Reply to comments made by Referee 1

HESS-2013-166: Towards the response of water balance to sugarcane expansion in the Rio Grande Basin, Brazil

Our reply is in italic.

Firstly we would like to extend our appreciation towards your efforts in understanding the importance of our research. We would also like to thank you for the very constructive feedback on this submission.

General Comments: **The paper deals with a relevant and updated issue, i.e., land-use changes (sugarcane expansion in Brazil) and its possible hydrological effects in a large basin. The authors used a considerable data set and a hydrological model that seems suitable for the objectives of this research. The text has been, in general, clearly written, except for the item 4.3, where the presentation of results, which would suitably fit a table, is excessively long. It would be desirable to have less result description and more result discussion. The methodology is compatible with the objectives and the references are related to the theme and updated. Due to the merits of the paper, we understand that it can potentially be accepted for publication, but not in its present form.**

The main problem of the paper regards the interpretation of the computational results, and, before solving this question, we understand that it should not be published. Special concern is the conclusion that simulations showed that the annual accumulated values of evapotranspiration increase up to 180% while surface runoff is reduced to 20%" (i.e., an 80% decrease in the runoff) "of the values calculated using a land scenario from 1993 (p.5564 LL.20-23, see also p.5584 L.12 and conclusions, p.5585).Still according to the simulations, a 70% runoff reduction is expected if 4.7% of the Funil area is planted with sugarcane (p.5578 L.10),

whereas for the Camargos sub-basin 100% runoff reduction is expected if only 2% of the area would be used to grow sugarcane (p.5578 L.25). These results seem implausible, but could be true. However, the authors do have at their disposal measured data from 1970 to 2010 (p.5570 L.9) and sugarcane expansion within the period has been substantial: for instance, in the A Vermelha sub-basin alone, the sugarcane area increased from 9.4% in 1993 to 30.1% in 2007 (Table 3). We would like to suggest the authors to investigate the stationarity (or not) of the hydrological series within the measurement period (1970 2010) to check if these changes have been observed as a natural response to sugarcane expansion. Visually, from Figures 4 and 5, no decrease trend could be identified, but there is a reference to runoff changes from 1993 to 2007 up to 1.5% (p.5576, L.26), far below the figures presented in the conclusions.

According to what has been suggested by the referee, the authors investigated the stationarity of the hydrological series as a natural response to sugarcane expansion. Our investigations were added to the manuscript as a new sub-section of Evaluation of seasonal patterns per sub-basin. Below goes its present form:

"Evaluation of seasonal patterns per sub-basin

For a better understanding of the influence of sugarcane expansion on the water balance of the Rio Grande basin, daily values of evapotranspiration, soil moisture as well as surface runoff obtained from CR1993, R2000, R2007 and REMBRAPA were aggregated to monthly totals. In this section, percentage differences in monthly evapotranspiration, soil moisture and surface runoff between CR1993, R2000, R2007 and REMBRAPA were estimated and, together with observed monthly rainfall, they were used to identify shifts and modifications in the hydrological regime under sugarcane expansion. Moreover, trend analyses were applied to monthly runoff data from 1970 to 2010 in order to detect ongoing response of the water balance to sugarcane expansion and to support results obtained from CR1993, R2000, R2007 *and REMBRAPA.*

Analysis of runoff trends

The non-parametric Mann-Kendall (MK) statistical test (Yue et al., 2002; Rao and Hsu, 2008) is used to assess the significance of trend in monthly runoff data under the null hypothesis of stationarity of the Funil, Camargos, Furnas, P Colombia, Marimbondo and A Vermelha sub-basins. The results of trend test performed by using the MK tests at 95% significance level are shown in table 1.

Table 1: Trend test results for monthly runoff time series at 95% significance level.

