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Advances in Water Resources 28 (2005) 1310–1315
Advances in Water Resources
www.elsevier.com/locate/advwatres

Comments on "Evidence for global runoff increase related to climate warming" by Labat et al.

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Received 12 October 2004; received in revised form 19 January 2005; accepted 19 January 2005
Available online 14 June 2005

Abstract

We have examined the evidence presented by Labat et al. and found that (1) their claims for a 4% increase in global runoff arising from a 1 °C increase in air temperature and (2) that their article provides the "first experimental data-based evidence demonstrating the link between the global warming and the intensification of the global hydrological cycle" are not supported by the data presented. Our conclusions are based on the facts that (1) their discharge records exhibit non-climatic influences and trends, (2) their work cannot refute previous studies finding no relation between air temperature and runoff, (3) their conclusions cannot explain relations before 1925, and (4) the statistical significance of their results hinges on a single data point that exerts undue influence on the slope of the regression line. We argue that Labat et al. have not provided sufficient evidence to support their claim for having detected increases in global runoff resulting from climate warming.

A recent article by Labat et al. [5] suggests observational evidence for a correlation between global annual temperature and runoff exists; specifically, that a 4% increase in global runoff has resulted from a 1 °C increase in global temperature. These results vary by continent, however, from a negative trend over Africa to a pronounced positive trend for North America—but most continents exhibit a statistically significant trend. It is postulated that increasing temperatures lead to increased oceanic evaporation and, consequently, increased terrestrial precipitation and continental runoff.

The Labat et al. paper [5] claims, "this contribution provides the first experimental data-based evidence demonstrating the link between the global warming and the intensification of the global hydrological cycle" (p. 641). If true, this result has profound implications for our understanding of climate change mechanisms and for finding a direct link between changes in the energy and water balances. A long-standing discussion has argued that an increase in global air temperatures might lead to increased runoff due to increased precipitation (as suggested by Labat et al.) or decreased runoff due to increased continental evaporation rates and hence continental drying. Labat et al.'s results strongly argue that increased precipitation would outweigh the increase in evapotranspiration.

Labat et al. [5] have tried to address a complicated problem for which too few data and too many confounding effects exist. Therefore, we believe that the conclusions reached by Labat et al. [5] are incorrect owing to a number of concerns. In particular, their analysis (1) uses discharge records that exhibit non-climatic trends, (2) does not attempt to refute previous studies that found no relation between air temperature and runoff, (3) inappropriately estimates data to fill gaps in long-term streamflow records, (4) does not explain relations before 1925, and (5) is based on regression

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0309-1708/$ - see front matter
doi:10.1016/j.advwatres.2005.04.006

results that are adversely affected by a single influence point. We address each of these issues, as well as additional concerns in the manuscript, below.

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

Streamflow records are reflective of both climatic variations over a river basin as well as changes in land use, land cover, and stream characteristics. Streamflow dynamics are not simply a first-order response to existing atmospheric conditions; but rather, represent a filtered or dampened account of the meteorological forcing due to watershed characteristics. Most significantly, the ability of streamflow records to reflect variations in (and relations with) the prevailing climate is conditioned on the absence of any confounding anthropogenic activities. Such activities include flow diversions or augmentations, regulation of streamflow by some containment structure, reduction of base flow by excessive pumping of groundwater reserves, or other effects to the watershed such as widespread changes in land use/land cover by, for example, urbanization or clearcutting. Such anthropogenic effects on streamflow records must be properly taken into account if streamflow records are used to reflect climate variability and changes.

Unfortunately, the streamgauging records for the 221 rivers used in the Labat et al. study [5] are all subject to confounding anthropogenic influences and many are among the most highly impacted basins from around the globe. Nearly one half of these records are taken from gauges that drain areas in excess of 100,000 square kilometers (km^2) and more than a dozen from drainages exceeding 1,000,000 km^2. The authors do acknowledge and address some highly significant anthropogenic effects—for example, they note, "Anthropogenic effects are first removed by truncation. For instance, *Nile* discharges after Assam Dam construction are removed" (p. 634) [5]. However, they fail to recognize (or document) the adverse influence other anthropogenic effects can have. Indeed, they state,

> "The key difficulty encountered in the analysis of the fluctuations in the runoff of large rivers is the multi-scale property of the signal in relation to several hydrological processes. Monthly fluctuations generally reflect the occurrence of low or high intensity events. Annual fluctuations record the variations of the annual water budget highlighting dry and humid years. *Multi-annual* fluctuations reflect the largest scale variations related to global general meteorological circulations and long term climate change." (p. 632) [5].

