Biogeosciences Discuss., 8, C5317–C5330, 2012
www.biogeosciences-discuss.net/8/C5317/2012/

Biogeosciences Discussions

Interactive comment on "How do more extreme rainfall regimes affect ecosystem fluxes in seasonally water-limited Northern Hemisphere temperate shrublands and forests?" *by* I. Ross et al.

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Received and published: 13 January 2012

Many thanks to the reviewer for a detailed and useful review of our paper. Here, we address the six main issues in the review – minor and technical comments will be incorporated into any revised manuscript that we submit. We believe that it should be relatively straightforward to address these issues.

1 Weakness in approach to removing influence from annual rainfall with Equation 1

The structure (form) of equation 1 is loosely justified (though the statistics on fit are missing e.g. R^2 and standard error). However there appears to be structure in the residuals and an alternative form may be more appropriate. Choosing an appropriate model for this is critical because it serves as a reference seeking to remove the effects of annual precipitation. Furthermore, and more importantly, the model in Eq1 does not provide a good fit to the relationships within *the dry and wet populations. For example, within the dry site population, the model seems to overestimate GPP and NEP at nearly all of the sites and years. Especially because these populations are analyzed separately in successive analyses, the structure to any residuals confounds the analysis of control by daily rainfall intensity. One approach to address this would be to model fluxes versus annual precipitation for the dry and wet populations separately and then study their separate residuals versus the target of interest, annual mean daily rainfall intensity. Authors may also want to consider a simple bin-average as the reference for different levels of annual rainfall. While clearly a heavily empirical approach and specific to the dataset on hand, it has the major advantage of providing residuals with little to no structure. This general concern really should be resolved before the paper is awarded final publication. The good news is that it should be easy to make the adjustments.*

We agree that this is a critical issue and are certainly open to the suggestion that the approach we have chosen is not the most ideal possible. The main motivation for choosing the exponential model that we used in the submitted manuscript was to have a model that behaved reasonably at small precipitation values. This is admittedly a weak justification, and a different, simpler, model might be easier to justify.

The main considerations here are the structure of the residuals of the exponential model, the possibilities for using alternative models and the separate fitting of dry and wet site populations.

1.1 Structure of residuals

In fact, there is little structure in the residuals from either the GPP or RE fits to the exponential rainfall amount model. There is no significant trend in the residuals for either fit, or for the absolute values of the residuals. There is some noticeable difference in the signs of the residuals:

	GPP		**RE**	
	DRY	**WET**	**DRY**	**WET**
Negative	22	20	23	20
Positive	11	32	10	32

About twice as many dry site-years have negative residuals as positive for both quantities, compared to a more equal spread for the wet site-years, but given the absence of any significant overall trend in the residuals, this doesn't seem very relevant. That said, other models can certainly also be constructed that have unstructured residuals.

1.2 Alternative models

It is difficult to know exactly what might be the best model to use to capture the variability due to total rainfall amount, since there is significant spread in the flux data. Three reasonable approaches to compare would seem to be our original exponential model, a through-origin linear fit, and a piecewise-constant model, with one value for dry sites and one for wet (using the mean flux values for the two groups as unbiased estimators of the group flux values). The following table shows R^2 values for the exponential, through-origin linear and two piecewise-constant models:

	GPP	**RE**
Exponential	0.329	0.249
Linear (through-origin)	0.150	0.087
Piecewise-constant	0.404	0.310
Piecewise-constant (optimised)	0.484	0.401

The first piecewise-constant model used the same “dry”/“wet” classification as in the original manuscript, while the “optimised” model uses a stratification into “dry” and “wet” sites chosen to maximise the mean R^2 value of the GPP and RE models. Even in the unoptimised case, the piecewise-constant model clearly does a better job at representing the flux differences between the dry and wet site populations. The optimised version of the piecewise-constant model is better still.

