Reply to comments made by Referee 2

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:

In their paper "Towards the response of water balance to sugarcane expansion", F. F. Pereira et al. assess the hypothetical changes in the hydrologic cycle, by simulation of different sugarcane areas under the same climate. The paper is well structured and in the 1st half of the MS well written and providing sufficient details to follow the calibration and validation procedure of their key-tool the MGB-IPH model. However, there are some issues in the calibration procedure which need to be addressed and clarified by the authors.

In the results section, the link between the biophysical conditions and the effects claimed to follow from the conditions is not always clear (see details below).

The discussion/conclusion section does not provide any comparative analysis with similar studies, nor as a minimum, recycle the papers used in the introduction.

The authors agree with the referee. It is very important to provide to the readers how the results of our research match results that were already shown by other research articles. The authors therefore rewrote the section of conclusions. Now, it is written as follows:

"In this study, impacts of land use changes on water balance were investigated in a basin under ongoing sugarcane expansion. Sugarcane plantations were then tracked using satellite images captured in 1993, 2000 and 2007 and, along with the mapping of areas suitable for cultivation of sugarcane made by EMBRAPA, were used to generate historical and future land use in the Rio Grande basin. Finally, impacts of such sugarcane expansion were estimated as fluctuations in runoff, evapotranspiration and soil water content on daily, annual and decadal basis over 20 years.

On a daily basis, sets of percentage differences in daily runoff were generated in order to highlight trends resulting from short-term effects of sugarcane expansion on runoff. Similarly, sets of percentage differences in annual runoff, evapotranspiration and soil water content aggregated over the entire annual phenological cycle of sugarcane were used to evaluate seasonal and inter-annual variability in the water balance of the Rio Grande basin. Thereafter, long-term impacts were estimated as differences in runoff and evapotranspiration accumulated over 20 years.

As suggested by Warburton et al. (2011) as a good practice to adequately estimate impacts of land use change on water resources, this study assessed the water balance at different spatial

and temporal scales. Overall, four factors could be identified as highly related to the impacts of sugarcane expansion on the water balance of the Rio Grande basin. These factors are the amount of areas replaced with sugarcane plantations, their location within the basin, regional soil properties and local groundwater contribution to stream flow.
This study also revealed that water loss by evapotranspiration due to sugarcane expansion achieves up to 4 m/m^2 over 20 years. Considering the soil characteristics of the sub-basin and area of sugarcane expansion, this value is close to the ones estimated and observed by Watanabe et al. (2004) and is greater than values of evapotranspiration estimated by Marin et al. (2013). The latter, though, calculated evapotranspiration based on downscaled outputs from general climate models (GCMs), which often underestimate evapotranspiration rates (Milly, 1991; Rotstayn et al., 2006; Pereira et al., 2013). Consequently, it may have led to an underestimation of effects of climate change on water efficiency use in the State of São Paulo.
Finally, it is shown that sugarcane expansion mostly affected the water balance if it happens over the headwater areas of low soil water storage capacity. Since headwater basins are dominated by pasture, sugarcane expansion significantly increased evapotranspiration whereas reduced runoff and soil moisture content. "

In the two decades covered by the study, many other conditions may have changed as well. I consider it as indispensable to inform the reader about e.g. (dis-)intensification processes, in all relevant land-use types, i.e. sugarcane, pastures and cereals. It needs to be shown, or at least discussed how de-/increasing plant growth and ET of ALL land uses and the forest were contributing to the effects on runoff etc., currently exclusively attributed to sugarcane. Beyond, if crop yields (and thereby automatically ET and other hydrological parameters) and land use have changed over time a different calibration and validation strategy is needed.

As clearly presented by the title itself, this study evaluates the impacts of sugarcane expansion on water balance. Therefore, only sugarcane plantations have been mapped and tracked using satellite images. It has constantly been mentioned along the manuscript as, for example:

P.5566 L.5-10: "In Brazil, for instance, impacts of the rapid expansion of sugarcane on surface runoff after the Pro-Álcool were not carefully investigated since sugarcane fields were not completely mapped (Cheesman, 2004; James, 2008). In order to fill up this gap, this work aims to map sugarcane fields and their expansion during the past 20 years in a Brazilian river basin."

or

P.5567 L.10-13: "To reproduce the sugarcane expansion in the Rio Grande Basin during the latest 20 yr, three land use scenarios were defined based on satellite images and are compared to a scenario based on the mapping of areas suitable for cultivation of sugarcane made by the

Brazilian Institute for Agricultural Research EMBRAPA"

or

P.5570 L.17-18: "An automatic classification of Landsat satellite images showed in Rudorff et al. (2010) was used for mapping sugarcane fields."

