Robust assessment of future changes in extreme precipitation over the Rhine basin using a GCM

Author response to anonymous referee 1

SPECIFIC COMMENTS

1. **Discuss limitations of approach, given that it is based on 1 GCM and 1 emission scenario only.**

   We will add a discussion of the limitations to our final section.

2. **P9044, L10: Confusing use of term 'scaling' or 'simple scaling'**

   We agree, and now see that there are two differing uses of the term 'scaling' in the abstract (L10, L11) in neighboring sentences that are potentially confusing.

   By 'simple scaling methods' we were referring to a simple form of the Delta change method in which an observed precipitation series is multiplied (scaled) by a constant factor to simulate a future series of increased intensity. When we used the term 'scaling behavior', that was with reference to the fractional change in precipitation quantiles between the control and future reference period, which is later defined in equation (1), and the behavior of that change with respect to the summation period, n.

   We propose to leave our definition of scaling where it is on page 9048 after equation (1), but to make the following adjustments to the text:

   P9044, L11: *We show that this scaling behavior is sensitive to the ensemble size* →
   We show that the dependence of quantile changes on summation time is sensitive to the ensemble size.

   P9045, L10: *a method that applies mean changes in climate parameters to transform historical precipitation sequences to future time series for input to hydrological models* →
   a method that uses mean changes in climate parameters to transform historical precipitation sequences, by multiplication with a scale factor, to future time series for input to hydrological models.

   P9051, L7: *In summer, a non-trivial scaling with accumulation interval is observed* →
   In summer, a non-trivial dependence of the scaling on accumulation interval is observed.
   P9052, L1; P9053, L16, L20: *non-trivial scaling* → *non-trivial scaling behavior.*

3. **P9046, L3: Given return period only valid for Dutch Dikes.**

   Thank you for the correction. The text will be changed to the following: *The annual mean discharge (1901-2000) at Lobith (Fig. 1) is* 2200 m^3 s^{-1} *and current defences in the Netherlands are designed to withstand a 1 in 1250 year flood event.*

4. **P9047, L10: 2 of the 8 ESSENCE grid cells (east cell of North Rhine, west cell of Central Rhine) are only covered to a rather small fraction by the Rhine basin. Could this mismatch between observation area and model area cause problems?**

   On re-making Fig. 2 and Fig. A1 with the east-most cell of the North Rhine region and the west-most cell of the Central Rhine region removed, there are only very small changes to be seen. The number of dry days is slightly raised if the number of cells representing a region are reduced, which, in summer, increases the difference between the model and observations. The differences between the observations and the model PDFs are larger than (and therefore are not explained by) the minor changes to the ESSENCE PDF obtained using a different number of model grid cells. An advantage of using more than one grid cell for a region is the smoothing of model noise.

5. **P9048, L14: Problems understanding the 2 questions. Could they be reformulated in order to be better intelligible?**

   We have reformulated the questions so that they are more direct are easier to compare:

   A.
   How much is it likely to rain in a 10-day period in the future compared to now?
   $\rightarrow$
   What sum of rain can we expect over a randomly selected 10-day period in the future compared to now?

   B.
   If it rains at least once in a 10-day period, how much is it likely to rain in the future compared to now?
   $\rightarrow$
   What sum of rain can we expect over a 10-day period in the future compared to now, on the condition that we know at least some rain falls in that period?

6. **Discuss finding that wet-day frequency and wet-period duration remain largely unchanged in view of other literature that finds**

increases in frequency and duration of westerly atmospheric circulation types. Although detected past changes (Petrow et al., 2009) should not necessarily be expected in the future as well, it could be interesting to discuss this issue.

Petrow et al. discuss observed changes over a 52-year period. Trends within ESSENCE over that time scale are uncertain, particularly at the beginning of the series. However, we do not deny a connection between increased frequency of westerly circulation types and increases in wet-day frequency or event duration within the evolution of individual ensemble members (P9055, L26-27).

We note that the majority of single transient climate-model runs, including ECHAM5 from which ESSENCE is derived, show an increase in westerly flow in winter and a decrease in summer (Fig. 14 in van Ulden and van Oldenborgh, 2006). Further, Sterl (2010) has examined the wind climate in the Netherlands in the ESSENCE ensemble for January and August, reported here:
`http://www.knmi.nl/cms/content/84072/the_essence_project_the_power_of_a_large_model_ensemble`.
He writes 'the ensemble mean shows an increase in westerly flow during winter and an increase in easterly flow during summer... However, the spread between the ensemble members is so large that for the coming century the climate change signal in the circulation over the Netherlands can be masked by the internal variability of the climate.' For this reason, creating future climate scenarios both with and without circulation change is sensible (van den Hurk et al., 2007).

We find that: (1) Although the ESSENCE ensemble mean gives increased westerlies in winter, there is hardly any change in the ensemble mean winter wet-day frequency or wet event duration. (2) There is a climate change signal in the mean intensity of winter precipitation.

We propose to adapt the text to make it clear that there is indeed an ensemble-mean circulation change in ESSENCE.

TECHNICAL CORRECTIONS

1. P9047, L10: We will adjust the text as suggested to *We upscale the CHR data to the approximate size of the three zonal regions (North Rhine, Central Rhine, Alpine Rhine) by area averaging the daily totals for the group of sub-basins whose centers lie within the boundaries of a particular region (Fig. 1).*
2. P9051-4: Unfortunately, the flaws concerning figure reference numbers (all figures after Fig. 3) occurred in the type-setting stage of this discussion document when figure 3 was split over two pages.

P9051.
All references to Fig. 6 (L4, L7, L13, L22, L23) should be changed to Fig. 3 except for the last line (L28) which should read 'We also find that the PDF of wet and dry spell durations in winter does not significantly change (Fig. 4c-d).'

P9052.
All references to Fig. 6 (L7, 12) should be changed to Fig. 3 except for the third (L24) which should read 'The PDF of summer wet and dry spells supports this showing that dry spells are projected to become longer and wet spells shorter (Fig. 4a-b).'

P9053.
The two references to Fig. 6 in the remainder of section 5.1 (L2, L9) should be changed to Fig. 5.
In section 5.2 the first two figure references remain for Fig. 6.
The last line (L28) should read 'In Fig. 7a we display the direct relationship between the 1-day and'.

P9054.
The first two references (L1, L6) to Fig. 6 remain unchanged.
Line 8 should read 'not distinguishable for smaller ensembles (Fig. 7b).'
Line 14 should read 'are also added (dashed error bars) to Fig. 3.'

REFERENCES

Petrow, T., Zimmer, J., and Merz, B.: Changes in the flood hazard in Germany through changing frequency and persistence of circulation patterns, Nat. Hazards Earth Syst. Sci., 9, 1409–1423, 2009.

Van den Hurk, B., Tank, A. K., Lenderink, G., Ulden, A., van Oldenborgh, G. J., Katsman, C., Brink, H., Keller, F., Bessembinder, J., Burgers, G., Komen, G., Hazeleger, W., and Drijfhout, S.: New climate change scenarios for the Netherlands, Water Sci. Technol., 56, 27–33, 2007.

Van Ulden, A. P. and van Oldenborgh, G. J.: Large-scale atmospheric circulation biases and changes in global climate model simulations and their impor tance for climate change in Central Europe, Atmos. Chem. Phys., 6, 863–881, doi:10.5194/acp-6-863-2006, 2006.