Systematic assessments of the differential contributions of climate and anthropogenic effects have not yet been assessed for rivers at a continental scale, much less the global scale. In the absence of such documentation, the authors have no meaningful basis for their claim that a 1 °C increase in air temperature leads to a 4% increase in global runoff. Labat et al.'s use of such records violates a long-accepted and well-documented practice in hydroclimatic research.

Going back to the early work of Walter Langbein [6], studies that attempt to explain hydrologic conditions and variability in a climatic context (usually focusing on air temperature and precipitation) have always taken care to use only streamgauge records from unimpaired watercourses and basins [1,7,9]. This is the only way to ensure that variations in streamflow are truly reflective of climatic variations and are devoid of confounding anthropogenic influences. Toward that end, both Canada and the United States have identified those gauges in their national streamgauging networks that are 'climate-sensitive'. Because Labat et al. [5] specify only the rivers for which data were acquired, rather than the specific streamgauging stations that were used, it is impossible to ascertain whether any of their records are truly climate-sensitive.

Only Canada and the United States have published lists of their climate-sensitive streamgauges (the number of which are few relative to the total number of gauges operated by the two countries) and the Global Runoff Data Centre (Koblenz, Germany) freely acknowledges that it cannot validate the quality or characteristics of the records it receives from the various national hydrological services. Thus, most of the data used by Labat et al. [5] *must* reflect anthropogenic changes on the watershed to varying degrees. This precisely is why there have been, to date, no comprehensive, published results of worldwide trends in streamflow. Simply put, the database required to perform such an assessment does not exist. Consequently, Labat et al.'s analysis does not isolate climatic effects on streamflow and their conclusions are unfounded.

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

The Labat et al. [5] study is not the first attempt to assess the relationship between air temperature and runoff. Using data from 82 climate-sensitive streamgauging stations (i.e., documented as free from significant anthropogenic effects), Karl and Riebsame [4] evaluated the correlation between streamflow and both air temperature and precipitation. Their streamgauges represented watersheds ranging in size from 10 km^2 to 75,000 km^2, with a median value of 2100 km^2. Given that Karl and Riebsame selected gauges representing watersheds for which anthropogenic influences were minimal, they had the best possible data for deriving such relations, if they existed. Notably, they summarized their findings as follows:

"Our version of Langbein's nomogram…, based on temporal fluctuations of climate and runoff in 82 basins with minimum human impact, indicates that precipitation changes may be amplified one to six times in relative runoff changes. However, even 1° to 2° [C] average temperature changes often have little effect on annual runoff." (p. 445) [4].

The Labat et al. results are diametrically opposed to the findings of Karl and Riebsame [4]; however, Labat et al. do not reference the Karl and Riebsame study. This underscores the problems inherent in Labat et al.'s data, most notably the co-mingling of anthropogenic and climatic effects in the gauge records, and thus raises serious doubts about the efficacy of Labat et al.'s findings. When new research findings challenge conventional wisdom, it is necessary to explain why the new results supersede the previous findings and merit general acceptance by the research community. Labat et al. do not provide any explanation as to why their results contradict those of Karl and Riebsame.

The focus of Labat et al. on temperature as an explanatory variable for changes in runoff is interesting given that precipitation is the obvious driving variable. The Third IPCC Scientific Assessment Report [2] concludes "where data are available, changes in annual streamflow usually relate well to changes in total precipitation" (p. 103). The IPCC's Fig. 2.25 [2] presents changes in continental-scale *precipitation* which, when compared to continental-scale runoff, shows in striking detail a strong correspondence. Using their wavelet analysis, Labat et al. claim to have found increases in runoff during the 20th Century for North America, Asia, and South America, a decrease in runoff for Africa, and no significant change for Europe. An examination of the IPCC's Fig. 2.25 [2] shows, for the 20th Century, a net precipitation increase for North America, Asia, and South America (except Chile), precipitation decreases across virtually all of Africa, and a combination of both increases and decreases in precipitation in Europe (although increases appear to be dominant). Clearly, precipitation trends can easily explain the observed changes in continental-scale runoff—both on empirical and theoretical grounds.

