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Interactive comment on "Analyzing precipitationsheds to understand the vulnerability of rainfall dependent regions" *by* P. W. Keys et al.

P. W. Keys et al.

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We would like to thank the Reviewer (Obbe Tuinenburg) for his positive comment stating that the paper is well written and presents a new concept. Below we reply in detail to his other comments.

1. Comment: "As the precipitationshed is the novel idea in this paper, the authors should consider to explain the concept in a section of its own. Possibly part of the "Background" section can be merged with the introduction section and a section presenting the precipitationsheds can follow the introduction section?"

Response: This feedback is consistent with the feedback of one of the other reviewers (P. Laux). A descriptive paragraph of the precipitationshed concept is found on 10490

L. 17 to 10491 L.4. We will expand this section to include a bit more on the conceptual nature of the precipitationshed, particularly some of the important characteristics and the thought-process involved in its development. We will also add a header, clearly delineating the section “The precipitationshed concept.”

2. Comment: “In the Data and Methods section, the shortcomings and assumptions of the methods used should be more highlighted. As the water accounting model (WAM) calculates vertically integrated fluxes, it will do a good job in areas where the variability of horizontal moisture transport with height is small. However, in areas where this variability is high, it will perform less.”

Response: We agree with this comment, and since this has also been suggested by another Reviewer (P. Laux), and we propose the following text:

“Limitations associated with vertically integrating moisture fluxes may include potential distortions in areas where there is large heterogeneity in the atmospheric column. For example, in West Africa, there can be near surface dynamics related to the ITCZ, while the high altitude dynamics, such as the African or Tropical Easterly Jet, move in a different direction. However, as demonstrated by van der Ent et al. (2010), the large-scale features of regional and global moisture fluxes are preserved.”

We will also include a comment at the end of page 10493 regarding the fact that in areas where there is large heterogeneity in the atmospheric column, that the vertical integration of moisture flux may be less accurate. To be inserted end of 10493:

“The major concern is the vertically integrated moisture flux employed by the model as well as the well-mixed assumption of the atmosphere (e.g. Laux, 2011; Tuinenburg, 2011). Future studies are expected to bring more insight into the consequences this will have for the results (Dirmeyer, 2011; van der Ent, 2011).

3. Comment: “Related to the previous point and the WAM, the 1.5 degree resolution of the input data might be a bit coarse. At this data resolution, the moisture conver-

gence/divergence that is implicitly calculated by the WAM might suffer from numerical errors. I do not know how these errors propagate in the current analysis (maybe the overall effect on the shape of the precipitationsheds is quite small for some precipitationsheds), but they should be discussed."

Response: We recognize the concern that moisture convergence/divergence issues could lead to numerical errors. van der Ent et al. (2010) explicitly addressed this by reducing the Courant number:

"The reanalysis data set has been reduced to 0.5-h resolution to reduce the Courant number." (van der Ent et al., 2010)

The numerical dispersion that a small Courant number will cause was found not to influence the results (of van der Ent et al., 2010). We do not feel that we should explicitly discuss this issue as well in the current paper, because we already refer to van der Ent et al. (2010) and will include further cautionary notes in the paper based on the reviews.

4. Comment: "How large is the interannual variability in the (shape of the) precipitationsheds? And how does this relate to variability in evaporation, wind and precipitation patterns? The variability on this spatial scale is probably not very large, but it would be good to give the reader an impression of the robustness of the precipitationsheds. For a similar study done for the Indian subcontinent (http://www.agu.org/pubs/crossref/pip/2011JD016221.shtml), we found that the variability in moisture recycling (related to the precipitationsheds presented here) was mainly due to the variability in wind and precipitation patterns, and much less due to variability in evaporation."

Response: Thank you for pointing us in the direction of this paper. The seasonal variability was not explored in this study, particularly because we are interested only in the growing season for the sink regions to link the precipitationshed to vulnerability of food production. Exploring other seasons (or months) is outside of the scope of this paper, but it is certainly important for understanding how the origins of precipitation change throughout the year. As for the interannual variability we will add a sentence at the end of 4.2:

"The interannual variability of the size 70%-precipitationsheds (during the growing season) is generally in the order of 8-35% of the average precipitationshed size. The maximum we found for Pakistan (35%) and the minimum for North China, East China and West Sahel (8%). For more details see Fig.S8 and Table S1."

Concerning the question what dominates a precipitationshed, we already mentioned this on 10497 L 6-14:

“Also, the spatial extent and the shape of the precipitationsheds generally reflect prevailing storm tracks and wind directions. The absolute precipitationsheds are interrupted by vast areas of no contribution (e.g. if there is a desert), and then have significant contribution much further away (e.g. precipitationsheds of Western Sahel, Eastern Sahel, Pakistan-India, and Eastern China). The relative precipitationsheds are spatially contiguous (lacking the fragmentation of the absolute precipitationsheds), including areas of potential (but not current) evaporation contribution.”

