Reply to comment of Legates et al.

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In the previous comment, Legates et al. [12] express concern about the statistical reliability of the positive runoff–temperature relationship presented by Labat et al. [10]. We are grateful for this opportunity to respond to these concerns. As Legates et al. [12] correctly points out, the effect of temperature on runoff is a complex relationship, which involves precipitation, evaporation, anthropomorphic affects, among others. As such, the effect of increased temperature on runoff is strongly dependent on the identity of the watershed of interest. For example, a watershed located in a glaciated region, such as Iceland, exhibits a strong positive correlation between runoff and temperature, whereas a watershed located in a arid climate, such as the Sahara desert, exhibits a negative correlation; often there is no run off at all during the summer months in such watersheds.

These differences make it extremely challenging to estimate the relationship between temperature and runoff at the global scale. What these differences tell us, however, is that any studies limited to a single watershed, or even a single continent are inadequate to determine the global affects of temperature on runoff.

Labat et al. [10] presented the first attempt to determine the relationship between temperature and runoff at a global scale. They observed a small positive correlation; runoff was found to increase 4% for each increase in 1 °C of temperature increase. If true, this result has major implications on the feedback between temperature and continental weathering in global geochemical models. It is important to emphasise, as pointed out by Legates et al. [12], that the correlation presented by Labat et al. [10] has a significant uncertainty and depends strongly on the quality of the database; a change in the data considered in the correlation could either increase or decrease the computed effect of temperature on runoff (although which would remain positive as we discussed below in the technical reply). This observation illustrates the critical need for improved data on the connection between temperature and runoff, that is not limited to a single watershed or continent, but on a global scale. Such data are essential to refine this correlation to better constrain this important relationship at a global scale.

1. Technical reply

1.1. Use of discharge records that reflect non-climatic trends

We refute the assertion that "Labat et al. [5] specify only the rivers for which data were acquired, rather than the specific streamgauging stations that were used". Effectively, all gauging stations are clearly identified by latitude and longitude in Tables 1–3 and Fig. 1.

Indeed, they are located at the mouth of the watersheds, thus integrating all the climatic and anthropogenic effects over the watersheds. Legates et al. [12] insist in general on the Assam Dam influence on Nile discharges whereas this example has been clearly identified and clarified by Labat et al. [5].

Ref. [1] in Legates et al. [12] deals only with high streamflow events in relation with high precipitation events. This cannot be compared to our study since we deal with complete annual runoff timeseries. We also note that Ref. [9] in Legates et al. [12] argues that the United States are getting wetter, in agreement with our conclusions based on a large watershed study with gauging station located at the mouth.

Legates et al. [12] claim that "Labat et al.'s use of such records violates a long-accepted and well-documented practice in hydroclimatic research". Labat et al. [10] is the first study dealing with global runoff.

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Of course, small catchments (i.e. below 20,000 km^2) may be strongly perturbed by anthropogenic activities, and should not be used for studies that attempt to link global climate and runoff. But, a quick overview of the literature supports the idea that large watershed hydrological response allows an identification of climatic oscillations ([1–9,11,13,15,18–20]; among others).

In conclusion, Legates et al. [12] suggest that the larger the watershed, the larger will be the anthropic effects on the hydrologic signal. We argue that the larger watershed, the most clear will be the climatic signal (as previously demonstrated by Probst et al. [16,17,15]).

1.2. Documented lack of a relation between streamflow and air temperature in previous studies

We note that the entire discussion in Legates et al. [12] focuses on the United States, where they argue that no climatic signal can be observed in the streamflows. The systematic extrapolation of these results obtained for the US to all continents is clearly doubtful.

We never claim that precipitations are not the main driving force of change in runoff. The relationship identified between air temperature and runoff was found at global scale, but this do not preclude any cross relationship between air temperature, precipitations and runoff. Furthermore, the study of Karl and Riebsame [8] deals with much smaller watershed than Labat et al. [10], working at continental scale. As we have shown in the paper [10], the relationship between air temperature and runoff at continental scale differs from the relationship identified at global scale.

1.3. Inappropriate estimation of data to fill gaps in long-term streamflow records

Concerning the data-reconstruction method, Legates et al. [12] claim that wavelets are inappropriate (1) to isolate climatic effects from anthropogenic effects; and (2) to estimate data when missing for long time periods.

Nakken [14] shows that wavelets have already been used to isolate climatic effects from anthropogenic effects.

In Labat et al. [10], most time series extend over more than 10 years. We acknowledge that short time series have been used for some minor rivers. Extrapolating 10- or 20-year hydrological time series to centenial scales is staticaslly correct since the longest climatic oscillations correspond approximatively to 30 years. Therefore, the original 10- to 20-year series already reflects the long-term climatic response.

Furthermore, the method used in Labat et al. [10] is proved to be correct, since we show that the correlation coefficients between observed and reconstructed annual runoff are equal to 0.8 (which is quite significant).

Then, Legates et al. [12] also argue that removing a single point of the runoff-temperature relationship tends to unvalidate the statistical validity of this relationship. First, our study deals, for the first time with global data, and large dispersion of the points is of course expected. But, this is not by itself a justification for removing outliers. All available data must be considered.

Furthermore, the outlier corresponds to the year 1926 and removing this point i.e. calculating slope starting in 1927 leads to a 0.25 slope coefficient but in no way to a null coefficient (Fig. 1).