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

Labat et al. [5] make a strong argument that wavelet transforms can be used to estimate missing runoff observations and to fill gaps in records resulting from their truncation of obvious anthropogenic biases resulting from their perceptions of dam and irrigation effects (e.g., the Nile River discharges after construction of the Assam Dam). Indeed, wavelets (like other time series methods) can prove useful in data smoothing applications and the unbiased estimation of short runs of missing data when a significant trend is present [10]. However, it is inappropriate to estimate data when data are missing for long time periods as significant biases can result. For some of these gauging stations, only 10–40 years of data exist. Considerable uncertainty is introduced in the estimated series when a large portion of it is statistically derived. Important unanswered questions relate to how large is the uncertainty and how does it affect the resulting analysis. The wavelet-reconstructed time series was subsequently evaluated in Labat et al. [5], but no discussion was devoted to the magnitude of its estimation errors or to its influence on the results. Moreover, the documentation regarding the completeness of the discharge records and how much data had to be reconstructed is lacking.

We further argue that the estimation errors introduced by the wavelet transform method are sufficiently large to invalidate Labat et al.'s [5] conclusion. Consider the inter-annual variability in continental-scale runoff presented in Labat et al.'s [5] Fig. 3 where the coefficient of variation (the ratio of the standard deviation to the mean) is approximately 8%. If this ratio is used to represent the average variability in the individual gauge records, then the average uncertainty in wavelet-interpolated runoff is about 8% of the mean value. A quick perusal of Tables 1–3 of Labat et al. [5] (where the time period of record are given for all the basins used) indicate that many stations do not have records extending prior to the 1950s and a number of stations have records which end in the late 1980s. This implies that many of the data used in their 1925–1994 analysis have been estimated using the wavelet transformation. Given the tenuous relationship of statistical significance that Labat et al. [5] found between runoff and air temperature (note in Section 5, that the Coefficient of Determination (R^2) decreased from 0.0202 to 0.0089 when just a single year was removed from the analysis) an uncertainty in interpolation of 8% is huge, even if a quarter of the record is interpolated.

Since Labat et al. [5] never convincingly demonstrate all significant anthropogenic effects have been removed from their gauge records, it is likely the interpolated data would be biased. Discontinuities in the observational record are often easy to detect and remove (such as those that result from dam construction or channelization efforts), but continued successive changes (arising from urbanization and other long-term changes in land use/land cover, for example) cannot be differentiated from climate change signals [8]. The only way to be \assured that such non-climatic signals have not biased the gauge records is to select watersheds for which anthropogenic influences are minimal—those that have been adjudged to be climate-sensitive. Extending the time period by interpolation of a heterogeneous record is tenuous since it is impossible to ascertain whether the non-climatic signals have remained constant. No matter how viable the analytical approach, data with anthropogenic biases will always adversely affect the interpolated results; fatally so, in this case.

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

The methods used by Labat et al. [5] do not properly account for the changing distribution of gauging stations over time. They admit "river discharges have been measured in some cases for only a few decades, while others have been sampled back to 1870. Sampling periods for the different rivers ranges from 4 to 182 years." (p. 632) [5]. Widely varying record lengths are evident in their Table 1. The appearance or disappearance of river discharges at key times can obscure important trends or introduce spurious ones. Perhaps that is why their regression analyses focus on the 1925–1994 time period, when the data are more complete. Nevertheless, significant breaks in the gauge records occur during this period, as is evidenced in their Table 1. It is curious, however, that the choice of 1925 (which may be an outlier/influence point—see next section) as a starting date likely provides the only time period that yields a statistically significant relationship between runoff and air temperature.

Before 1925, Labat et al. [5] argue "the 1875–1925 temperature decrease is correlated with global runoff decrease over the same interval" (p. 639). The IPCC shows that terrestrial (land-based) air temperatures decreased from 1875 to about 1890 and then actually increased until 1925 (see Fig. 1) [2,3]. However, Labat et al.'s Fig. 4 (see our Fig. 2) indicates a generally steady decrease in air temperature until about 1910. When