*Although it may appear as a limitation of this study, BRASIL (2009) and (FAURGS, 2007) revealed that land use changes due to shrinkage/expansion of areas covered by pasture, cereals or forest are marginal compared to sugarcane expansion in the Rio Grande basin over the past two decades. And, since effects of the replacement of pastures, cereals and forests by sugarcane on water balance have currently been covered by this study **(Referee: "currently exclusively attributed to sugarcane")**, the authors believe a different calibration and validation strategy is no longer needed.*

However, the authors agree with the referee that this idea is indispensable and must be clearly passed to the readers. We therefore replaced the following paragraph:

"Each land use map was classified into five dominant types as areas covered by water bodies, Atlantic Rainforest, agriculture of grain crops, pasture lands and sugarcane fields according to their spectral signatures. Except for sugarcane fields, all spectral signatures were adopted as defined by Mendes and Cirilo (2001)."

by

"Each land use map was classified into five dominant types as areas covered by water bodies, Atlantic Rainforest, agriculture of grain crops, pasture lands and sugarcane plantations according to their spectral signatures. Except for sugarcane plantations, all spectral signatures were adopted as defined by Mendes and Cirilo (2001) and only mapped for 1993. Although it may appear as a limitation, BRASIL (2009) and (FAURGS, 2007) revealed that land use changes due to shrinkage/expansion of areas covered by pasture, cereals or forest are marginal compared to sugarcane expansion in the Rio Grande basin over the past two decades."

The results section is confusing in various sections, as the authors present a mix of soil, land-use, hydrological information, while phenological information is lacking and in many instances the conclusions drawn from the facts they present seem not logical. This problem could either be attributed to biophysical interpretations or grammatical problems, but as a result, I as a "professional reader" in many parts either do not understand their logic or disagree. Thus, I suggest to restructure the text, more clearly addressing causal links and effects separately and investing a couple of additional phrases in the results section to enable readers to understand the simulation results. Alternatively, the authors could try to identify some generic effects, which they introduce in a section

before providing the sub-basin details.

*Indeed. The authors recognize that, along with the section of conclusion, the section of results and discussions was very unclear. A great effort has therefore been made to restructure the text there. It now counts on new analysis, results and discussions added as suggested by the first referee. The new section of **Results and discussions** takes the following form:*

"

1 Results and discussion

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 soil water content are assessed at inter-annual and decadal temporal scales, respectively.

1.1 An overview of the sugarcane expansion in the Rio Grande Basin

In general, altitude and terrain slope were equally important factors that drove sugarcane expansion between 1993 and 2007 in the Rio Grande basin. Since sugarcane plantations do not tolerate frosts (Eggleston et al., 2004; Tai and Miller, 1993), altitude appeared as a limiting factor which restricted sugarcane expansion to areas below 700 m.a.s.l.. In addition, mechanical harvesting and transport facilities directed sugarcane expansion to regions of terrain slope less than 12%. The evolution of areas covered by sugarcane plantations is shown in table 3 for each sub-basin.

Table 3

From 1993 to 2007, table 3 reveals very little or no sugarcane plantations over Funil, Camargos and Furnas sub-basins. Characterized by high elevations, these sub-basins present low temperatures that may reach 8°C in the austral summer. Under such climate conditions, sugarcane productivity would negatively be affected by low temperatures, which induce damage to young leaves and lateral buds. This makes Funil, Camargos and Furnas less attractive to grow sugarcane.
On the other hand, further downstream, areas covered by sugarcane represent up to 27.9% of the Marimbondo sub-basin already in 1993. In addition, areas for growing sugarcane have more than tripled over 14 years (e.g. A Vermelha). This sugarcane expansion has basically been observed in P Colômbia, Marimbondo and A Vermelha over areas of flat land at low

elevations. These results are in accordance with what has been suggested by EMBRAPA as areas potentially suitable for cultivation of sugarcane in the Rio Grande basin (see figure 1). A chronological analysis indicates different rates of sugarcane expansion for P Colômbia, Marimbondo and A Vermelha sub-basins. Between 1993 and 2000,for example, P Colômbia presented an increase of 9.8% in sugarcane plantations. During the same period, Marimbondo and A Vermelha showed an expansion of only 3.2% and 2.9%, respectively. In contrast, from 2000 to 2007, a higher sugarcane expansion has been observed over Marimbondo and A Vermelha than P Colômbia. While Marimbondo and A Vermelha pointed to an increase of 10.9% and 17.8% in areas covered by sugarcane, the expansion over P Colômbia corresponded to 5.1% (see table 3).

