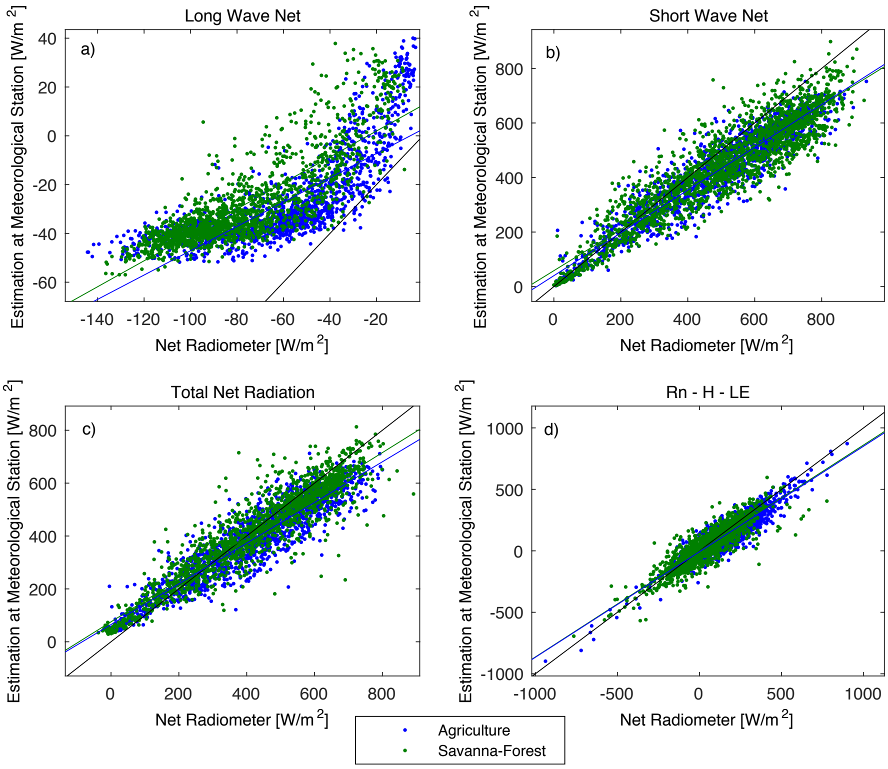


Figure 2: Distribution of albedo by landcover (Agricultural, Wetland, and Forest) and by month for the study period. The central dot is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the most extreme data points not considered outliers, and outliers are plotted individually. Average values for various land-covers listed by Brutsaert (1982) are drawn and labelled to the right. Ranges for these are shown in

dotted lines. Our values mostly range between those of bare field or green grass and dry soils and desert, with dry prairie or savanna making a good mid value.



	Agriculture	Savanna-Forest
a) LW_{net}	0.58	0.50
b) SW_{net}	0.76	0.78
c) R_n	0.80	0.77
R_n-H- L_eE	0.86	0.86

Figure 3: Comparison of measurements and calculations on a half hour scale of (a) net short wave, (b) net long wave, and (c) total radiation and the residual (not shown, correlation in table) after subtracting the measured turbulent fluxes. In all cases the slope is less than 1, which means that the measurements are greater than the calculation. The slopes of the regression lines are in the accompanying table. In each plot, measurements over the agricultural field are shown in blue and over the savanna-forest are shown in green. Black lines show the one to one line and coloured lines show the least squared regression lines.