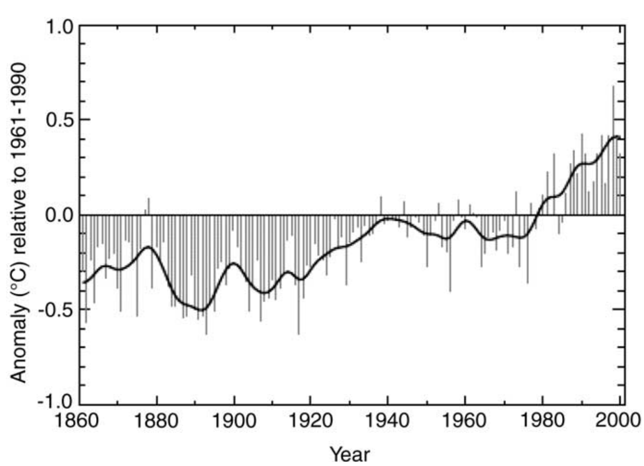

Fig. 1. Annual anomalies of global averaged terrestrial (land surface) air temperature (°C) from 1861 to 2000, relative to 1961 to 1990 values. Taken from Fig. 2.1 of the IPCC report [2], which is based on data from Jones et al. [3].

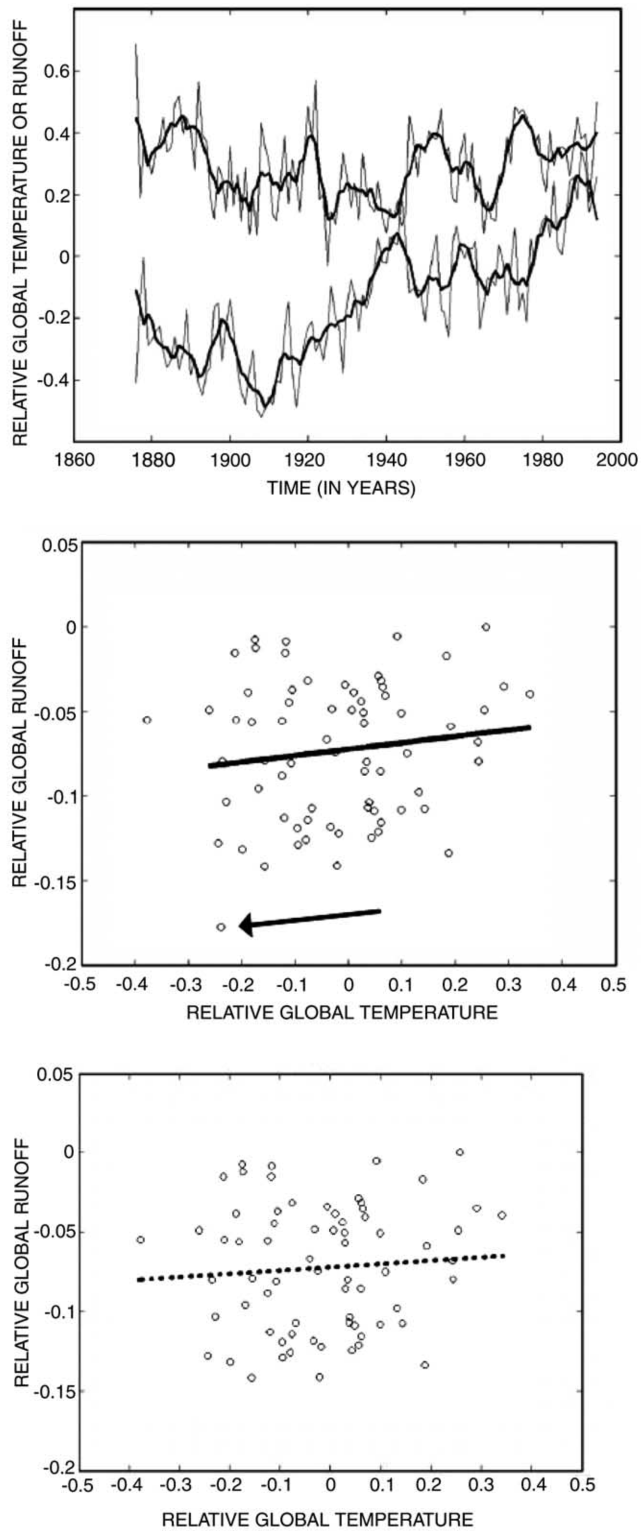

Fig. 2. Top: Annual global temperature (lower line) and global runoff (upper line) as presented by Labat et al. [5] in the top panel of their Fig. 4. Middle: Global runoff regressed against air temperature as presented by Labat et al. [5] in the bottom panel of their Fig. 4. The arrow highlights the potential influence point. Bottom: Same as middle panel except the influence point has been removed and the regression line has been redrawn (dashed line)—no significant correlation is apparent ($R^2 = 0.0089$). For color versions of these figures, see Fig. 4 of Labat et al. [5].

compared with Labat et al.'s global runoff, the period before 1925 contradicts their claim of increasing runoff being caused by increasing air temperatures. Thus, their Fig. 4 is inconsistent with the IPCC and confounds their argument of a strong air temperature/runoff relation.