The only possible disadvantage to this optimisation approach is that it partitions the sites rather unevenly, with only 10 sites and 21 site-years in the “dry” group as compared to 18 sites and 64 site-years in the “wet” group. This is a consequence of the smaller variance of ecosystem fluxes for larger precipitation totals compared to smaller totals (part of the reason for originally choosing the exponential model). From that perspective, the uneven distribution into “dry” and “wet” groups could be viewed as an advantage, since it eliminates a potential source of spurious within-group variability, although it does mean that sample sizes for comparing effect sizes in the “dry” group are rather small (see below).

On balance, we agree that using a piecewise-constant model for the overall precipitation amount effect on fluxes makes sense. An ancillary benefit of using a split into “dry” and “wet” sites that maximises the variance explained by the overall precipitation amount effect is that it, at least to some extent, neutralises the objection that the division into “dry” and “wet” is arbitrary.

1.3 Separate fitting of dry and wet site populations

We are not completely clear on the issue of the total rainfall model needing to explain variability within the two groups of sites when fitted to data for those sites individually, since the purpose of the model is to compensate for differences *between* drier and wetter sites. Perhaps this consideration is irrelevant, since, if we use a piecewise-constant model for the overall precipitation amount response, we are essentially modelling the two groups of sites separately anyway.

2 Ambiguity in how/why data were pooled across sites and standardized in the way they were

It is not clear why and how the standardization of predictor variables was calculated. Additional information on this should be provided around page 9822, L8-21 to explain why and how. For example, does this part of the analysis rely on residuals from the C-flux relationships predicted by Eq 1 and based on annual precipitation? Probably not given that the slopes in Fig 2 and Table 3 are not alike, however this is unclear. Is precipitation intensity calculated for each year at each site, and then the site-level mean across years and standard deviation across years are used to normalize this? If yes, it seems that this would remove the between-site variability and isolate within-site anomalies, which could be desirable but should be explained. Alternatively, is each site's mean annual precipitation intensity normalized by the across-site mean and standard deviation of site-level mean annual precipitation intensity? This isolates between-site gradients and removes within site, year-to-year variation and would answer different questions. A third approach would be to retain each site-year of data as a sample in the multi-site, multi-year population, and normalize these by the mean and standard deviation of the mutli-site, multi-year pool. This offers still another possibility, and is probably what was performed. However, it leads to a confounded interpreta-

tion because one would expect the sensitivity of year-specific anomalies at a site to be different from site-to-site anomalies. The paper should be more clear about what, precisely, has been performed, presenting the equations that fully document the approach, as well as the justification for the approach adopted. Without this information it is not possible to judge the present interpretation. Authors might consider seeking to split the analysis into separate spatial and temporal elements, where standardization options one and two described above are adopted. Of course, sample sizes may become prohibitively small so it is not clear that this is feasible.

Both reviewers commented that this section was unclear. We definitely need to expand the explanation here and make it quite unambiguous both how the analysis is performed and what justification there is for taking the approach that we do.

In fact, the approach we took is the third described by the reviewer, i.e. to treat site-years as independent data points. We are aware that this approach confounds spatial and temporal variability, and this was a point of contention during the preparation of the manuscript. The problem, as noted by the reviewer, is that attempting to extract spatial (inter-site) and temporal (intra-site) variability as separate effects is made difficult by the small sample sizes. We have 85 site-years of data, for 28 sites, with a maximum of six years data per site (3 sites) and several sites with only one (3 sites) or two (10 sites) years of data – the following table shows the distribution of site-years per site (D/W indicates whether the site is a "dry" or a "wet" site according to the classification maximising the R^2 of the total precipitation amount model):

Site	No.	Site	No.	Site	No.	Site	No.
US-MMS (W)	6	IT-SRo (W)	4	ES-LMa (W)	3	PT-Esp (W)	2
IT-Cpz (W)	6	US-SRM (D)	3	US-SP2 (W)	2	IT-PT1 (W)	2
FR-Pue (W)	6	US-SO4 (D)	3	US-SO3 (D)	2	IT-Non (W)	2
US-Ton (W)	5	US-SO2 (D)	3	US-MOz (W)	2	IL-Yat (D)	2
US-Blo (W)	5	US-KS2 (W)	3	US-Me4 (D)	2	PT-Mi1 (D)	1
IT-Ro1 (W)	5	US-Dk3 (W)	3	US-Me3 (D)	2	IT-Lec (D)	1
US-SP3 (W)	4	IT-Ro2 (W)	3	US-Me2 (D)	2	IT-Col (W)	1

Given this data, extracting spatial variability should not be a problem, but evaluation of intra-site temporal variability will realistically have to be confined to the 8 sites with four or more years of data, all of which are "wet" sites.