The important point is that the slope significantly differs from 0 and is positive. We show in Fig. 1 the value of the slope as a function of the starting year of the time series. Using this correct statistical approach, the slope is maximum when series start around 1925 and then decreases to 1.5–2%, but remains positive. We acknowledge that the 4% slope claimed in Labat et al. [10] must be considered as a maximum but we refute the Legates et al. [12] assertion of a null-slope relationship between runoff and temperature.

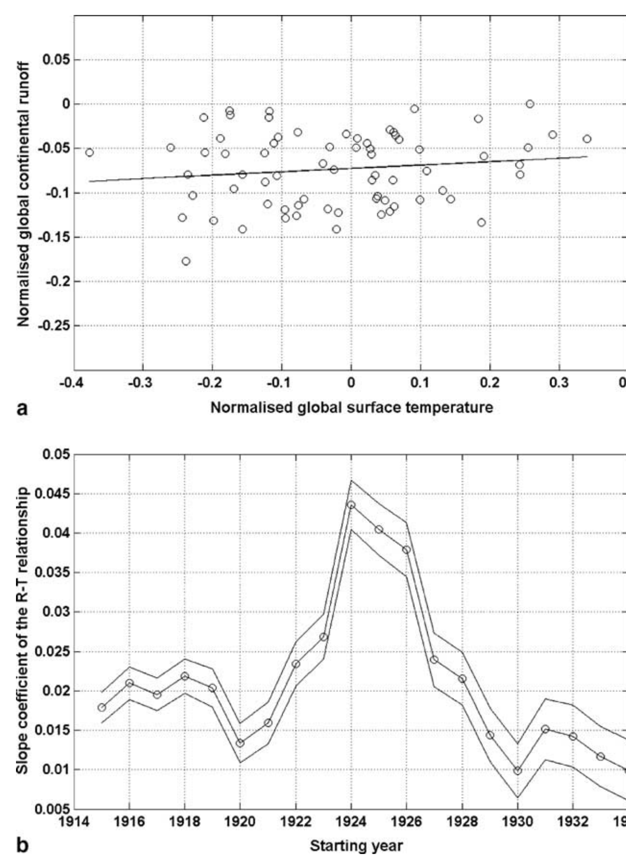

Fig. 1. Top: Runoff–temperature relationship with the positive slope. Bottom: Value of the slope as a function of the starting year of the time series. We show, using this statistical approach, that the slope is maximum when series start around 1925 and then decreases to 1.5–2% but remains positive. The up and down lines corresponds to the confidence interval of the slope value for each starting years.

1.4. Selection of the time period analyzed and lack of explanation for relationships before 1925

The 1925–1994 period was selected so that our results may be directly compared to the study [16], which is up to now the only data-based study of global runoff change linked to global climatic change.

Legates et al. [12] indicate that "Fig. 4 is inconsistent with the IPCC and confounds their argument of a strong air temperature/runoff relation". Fig. 4 in Labat et al. [10] is certainly consistent with the IPCC. Legates et al. [12] refers to the behaviour of the continental air temperature alone, which displays a distinct behaviour for the 1890–1925 period. In fact, we used global averaged temperature shown in Fig. 2.8, p. 115, 2001 IPPC report (Jones et al. 2001). This series include both continental air temperature and sea surface temperature. The global averaged temperature is the only reliable global temperature measurement when dealing with changes in the global hydrologic cycle.

1.5. Regression and the presence of an influence point

The 15 year shift observed between temperature and runoff response was based on a visual observation, mainly focusing on the peak observed in the 50's for runoff, while an apparent similar peak is observed in temperature 15 years earlier. We think that this shift might be insignificant.

Legates et al. [12] claim that "there are 69 years of pairwise comparisons, but it is inappropriate to assume that there are $68(n-1)$ degrees of freedom because the data are temporally autocorrelated". The T-student test is commonly applied in hydrological studies, despite the existence of correlations, as long as this correlation is rather weak. Indeed, we are not working with the 3 year mobile average of the temperature signal (as probably suspected by Legates et al., and which displays a strong auto-correlation), but with the annual average. This annual average is characterized by a lag-1 correlation coefficient equals to 0.4, and a lag-3 correlation coefficient reaching 0.18. This demonstrates a weak autocorrelation of the signal, validating the use of the T-student test and the use of 68 degrees of freedom in the T-student test.

The T-test clearly shows the statistical significance of the runoff-temperature relationship. We also mention in Fig. 1 the up and down bounds of the confidence interval of the slope regression coefficient. As we already mentioned earlier, we acknowledge that the 4% slope claimed in Labat et al. [10] must be considered as a maximum but refute the Legates et al. [12] assertion of a null-slope relationship between runoff and temperature.

2. Conclusion

Legates et al. [12] argue that no climatic signal can be observed in the streamflows which is clearly wrong (see Section 1). They systematically extrapolate results obtained over the United States continent to all continents which is clearly doubtful.

We think that Legates et al. [12] are wrong when discussing the anthropogenic impact on the continental runoff. Of course, small catchments (<20,000 km^2) may be strongly perturbed by anthropogenic activities, and cannot be used for studies that attempts to link global climate and runoff. But, a quick overview of the literature demonstrates that this is not true for large scale catchments, but are able to record global climatic changes despite anthropogenic disturbances. We also systematically refute all the statistical issues mentioned by Legates et al. [12].

For all these reasons, we strongly claim that we effectively provide the first data-based positive relationship of the runoff-temperature relationship and that this positive relationship has profound implications in our understanding of climate changes.

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