Sub-basin	Z	p-value	(%) Null Hypothesis (H)
Funil	-0.39	0.347	Not rejected (Stationary)
Camargos	-0.51	0.304	Not rejected (Stationary)
Furnas	-0.21	0.416	Not rejected (Stationary)
P Colombia	-1.39	0.082	Not rejected (Stationary)
Marimbondo	-1.33	0.092	Not rejected (Stationary)
A Vermelha	-1.82	0.035	Not rejected (Stationary)

Table 1 reveals that MK trend tests on 1970-2010 time series of monthly runoff data did not reject the null hypothesis - stationarity - for all sub-basins. However, the outcome of the test also shows evidences of positive and negative trends according to the standardized MK statistic Z and the probability value P (p-value) calculated for each sub-basin. For independent sample data without trend, for instance, p-value and Z should be equal to 0.5 and 0, respectively. P-values closer to 1 and positive values for Z indicate data with positive trend whereas data with negative trend yields p-values closer to 0 and negative values for Z. In light of the results obtained from the mapping of sugarcane plantations, MK trend tests show that sugarcane expansion is associated with downward trends in monthly runoff for the 40-year period. This is because negative trends are present in all sub-basins that have substantial expansion (i.e. P Colombia, Marimbondo and A Vermelha). Despite Funil, Camargos and Furnas also present downward trends represented by negative values for Z and p-values lower than 0.5, their absolute values are small to be considered as evidences for trends.

..."

Besides, the differences of runoff and evapotranspiration plotted in Figures 7 10 show a clear instability (see, e.g., Figure 7b,where differences range from -100% to +65% within six months, see also p.5578 L.25), which could be a computational feature that should be interpreted (maybe cumulative differences between scenarios would provide a more useful result). If, indeed, the measured hydrological behavior differs from that of the computational simulations, the authors should present and interpret this inconsistency.

Indeed. The authors agree with the referee that percentage differences in monthly runoff and evapotranspiration fluctuate in a large range within six months. However, we do not believe that these fluctuations may be related to numerical instability. Since the water availability shown by percentage differences in runoff and evapotranspiration varies according to the phenological cycle of sugarcane, we address these fluctuations to the sugarcane expansion over each sub-basin instead. In the way it is written and presented in the manuscript, we agree with the referee that this idea was not clearly expressed, which might lead the readers to misunderstanding and confusion. Therefore, the authors edited this entire item (item 4.3) following the suggestions proposed by the referee (e.g. replacing percentage differences with cumulative differences). Now, the item 4.3 is written as it follows:

"... For a better understanding of the influence of sugarcane expansion on the water balance of the Rio Grande basin, cumulative differences in evapotranspiration and surface runoff were investigated. In order to standardize comparisons across sub-basins, surface runoff and evapotranspiration are given in meters per square meter of drainage area. Thereafter, changes in the hydrological regime under sugarcane expansion were estimated as cumulative differences between the control run CR1993 and the scenarios of sugarcane expansion (i.e.

R2000, R2007 and REMBRAPA). Moreover, trend analyses were applied to monthly runoff data from 1970 to 2010 for detecting ongoing response of the water balance to sugarcane expansion and for supporting results obtained from CR1993, R2000, R2007 and REMBRAPA.

Analysis of runoff trends

The non-parametric Mann-Kendall (MK) statistical test (Yue et al., 2002; Rao and Hsu, 2008) is used to assess the significance of trend in monthly runoff data under the null hypothesis of stationarity of the Funil, Camargos, Furnas, P Colombia, Marimbondo and A Vermelha sub-basins. The results of trend test performed by using the MK tests at 95% significance level are shown in table 1.

Table 1

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In light of the results obtained from the mapping of sugarcane plantations, MK trend tests show that sugarcane expansion is associated with downward trends in monthly runoff for the 40-year period. This is because negative trends are present in all sub-basins that have substantial expansion (i.e. P Colombia, Marimbondo and A Vermelha). Despite Funil, Camargos and Furnas also present downward trends represented by negative values for Z and p-values lower than 0.5, their absolute values are small to be considered as evidences for *trends.*

Funil sub-basin

Funil is a headwater sub-basin of the Rio Grande basin where values of altitude are up to 900 m.a.s.l.. For this reason, only the land use scenario proposed by EMBRAPA presented areas for cultivation of sugarcane in this sub-basin. EMBRAPA suggested that 4.7% of the Funil sub-basin are suitable for sugarcane fields from which 4.4% were previously classified as pasture lands and 0.3% as Atlantic Rainforest.

Figure 11a presents cumulative differences in surface runoff and evapotransporation (ET) between the scenarios of sugarcane expansion and the control run for Funil sub-basin. In this sub-basin, sugarcane expansion was observed in neither R2000 nor R2007. Hence, cumulative differences in surface runoff and evapotranspiration are equal to 0; and therefore, the following findings only refer to comparisons between REMBRAPA and CR1993.