A closer examination of Labat et al.'s [5] time series for North America and Europe seem to indicate further a strong North Atlantic Oscillation (NAO) influence. Indeed, if the NAO signal is removed from these time series, there is likely to be little or no trend. This underscores the importance of examining causal and more direct relations than investigating weak relations such as exist between air temperature and runoff.

5. Regression and the presence of an influence point

One of the most important statements made by Labat et al. [5] is "a correlation is highlighted between global annual temperature and runoff, suggesting a 4% global runoff increase by 1 °C global temperature rise" (p. 631). Their Fig. 4 (here, reproduced as the middle panel of Fig. 2) supports this statement, where 'relative global runoff' is regressed against 'relative global temperature' for the 1926–1994 period. But in the caption to Fig. 4 and in the text, they note, "a 15 year shift is observed between temperature and runoff response" (p. 639) [5]. How was this shift determined and why was it not incorporated into their linear regression or incremental method analyses? This issue is important to their most significant finding (namely, the relation between global runoff and global air temperature) and thus invalidates their direct comparison between global runoff for a given year and global air temperature fluctuations in that same year.

Labat et al. [5], in the bottom panel of Fig. 4, (here, the center panel of Fig. 2) claim that the regression line has a slope of 0.039 $°C^{-1}$ (4% per °C) and is statistically significant with a Student's T statistic of 12.4. They do not indicate, however, how many degrees of freedom were used in the test nor do they provide results of other regression diagnostics. 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. Labat et al. give an example for 10 degrees of freedom, but there is no indication how this number was obtained or whether it is appropriate for use with these data.

Issues related to the degrees of freedom aside, Fig. 2 (their Fig. 4) is quite puzzling because the middle panel indicates relative global runoff is almost always non-positive while the data in the top panel show that relative global runoff since 1925 is always positive. We have no way to reconcile this discrepancy. But if the middle panel of Fig. 2 is taken by itself, a strong influence point/outlier clearly is evident (highlighted with the arrow). If this point is removed from the analysis (there is no way to ascertain what time period it represents owing to the discrepancy in the two panels), it is hard to argue that any significant trend could be derived (see bottom panel of Fig. 1). Labat et al.'s [5] Fig. 4 (middle panel of our Fig. 2) was digitized and the regression equation was recomputed with the influence point removed—the Coefficient of Determination (R^2) decreased from 0.0202 to 0.0089 and the slope of the regression line decreased from 0.039 $°C^{-1}$ (4% per °C) to 0.025 $°C^{-1}$ (2.5% per °C). For the resulting regression line, an F-statistic of only 0.6 was produced ($p = 0.44$), which indicates the slope of the line is not statistically different from zero. Thus, the claim by Labat et al. that a 4% global runoff increase is associated with a 1 °C increase in air temperature is incorrect; indeed, when that one observation is removed, no statistically significant relation exists.

6. Summary

In their recent article, Labat et al. [5] have made two strong claims. First, using data from 1926 through 1994, they claim that a 4% increase in global runoff has arisen from a 1 °C increase in global air temperature. We strongly question that claim based on the fact that the 221 discharge records used by Labat et al. include anthropogenic changes on the watershed to varying degrees, thus biasing the data. Verifying that the data used are truly 'climate-sensitive' is the only way to ensure that variations in runoff are truly reflective of climatic variations and are devoid of confounding anthropogenic influences. Moreover, their conclusions cannot explain relations before 1925, and the statistical significance of their result is based on a single observation that exerts undue influence on the slope of the regression line.

Their second claim is that their article provides the "first experimental data-based evidence demonstrating the link between the global warming and the intensification of the global hydrological cycle". Other studies have attempted to analyze relations between changes in air temperature and other components of the hydrologic cycle. Labat et al. [5] have not proven why their work overcomes the conclusions of and contradicts seminal papers on the subject [4]. We therefore conclude that, contrary to their arguments, Labat et al. have not provided sufficient evidence to support their claim for the existence of a relation between air temperature and runoff or that increases in global runoff have resulted from climate warming.

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