Note that, in the study mentioned by the reviewer (Tuinenburg et al., 2011), precipitation was considered to be a more important driver of moisture recycling rather than the evaporation, however, that study considers the destination of evaporation, while we investigate the origin of precipitation, which is naturally driven by upwind evaporation. The lack of evaporation from deserts e.g. means that they are not present in the absolute precipitationsheds, while the relative precipitationsheds reveal that the desert areas could enhance precipitation in the sink regions if they were to evaporate (e.g. if these areas were reforested). The 70%-precipitationshed size does show a strong correlation to precipitation in some areas (see the correlations below). Hence for each sink region there might be a very different combination of evaporation, precipitation and wind direction driving the precipitationshed size.

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Correlation between precipitation and precipitationshed size:

Argentina: 0.35

East China: 0.45

Eastern Sahel: 0.83

North China: 0.41

Pakistan-India: 0.16

Southern Africa: -0.27

Western Sahel: -0.05

5. Comment: "Related to the interannual variability of the precipitationsheds, I think that the vulnerability of the seven regions in this study should probably be based on the precipitation- sheds of the years with the lowest precipitation. Those are the years in which upwind evaporation can make the difference for water resources."

Response: This is an excellent idea, however it assumes that all dry years have the same characteristics, while it is not certain that this is the case. Therefore, we have retained the length of the data record used in this study (10 years). Using all the years was deemed important for identifying the mean shape of the precipitationsheds. On the other hand, the precipitationsheds of dry years could be a good item for future research.

6. Comment: "The anthromes composition in table 3 are displayed in pie-charts. Pie charts are hard to interpret, because people generally have difficulty to compare the differences in areas between the parts. I suggest to put the eight number on which the pie charts are based in the table, in that way they can be intercompared better."

Response: This is a very good suggestion, and we will include the numbers in this table, or since there may not be enough space, we might create a separate table for the Anthromes composition data.

7. Comment: “How are the anthromes compositions of the precipitationsheds determined? From the fractions ocean and land in table 3, the compositions seem to be determined by the areal fraction in the 70% relative precipitationshed. I suggest to weigh the anthromes composition by the contribution to precipitation in the sink region. In that way, the land uses that contribute a lot to the precipitation in the sink region are represented more in the anthromes composition than those that contribute less. Another advantage of weighing over the contribution to precipitation is that it can be done over the entire globe and the 70% cutoff value (which seems arbitrary) is not needed. (Because areas far away that contribute little to the precipitation in the sink region have only a small representation in the anthromes composition.).”

Response: The Anthromes compositions are determined using the 70% relative precipitationshed. Thus, weighing by the absolute evaporation contributions would be inconsistent. Whilst also this suggestion might be interesting for future research, this does not add to our purposes of the analysis, which is to develop a qualitative framework (p10497-L20).

8. Comment: “Figure S1: What is the message of this figure? The absolute and relative scales under each figure are very useful, showing that the absolute precipitation in the sink region is coupled to the evaporation in the source region, the concept of the precipitationshed. The comparison of figures S1(a) and S1(b) tells me only that color scales should be chosen wisely, which is probably not necessary for the readers of this paper. My suggestion is to put figure like S1(a) in the main paper and elaborate on the difference between the absolute and relative scale to define the concept of precipitationsheds.”

Response: Indeed, the comparison of Figs. S1a and S1b suggests that the color scales should be chosen wisely. The reviewer mentions that this is not necessary for the readers of the paper, but we think the comparison is quite important. First, it is in the supplementary material and thus not of crucial importance for the paper, and second, we considered the fact that readers will hopefully include fellow researchers to which we want to stress that the information such as provided by the second scale bar is in our opinion crucial to interpret the data. In many previous studies we feel that this information is lacking. For example in one of the figures in a study by the reviewer (Tuinenburg et al., 2011, Figure 6A) we would have liked to know directly from the figure how much of the source region evaporation ends up in the red, yellow, green and blue regions. As for the suggestion to put a figure like S1a in the paper, there actually already is one (Fig. 3a) and we elaborate on the difference between the absolute (Fig. 3a) and relative (Fig. 3b) precipitationshed on p.10496 L7-15.

9. Comment: “It would be helpful if the amount of precipitation in the growing season (in mm and mm/day) would be included in the caption of the precipitationshed figures, in that way the reader does not have to switch between the figures and table 1.”

Response: This is a good suggestion and growing season precipitation in (mm) will be included in the captions of the precipitationshed figures.

10. Comment: “p10496: "A large amount of evaporation originates within the Western Sahel sink region" –> A large amount of precipitation originates from evaporation within the Western Sahel. . .?”

Response: We thank the reviewer for this correction, he is correct that we meant to write:

“A large amount of precipitation originates from evaporation within the Western Sahel...”

11. Comment: “p10497 L11: "are spatially contiguous" –> is this the case in practice? Because theoretically this is not necessary.”

Response: In practice the relative precipitationshed is spatially contiguous, because source region contributions likely follow the same exponential decay curve. Thus, as the source regions radiate outwards from the sink region, the precipitationshed will

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expand in a contiguous manner. For small time scales the relative precipitationshed can become fragmented as well. To mention this in the paper would probably become confusing.

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