Overall, sugarcane plantations replaced mostly pasture lands and areas of agriculture of grain. Comparisons made between land use distribution in 2007 and 1993 showed that the replacement of pasture lands by sugarcane fields achieved 6.8%, 7.5% and 8.9% of the Marimbondo, P Colômbia and A Vermelha sub-basins, respectively. It is followed by the replacement of areas of agriculture of grain crops with 5.2%, 4.7% and 7.6%, and then Atlantic Rainforest with 2.1%, 1.6% and 3.8%, respectively.

1.2 Short-term impacts of sugarcane expansion on runoff

Since fluctuations in daily evapotranspiration and soil moisture rates are marginal, short-term impacts of sugarcane expansion on the water balance are exclusively evaluated in terms of daily runoff. Though, effects of sugarcane expansion on evapotranspiration and soil moisture are incorporated when evaluating over longer temporal horizons (see sections 1.3 and 1.4).

Three data sets are then generated from percentage differences in daily runoff between the scenarios of expansion (i.e. R2000, R2007 and EMBRAPA) and the CR1993 one. As each run was performed over a simulation period of 20 years, each of these sets corresponds to 7300 daily runoff differences. The statistical significance of these percentage differences were tested by means of bootstrap, using 1000 random samples, for a significance level of 0.01 and are presented in figure 2 per sub-basin.

Figure 2

According to bootstrap results, percentage differences in daily runoff between CR1993 and R2000 were not statistically significant at the 99% confidence level. It can be associated with the small expansion of sugarcane plantations between 1993 and 2000, which corresponded to a little over 2.5% of the Rio Grande basin. From 1993 to 2007, however, sugarcane (20.7%) surpassed agriculture of grain (11.8%) as the second-largest land use in the Rio Grande basin. It implied to reductions in average daily runoff from 0.25% to 1.5% at the outlets of the sub-basins (Fig. 2a). These reductions monotonically increase with the area converted to sugarcane over each sub-basin. Accordingly, average daily runoff at the outlets of A Vermelha and Marimbondo were the most affected by sugarcane expansion which have been reduced by up to 1% and 1.5%, respectively.

Figure 2b shows effects of sugarcane expansion on average daily runoff if the total area suggested by EMBRAPA as suitable for growing sugarcane is filled with sugarcane plantations.

In this case, percentage differences in average daily runoff were significant at 0.01 level as tested by bootstrap considering 1000 random re-sampling with replacement. Further, percentage differences in average daily runoff were lower than -10% at the outlets of the headwater sub-basins. Since the headwater sub-basins are dominantly composed by shallow soils, which easily become saturated, conversion of pasture to sugarcane significantly increased evapotranspiration rates reducing runoff at their outlets.

1.3 Medium-term impacts of sugarcane expansion on water balance

Medium-term impacts of sugarcane expansion on water balance are estimated as percentage differences in annual runoff, evapotranspiration and soil water content over 20 simulation years. Annual runoff, evapotranspiration and soil water content are accumulated from daily values calculated in CR1993, R200, R2007 and REMBRAPA over the annual phenological cycle of sugarcane, so that from June to May.
As differences in daily runoff between R2000 and CR1993 were not significant at the 99% confidence interval (see item 1.2), accumulated daily values throughout the year are also marginal. Therefore, figure 3 shows only percentage differences in annual runoff, evapotranspiration and soil water content between REMBRAPA, R2007 and CR1993.

Figure 3

A general pattern that emerges from figure 3 is that soil moisture content monotonically decreases with evapotranspiration. It indicates that water loss by evapotranspiration is higher over saturated soils than unsaturated ones. Therefore, since sugarcane infiltrates more than pasture (see table 2), the replacement of pasture by sugarcane implied to more humid soils and, hence, larger evapotranspiration rates.
Other implications of sugarcane expansion to the water balance can be observed in figure 3, and they are separately discussed for R2007-CR1993 and REMBRAPA-CR1993 as it follows below. Over 20 years, annual fluctuations in runoff, evapotranspiration and soil water content derived from the sugarcane expansion proposed between CR1993 and R2007 range -0.7 to 1%. It means that despite differences in daily runoff, for example, achieved up to -2.5% (see item 1.2), annual accumulated differences in runoff, evapotranspiration and soil water content are affected by the sugarcane growth stages, which may smooth impacts of sugarcane expansion on water balance over longer time frames. Locally, contribution from groundwater is also an influencing factor in reducing the impacts of sugarcane expansion on annual accumulated runoff. It can be seen from comparisons between Marimbondo and P Colômbia sub-basins, which present the same area of sugarcane expansion but different fluctuation rates — P Colômbia between 0.08 and 0.15% whereas Marimbondo from -0.16 to 0.08%.
Figure 3 also shows percentage differences in annual runoff, evapotranspiration and soil water content as a natural response of the water balance to a possible sugarcane expansion if areas suitable for growing sugarcane, as defined by EMBRAPA (BRASIL, 2009), are all filled with sugarcane plantations. It reveals that the water balance of headwater sub-basins is very sensitive to the sugarcane expansion since an expansion of only 4% of their drainage