Figure 1

As shown in figure 11a, replacing pasture lands with sugarcane plantations implies to runoff deficit at the outlet of the sub-basin. Further, over 20 simulation years, accumulated water loss due to sugarcane expansion represent 2 m of surface runoff. In contrast, the cumulative water budget in Funil indicates that evapotranspiration increases at the same rate as surface runoff decreases. Since sugarcane plantations mostly replaced pasture lands, the effects of sugarcane expansion on the water budget of Funil sub-basin are addressed to the increase of its averaged leaf area index.

Camargos sub-basin

Similarly to Funil, Camargos is a small headwater sub-basin. While sugarcane expansion was not observed in R2000, R2007 and CR1993, 2% of the Camargos sub-basin, previously classified as pasture lands, are categorized as suitable to be used for cultivation of sugarcane by EMBRAPA. The natural response of the hydrological cycle to this replacement of pasture *lands by sugarcane plantations is presented in terms of cumulative differences in surface runoff and evapotranspiration in figure 11b.*

Although sugarcane plantations cover only a small portion of the sub-basin, its water budget is significantly affected over 20 years of simulation. In total, sugarcane expansion over Camargos sub-basin represents water losses by evapotranspiration of 5 m and runoff deficit of 2.5 m after a 20 year-period.

Comparing to Funil, impacts of sugarcane expansion on water balance were larger in the Carmagos sub-basin; even though the area suitable for growing sugarcane in Camargos being smaller. This is because, rather than the portion covered by sugarcane, such impacts depended upon the types of soil in the Camargos sub-basin. Predominantly composed of shallow soils and, consequently, often saturated, Camargos sub-basin presents favorable characteristics for increasing evapotranspiration rates. Accordingly, by increasing the capillarity of soil as reflection of the replacement of pasture lands by sugarcane plantations, Camargos is more sensitive to sugarcane expansion than Funil.

Furnas sub-basin

Furnas is the first sub-basin downstream Funil and Camargos, and already at CR1993 presents 1.5% of its drainage area covered by sugarcane plantations. This portion remained constant in R2000 and R2007, but is expanded to 17% in REMBRAPA. At REMBRAPA scenario, the expansion of sugarcane plantations basically replaced pasture lands (12.5%), followed by Atlantic Rainforest (2%) and agriculture of grain crops (1%).

Unlike to Camargos, Furnas sub-basin presents a large water storage capacity in the soil since it is dominantly composed of deep soils. Due to this regional soil characteristic, cumulative differences in evapotranspiration between REMBRAPA and CR1993 are lower than 3 m. (Fig. 22a).

Figure 2

In respect to surface runoff, an expansion of 15.5% of sugarcane plantations means an accumulated reduction of 1.8 m for a 20-year period. Although sugarcane plantations repre-

sent almost one-fifth of the sub-basin, the runoff deficit derived from sugarcane expansion is smaller than Funil or Camargos. This is due to the fact that Furnas counts on the combination of a large water storage capacity and contributions from two subsidiary basins which makes runoff at its outlet more resistant to sugarcane expansion than Funil and Camargos.

P. Colombia sub-basin

P Colombia sub-basin has a drainage area of 75700 km and is located downstream Furnas sub-basin. For P Colombia sub-basin, sugarcane expansion was observed in all land use scenarios and it is briefly described for each of them as follows.
In CR1993, sugarcane plantations represented 11% of the sub-basin. Between CR1993 and R2000, they expanded to 20.8% and replaced areas of pasture lands (5%), agriculture of grain crops (3.2%) and Atlantic Rainforest (1.6%). From R2000 to R2007, the portion of the sub-basin covered by sugarcane plantations reached to 26% whereas REMBRAPA proposed that sugarcane replaces 16.4% of pasture lands, 3.2% of Atlantic Rainforest and 3.1% of agriculture of grain crops over one-third of the sub-basin.
Cumulative differences in surface runoff and evapotranspiration between CR1993, R2000, R2007 and REMBRAPA are shown in figure 22b. As agricultural practices are already ongoing in the P Colombia sub-basin, absolute values of cumulative differences in surface runoff and evapotranspiration over a 20-year period are lower than 1 m.
Regarding water losses by evapotranspiration, cumulative differences between R2007 and CR1993 reveal that after 20 years, the amount of water reaches to 0.3 m. This value goes up to 0.6 m for comparisons between REMBRAPA and CR1993. On the other hand, cumulative differences in surface runoff indicate neither up- nor downward trends between R2007, R2000 and the control scenario.In contrast, cumulative differences between REMBRAPA and CR1993 show a runoff deficit of 1 m.