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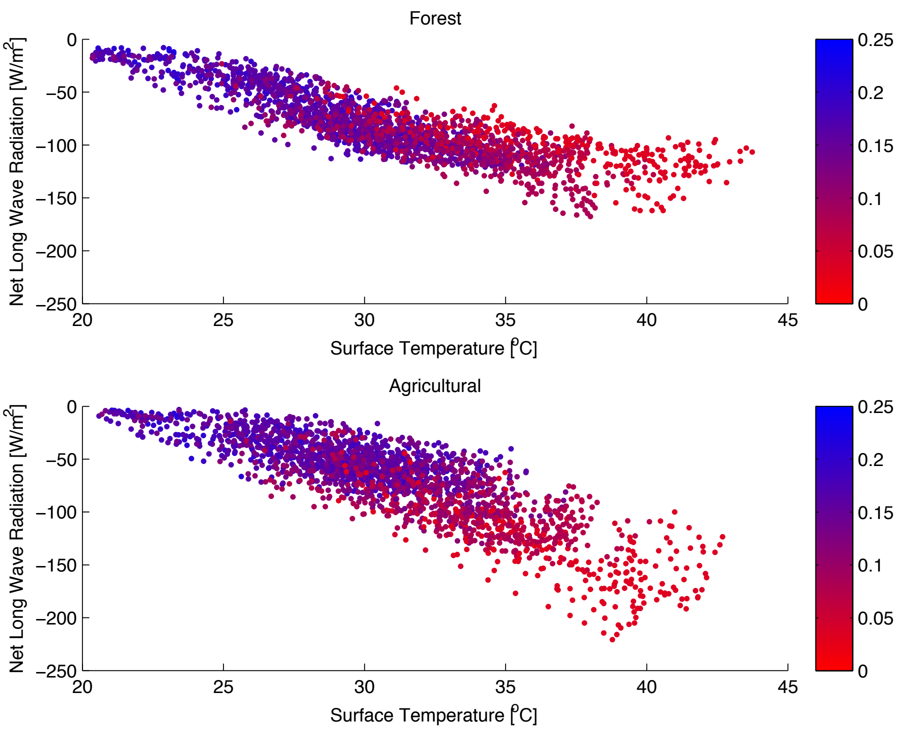

Figure 7: Net Long-wave Radiation Response to Soil Moisture and Surface Temperature. Surface temperature and net long wave radiation had a strong negative correlation with each other and also with volumetric soil water content, shown by the colour. The pattern of this correlation varied by land cover, savanna-forest above and agriculture below.

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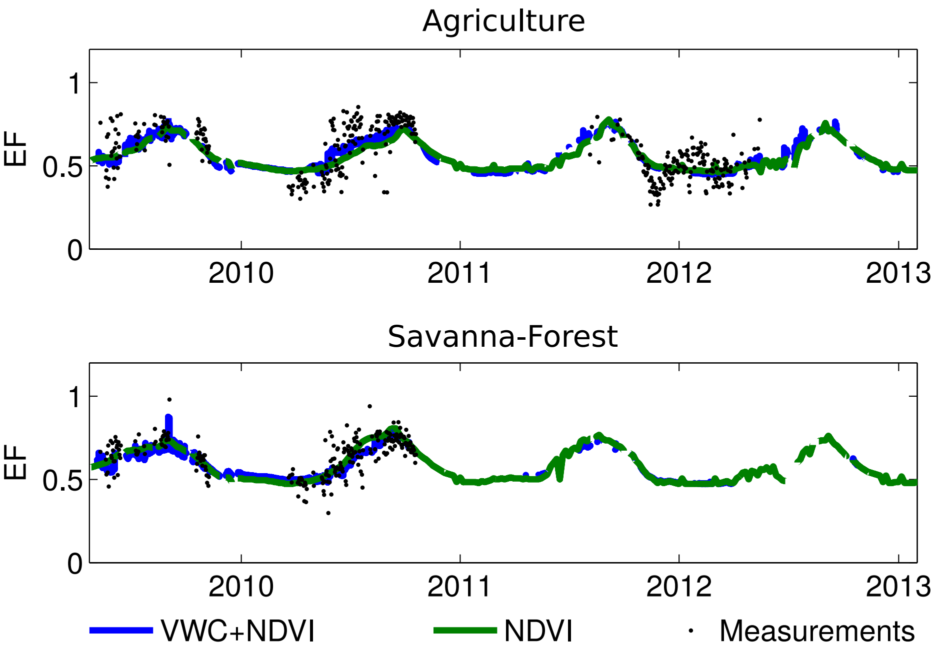

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Time series of evaporative fraction. Upper plot shows evaporative fraction over the field and lower plot shows evaporative fraction over the savanna-forest. Measured data points are in black (points), calculated evaporative fraction based on soil moisture and NDVI is shown in blue and just NDVI is shown in green.