Perhaps this is the best that can be done with the data that is available. In any resubmitted manuscript, we thus propose to present results of all three analyses (inter-site spatial variation only, intra-site temporal variation only, and combined spatial and temporal variation). This approach, combined with a clearer description of the analysis, should elucidate just what kinds of variability in ecosystem fluxes can be attributed to particular aspects of rainfall variability. We now recognise that the current treatment is not adequate to answer all the questions of interest here.

It would also help if figures used different symbols for different sites, providing a better indication of the site-year distribution for each population (dry, wet, all), and if results are driven more by across site gradients, or within-site year-to-year variation. Fig 1 already provides some indication but this could be useful for follow-on figures (2 and 4).

We have been experimenting with some different methods of presenting this data in a clearer fashion. With 28 sites, using different symbols for each site might be a little overwhelming, but one possibility (similar to the "range boxes" on Figure 1 in the

manuscript) is to join points from the same site with lines. This has the potential to allow a reader to get an idea of the variability associated with individual sites as well as then between-site variability. As yet, we don't have something that we are completely happy with, but we are keen to improve the presentation here and to propagate this information throughout the rest of the figures in the manuscript. (Figures 1 and 2 show an example of the sort of thing we have been trying, comparing one of the original figures with a modified version with some extra lines to identify data points from the same site. This is still a little confusing, but we have some other ideas that may help.)

3 Internal inconsistency in comparing effect sizes

Table 3 seeks to compare the sensitivity of ecosystem C fluxes to three different rainfall statistics, total annual rainfall, precipitation intensity, and the 95th percentile depth. Up to this point the overall analysis used the non-linear equation 1 to remove effects of mean annual rainfall, but this effect size analysis adopts instead a linear model. The change of framework adopted here leads to an abrupt and confusing change in interpretation, and presents a conceptual discontinuity in the approach and presentation. The weak justification is to allow for comparison of effects size between annual rainfall and intra-annual variability in rainfall (meaning the daily depth-intensity statistics). However, this raises a new problem, that the linear model is clearly flawed for the "All" sites population as shown in Fig 1.

We agree. On rereading, the introduction of the linear total precipitation amount model at this point in the analysis is not helpful. Following the reviewer's suggestion of using a piecewise-constant model for the total precipitation effect will make this simpler to deal with, and we will be able to treat all effect sizes on the same basis.

Also, statistics for the linear regressions are not presented, namely R^2, standard error of the regression and its parameters, and the intercept, so it is not possible to judge the veracity of these relationships. Slope alone is an insufficient representation of the relevance of this set of findings regarding effect size. The statistics reported in Figure 2 are for relationships with C-flux residuals after accounting for annual precipitation with Eq 1, and thus are not relevant in the current analysis that appears to rely on the raw C fluxes. The units on values presented in the table are missing (e.g. $\mathrm{gC\,m^{-2}\,y^{-1}}$ *per standardized statistic). These omissions make it difficult to judge the relative importance of each precipitation variable, and the weight of evidence for corresponding conclusions.*

These are all valid criticisms – we will add this information to any revised manuscript.

4 Possible contamination from effects of precipitation in a frozen form

Frozen precipitation (snow, hail, graupel, etc) should be treated differently or possibly removed by focusing on warm season or growing season anomalies only. The intensity of daily precipitation during frozen events is not mechanistically expected to have direct influence on GPP, RE, and NEP in the same way that rainfall events would. At least some of the sites being examined receive winter precipitation (frozen form) so this needs to be addressed.