Marimbondo sub-basin

Unlike P Colombia, Furnas, Camargos and Funil sub-basins, contributions to surface runoff *in the Marimbondo sub-basin come exclusively from rivers in the southern part of the Rio Grande basin whose drainage areas are characterized by intensive agricultural activities. Here, sugarcane plantations are found in all land use scenarios. In CR1993, the land use distribution consisted of 40.8% of pasture lands, 27.9% of sugarcane plantations, 17.2% of agriculture of grain, 13.1% of Atlantic Rainforest and 1% of areas covered by water bodies. R2000 indicates a replacement of 1.1% of pasture lands, 1% of agriculture of grain and 1% of Atlantic Rainforest by sugarcane whereas R2007 proposes that sugarcane plantations cover 42% of the sub-basin mostly replacing pasture lands. Finally, REMBRAPA assumes that 58% of Marimbondo is covered by sugarcane.*

The overall cumulative water budget over 20 simulation years for Marimbondo is shown in figure 33a. While cumulative differences between R2000, R2007 and the control run range from 0 to -0.2 m of surface runoff and from 0 to 0.2 m of evapotranspiration, they achieve -0.4 m and 2 m, respectively, between REMBRAPA and the control run.

Even though sugarcane represents almost half of the Marimbondo sub-basin after expansion, these results reveal that such expansion is not as important to the local water balance in this sub-basin as it is to Camargos, for example. This is due to the fact that since the 60's agriculture lands have already been introduced into the Marimbondo landscape (Tucci and Clarke, 1998); hence impacts of sugarcane expansion on its water balance correspond basically to regional shifts in crops.

A Vermelha sub-basin

A Vermelha is the first sub-basin upstream the outlet of the Rio Grande basin and downstream Marimbondo and P Colombia sub-basins. Since most of its incoming water is propagated from upstream sub-basins, surface runoff at the outlet of A Vermelha highly depends on land use changes over upstream sub-basins.

Here, areas covered by sugarcane begin from 9.4% in CR1993, expanded to 12.3% in R2000 and reach to 30% in R2007 whereas EMBRAPA suggests that 58% of the sub-basin are suitable for growing sugarcane. While sugarcane plantations replace pasture lands (8%), agriculture of grain (8%) and Atlantic Rainforest (5%) between CR1993 and R2007, comparisons

between CR1993 and REMBRAPA indicate that these percentage values go to 23%, 19.1% and 6.5% respectively.
As a natural response to these land use changes, interannual variations in the local water balance were observed and estimated as cumulative differencesin surface runoff and evapotranspiration (Fig. 33b). According to figure 33b, impacts of the sugarcane expansion from CR1993 to R2007 and REMBRAPA represent runoff deficit of 0.1 and 2.3 m at the outlet of the sub-basin. This decreasing trend in runoff is supported by trend analysis on observed data performed in section . In contrast to runoff, cumulative differences in evapotranspiration reveal an increasing trend. It is explained by the replacement of 23% of pasture lands by sugarcane, which implies an increase in the spatially averaged leaf area index of the sub-basin.

Figure 3

...”

Another related problem is the different expected change in runoff for different time steps (daily, monthly or annual).

In fact, MGB-IPH runs on a daily basis for all simulation. To emphasise this idea, a paragraph has been added in the section ***Methods*** *as it follows:*
”By default, MGB-IPH is employed using a daily time step. However, its time step may fluctuate depending on the purpose of study. In this work, MGB-IPH was used to simulate rainfall-runoff processes on a daily basis.”

Two conceptual questions should also be considered. First, the authors refer to short-, medium- and long-term impacts (p.5564 L.2), but we have not clearly identified these temporal horizons in the paper. Maybe the authors refer to time steps, please clarify.

The authors fully agree with the referee. The concept of short-, medium- and long-term

impacts as well as their temporal horizons were added to the manuscript in the following form:
"In this section, an overview of the sugarcane expansion as estimated by Landsat satellite images captured in 1993, 2000 and 2007 is presented. Results from the land use classification of these satellite images are discussed for each sub-basin of the Rio Grande basin. Moreover, short-, medium- and long-term impacts of sugarcane expansion on the water balance of the Rio Grande basin were separately evaluated.
In this study, short-term impacts of sugarcane expansion on the hydrological cycle are investigated by bootstrap analyses on variations in surface runoff at daily temporal scale. For the medium- and long-term, the variability of surface runoff, evapotranspiration and water soil content are assessed at inter-annual and annual temporal scales, respectively."

Secondly, there are references to land use scenarios of 1993, 2000 and 2007 (p.5574 L.18, for instance), but we comprehend that these are not scenarios in the worlds original meaning, rather historical land use of the basin.

The authors agree with the referee. The authors therefore edited all similar sentences within this context along the manuscript, such as:
"... twenty years of simulation using historical land use of the basin based on satellite images, ..."
"... a hydrological model. Twenty years of simulation are made using historical land use of the basin that include ..."

<u>Specific Comments:</u> Some minor notes are presented below.

p.5564 L.16 but also on the type instead of but also the type

Done.

p.5567 LL.6-8. Characterize the size and the representativeness of the series,

which generated the discharge values

This paragraph was edited. Now, size and representativeness of the discharge time series is defined. It takes the following form:
"Although most of surface runoff in the Rio Grande basin is regulated by dams, its hydrological regime is strongly induced by land use changes due to harvesting practices, shifting cultivation and deforestation (WWFBrasil, 2008). After the flow regulation, a representative sample of daily values of discharge collected at the outlet of the basin, from 1970 to 2010, indicates that surface runoff varies from minimum values of 500 m/s during the dry season (June-August) to maximum values over 12000 m/s during the rainy season (December-February)."

p.5569 L.2 plenty of data, which instead of plenty of data which.

Done.

Check for use of commas throughout the text (see also, e.g., p.5574 L.24; p.5583 L.16)

Done.

p.5571 L.7 and L.20 What do the authors mean by mean groundwater flow and upward flux of water?

The term "mean groundwater flow" has been replaced by "average groundwater flow" whereas "upward flux of water" was replaced by "upward water flux". They are components of the MGB-IPH module for estimating the exchange of water between soil and surface.

Please clarify p.5571 L.18 as being the most important during calibration instead

of as being important during calibration

Done.

p.5572 L.20-26 Why did the authors not use the data from 1970 to 1989?

The authors have edited this paragraph in order to address this concern raised by the referee. Now, it is written as follows:
"The adjustable parameters for sugarcane were estimated via calibration. Although disposal measured data spans a period of 40 years, only the 20 most recent years are used for calibration and validation. The calibration was performed for a eleven-year period (1990-2000), and consisted in fine-tuning the adjustable parameters by comparing calculated and observed discharges using relative volume error (RVE), Nash-Sutcliffe coefficient (NS) and root-mean-square error (RMSE) as efficiency criteria. Moreover, the set of the adjustable parameters for sugarcane defined during the calibration were validated over the seven-year period 2001-2007."

p.5572 L.27 Basin was first divided instead of Basin was firstly divided

Done.

p.5573 L.2 it has been used instead of it is been used

Done.

p.5573 L.10 Please clearly state where the gauging stations are located (if upstream or downstream from the reservoirs) and to which extent the operation of these reservoirs might affect the measured discharges

The authors edited this paragraph too. Now, it is written as:

*"...Thus, MGB-IPH parameters for sugarcane were calibrated for P Colombia, Marimbondo and A Vermelha sub-basins. Their gauging stations are approximately located 10 km upstream from the reservoirs in order to prevent backwater effects on measured discharges (**?**). Measured discharges were then used to evaluate estimates of the MGB-IPH using different sets of adjustable parameters."*

p.5573 L.25 Although baseflow recessions were. . . instead of Despite baseflow recessions were. . .

Done.

p.5574 L.3 In order to validate instead of In order to test and validate

Done.

p.5576 L.6 11.4% and 30.8%, respectively instead of 11.4% and 30.8%

Done.

p.5576 L.25 What exactly does reduction on daily runoff mean (see also p.5577 L.3)? A reduction in the average of daily discharges? Please clarify

That is right. The authors meant "reduction in the average of daily discharge". The terms have been replaced by:

"... the expansion of sugarcane resulted on reduction in the averaged of daily discharges from 0.25% to 1.5%."

and

"within their area consequently, no reduction in their average of daily discharge was ob-

served."

p.5576 L.26 The authors affirm that This reduction is directly proportional to the expansion area. Is it really directly proportional or just monotonically increasing? The same applies to p.5583 L.22, where the authors state that soil moisture content was inversely proportional to evapotranspiration in all sub-basins. Do you not mean monotonically decreasing, instead? Please check both cases.