This is a valid point and not something that we had considered. In order to include only precipitation from non-frozen conditions, we now exclude precipitation that falls during periods when the 3-day moving mean air temperature is below freezing. This ensures that only liquid precipitation that is likely to contribute to plant productivity is considered. For most sites, this change makes little or no difference, but some sites have significant wintertime precipitation and this modification to the data processing

changes the precipitation values used for these sites rather more – here are the largest 20 changes in percentage terms:

Site	**Year**	ΔP (%)	**Site**	**Year**	ΔP (%)
US-Me2	2003	-48.7342	US-Me2	2004	-13.5131
US-Me2	2005	-34.7466	US-Me3	2004	-12.8966
US-Me3	2005	-31.3046	US-Blo	2001	-12.5136
US-Ton	2001	-26.3204	US-Me4	1996	-12.4602
IT-Col	1996	-22.1708	US-Wrc	2000	-11.7733
US-Me4	2000	-18.812	US-Ton	2005	-11.7498
IT-Col	1998	-18.0659	US-Blo	2002	-10.8792
US-Blo	2004	-16.4957	IT-Col	1997	-10.3961
US-Wrc	2005	-14.4133	US-SO3	2006	-9.99639
US-Ton	2004	-14.0616	IT-Pia	2002	-9.62805

Figure 3 gives some impression of the impact of this change on the distribution of precipitation values as related to GPP. Overall, the change in distribution is relatively insignificant.

5 Improved precision of nomenclature

The terms "extreme" and "intra-annual" could be made more precise in their usage. An extreme rainfall regime could be one with large inter-annual variation, however the present analysis seeks to emphasize and isolate the daily intensity/frequency within a year. This should be clarified in the title and throughout. Similarly, intra-annual variability can refer to strong seasonality or alternatively, infrequent but large events evenly spread across a year. This too should be clarified and used in a more restricted and clear way throughout the manuscript, possibly "annual mean daily rainfall intensity".

Agreed. We were too loose in our use of the word “extreme”. It has too many meanings in the climate literature and in general usage, and we should choose more precise terms. In any modified manuscript, we will review the literature on “extreme” precipitation regimes to try to identify some more precise standard terminology and if such precise alternatives do not exist, we will follow the reviewer’s suggestion. In fact, the reviewer’s next point will also help with this problem.

6 Consider use of defined abbreviations may help

As noted above, the approach to standardizing precipitation variables, as well as the carbon fluxes (residuals or raw values) might be better represented and clarified by the use of symbols or abbreviations that are clearly defined in the text and re-explained briefly in the figure or table captions. For example, the standardized precipitation statistics might be represented with a Z-score type symbol (e.g. $Z_{\text{intensity}}$, *and* $Z_{R95\%}$*).*

This is a good idea. This should help to make the explanation of the effect sizes treatment a lot clearer, and will allow us to define terms precisely in one place without needing to repeat long descriptions again and again. We will do this.

Interactive comment on Biogeosciences Discuss., 8, 9813, 2011.