The terms "monotonically increasing" and "monotonically decreasing", suggested by the referee, fit better to what the authors meant in this context. They are now written as it follows: "From 1993 to 2007, the expansion of sugarcane resulted on reduction in the averaged of daily discharges from 0.25% to 1.5%. This reduction monotonically increases with the area converted to sugarcane over each sub-basin. ..."
and
"... is that soil moisture content monotonically decreases with evapotranspiration. Therefore, those sub-basins with ..."

p.5576 L.28 . . . was the most affected instead of . . . were the most affected

Done.

p.5577 L.2 within their area. Consequently, instead of within their area conse-

quently,

Done.

p.5580 L.7 113 hectares: please check unit

All units were rechecked along the manuscript.

p.5582 LL.21-24 What does attenuation in the text from Between CR1993. . . to upstream sub-basins mean? Please clarify

The item 4.3 was entirely rewritten according to previous remarks. The term "attenuation" no longer exists in the new version.

p.5583 L.21 A general pattern that emerges instead of A general pattern which emerges

Done.

p.5585 L.21 Did you mean up to 80%instead of up to 8% (although with disagree with these conclusions)?

No. Here, the authors refer to results from the bootstrap analyses on values of daily runoff. It really is "up to 8%". (See p.5577 L.11)

p.5586 L.2 The authors refer to runoff reduction of 12%, which is confusing

Indeed. The authors replaced "12%" by "20%", value obatained from the results. Now, this paragraph takes the following form:
"Finally, annual analysis made between results from CR1993 and REMBRAPA revealed that

annual surface runoff were reduced by up to 20% whereas annual values of evapotranspiration reached to an increase of 180% of the values calculated in the control run after each year of simulation in the headwater sub-basins. Despite annual values of surface runoff were only reduced by 12% at the outlet of the basin, locally, sugarcane expansion represented high impacts on the annual water balance of the Rio Grande basin."

Table 1 caption, first line:parameters used (or assumed) in this study instead of parameters adopted in this study (see also L.4)

Done.

Figure 11 is not visible.

The authors increased figure 11.

References

Rao, A. R. and Hsu, E.-C.: Streamflow data analyses, vol. 60 of *Water Science and Technology Library*, chap. 5, pp. 121 – 148, Springer, 2008.

Tucci, C. E. M. and Clarke, R. T.: Environmental issues in the la Plata basin, International Journal of Water Resources Development, 14, 157 – 173, 1998.

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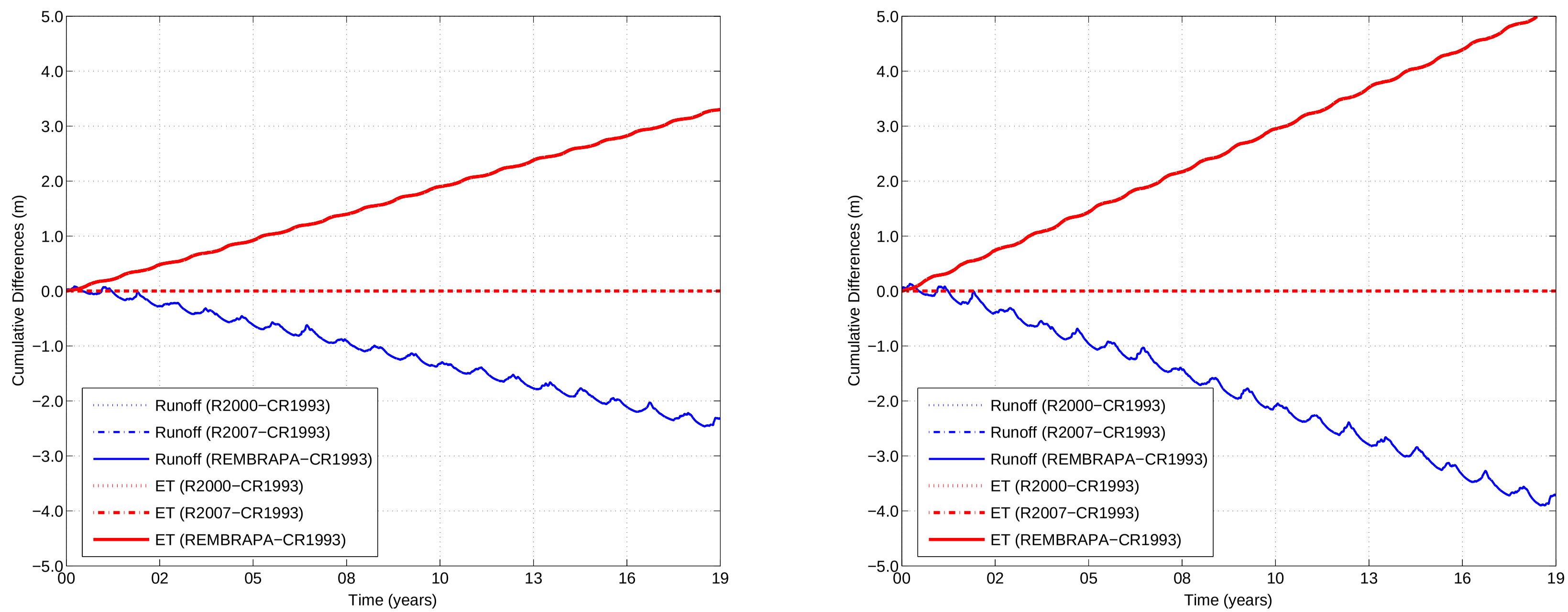
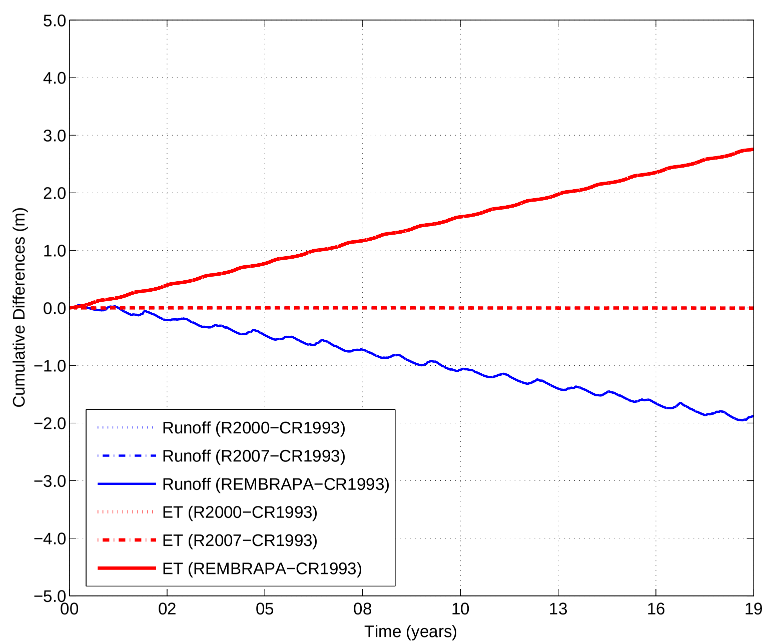
Yue, S., Pilon, P., Phinney, B., and Cavadias, G.: The influence of autocorrelation on the ability to detect trend in hydrological series., Hydrological Processes, 16, 1807 – 1829, 2002.