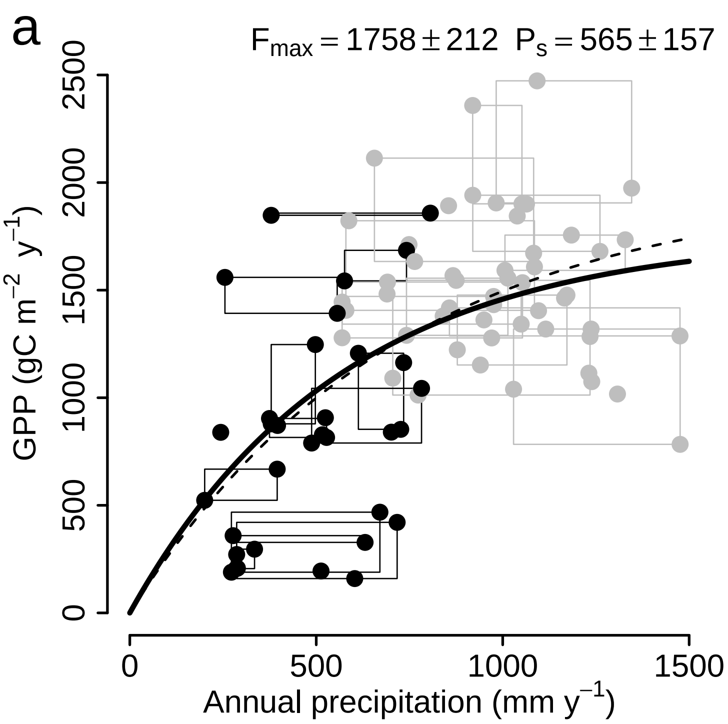

Fig. 1. Original Figure 1a from manuscript

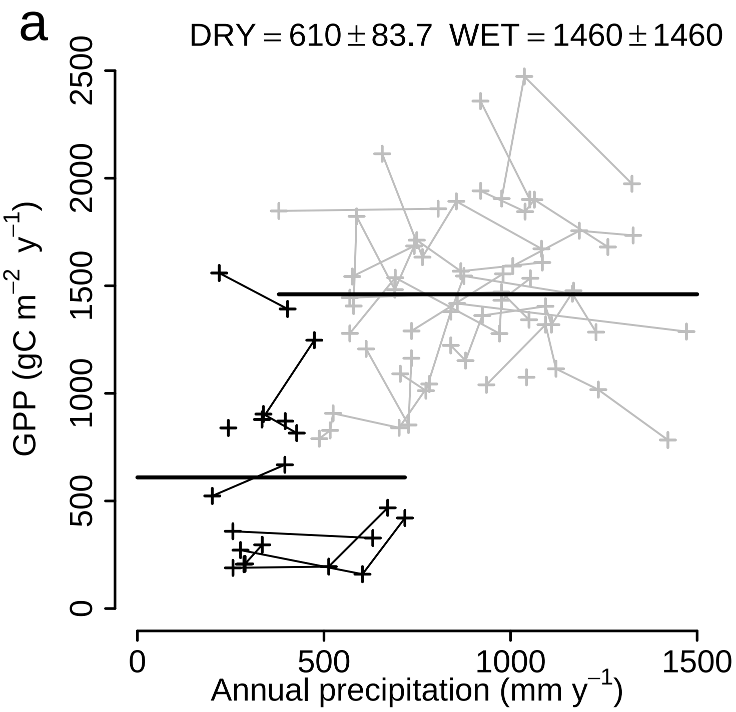

Fig. 2. Possible modification to Figure 1a to highlight inter-site and intra-site variability.

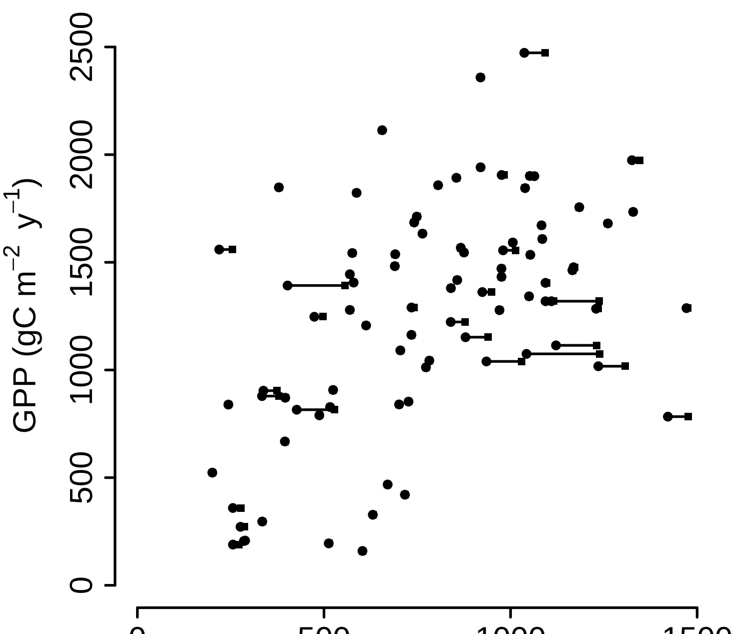

Fig. 3. Comparison of precipitation vs. GPP scatter plot for original precipitation calculation (including frozen precipitation: squares) and precipitation excluding frozen precipitation (circles).