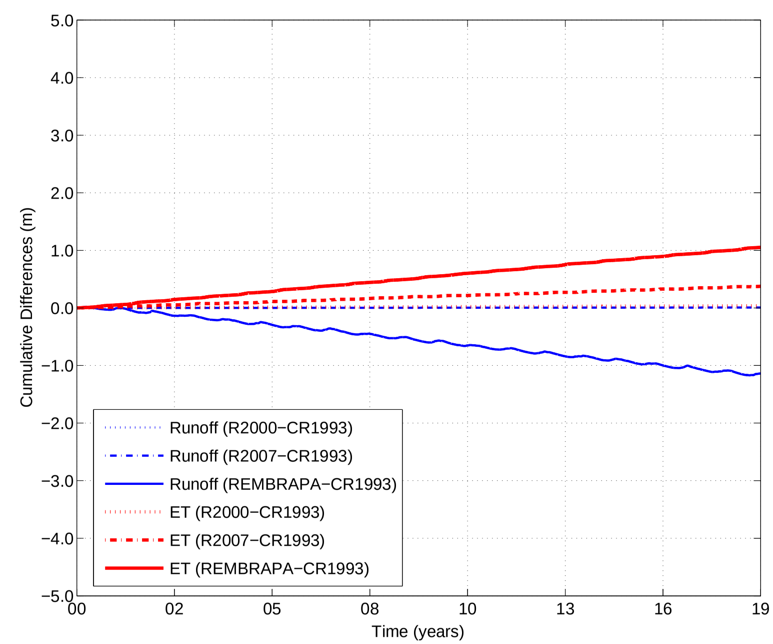
(a) Funil

(b) Camargos

Figure 1: Cumulative differences in surface runoff and evapotranspiration between CR1993, R2000, R2007 and REMBRAPA for Funil (a) and Camargos (b) sub-basins.

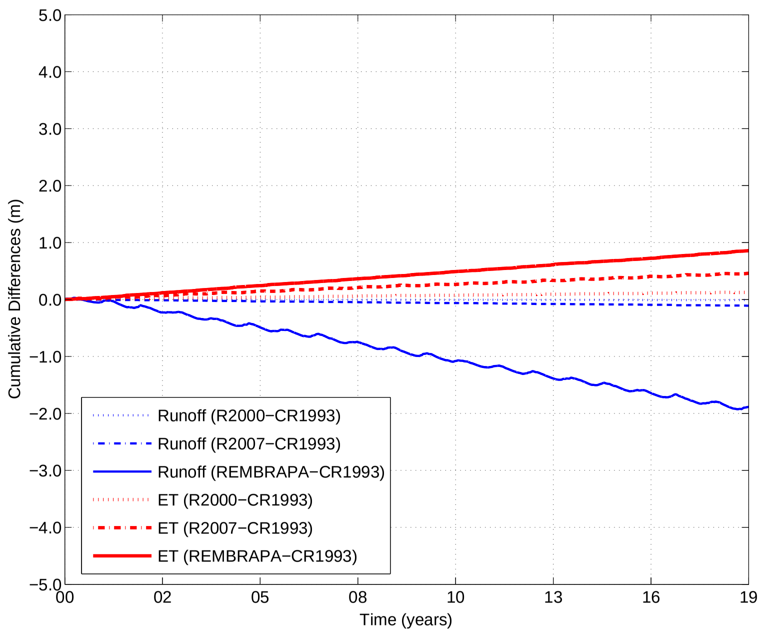


(a) Furnas

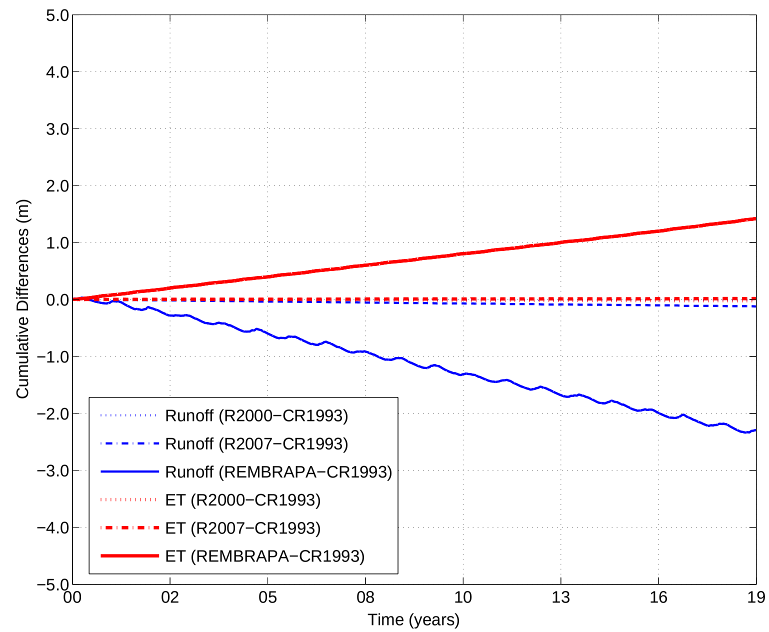


(b) P Colmbia

Figure 2: Cumulative differences in the local water balance of Furnas (a) and P Colmbia (b) sub-basins over a 20-year period.



(a) Marimbondo



(b)

Figure 3: Differences in surface runoff and evapotranspiration accumulated over 20 simulation years for Marimbondo (a) and A Vermelha (b) subbasins.