area represents a reduction of 33% and 60% in their annual soil water content. In addition, annual evapotranspiration rates nearly double whereas annual runoff decreases by up to 22% at the outlet of the headwater sub-basins. For the other sub-basins, however, absolute values of annual fluctuations in runoff, evapotranspiration and soil moisture content are no greater than 12%, 40% and 10%, respectively. The combination of shallow soils (i.e. continuously saturated) and low contribution from groundwater found in the headwater sub-basins appear as the main reasons for the larger impacts of sugarcane expansion on their annual water balance.

1.4 Long-term impacts of sugarcane expansion on water balance

For a better understanding of the influence of sugarcane expansion on 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.

1.4.1 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 Colômbia, 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 4.

Table 4

Table 4 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 Colômbia, 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.

1.4.2 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 4a 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 4

As shown in figure 4a, 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.

1.4.3 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 4b.
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.

1.4.4 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. 5a).

Figure 5

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 represent 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.

1.4.5 P. Colômbia sub-basin

P Colômbia sub-basin has a drainage area of 75700 km and is located downstream Furnas sub-basin. For P Colômbia 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 5b. As agricultural practices are already ongoing in the P Colômbia 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.

1.4.6 Marimbondo sub-basin

Unlike P Colômbia, 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 6a. 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.

1.4.7 A Vermelha sub-basin

A Vermelha is the first sub-basin upstream the outlet of the Rio Grande basin and downstream Marimbondo and P Colômbia 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 differences in surface runoff and evapotranspiration (Fig. 6b). According to figure 6b, 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 1.4.1. 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 6

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An additional figure showing typical annual ET pattern of the 4 major land use

and land cover types may help to understand also runoff and subsurface flow pattern of all 4.

Done. See previous remarks.

The authors do not link their findings with similar field or simulation studies, making it almost impossible for the reader to interpret the significance of the findings.

Done. See previous remarks.

To summarize, the paper has a high potential, but considerable additional efforts are needed before this paper can be accepted.

<u>Detailed Comments:</u>

case study region: Please provide more general hydrological information characterizing the (sub-)basins and helping the reader to interpret the changes caused by the simulated sugarcane expansion (rainfall, ET, runoff ratios or percentages e.g. in dry & rainy season).

*The authors have expanded the section **Study Area**. More hydrological information have been added including the main water use, rainfall, ET, runoff regime and ratios for the (sub-)basins. This information has been incorporated in the manuscript as follows:*

"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 and shifting cultivation (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 1000m/s (dry season) to maximum values over 12000m/s (rainy season). Locally, measurements of runoff are also monitored at hydroelectric power plants. At Funil, Camargos, Furnas, P Colômbia, Marimbondo and A Vermelha power plants, daily runoff ranges 70 – 3731m^3/s, 34 – 1253m^3/s, 174 – 7497m^3/s, 251 – 8367m^3/s, 532 – 9234m^3/s and 303 – 10186m^3/s, respectively.
Production of electrical power is the largest water use in the Rio Grande basin (IPT, 2008). Over 11% of the installed electric generation capacity of Brazil is at hydroelectric installations in the Rio Grande basin (ANEEL, 2005). To meet this demand for electricity, hydroelectric power plants are constrained by a minimum operating flow, which varies from power plant to power plant. As recently proposed by (ONS, 2013), the minimum operating flow at all hydroelectric power plants used in this study are shown in table 1.

Table 1

According to Espinosa (2011), spatial and temporal distribution of rainfall in the Rio Grande basin is highly induced by synoptic systems over the southeastern and south-central Brazil. In

addition, annual rainfall analysis carried out by CPRM (2012) indicate that annual average rainfall varies from 1500 to 2000mm in the basin.
Annual average evapotranspiration ranges from 800 to 1000mm (Ruhoff, 2011). Throughout the year, a seasonal variability of evapotranspiration has been identified by Rocha et al. (2002). Over the Rio Grande basin, their studies revealed that daily evapotranspiration can oscillate between 6mm/d^{-1} in the rainy season and 1mm/d^{-1} in the dry season. "

Water users: Unfortunately, no information is provided about other water users in the basin and how the patterns and amount of water use has changed over time between 1993 and 2007. As all water users influence the gauges used for calibrating the model, it is absolutely essential to take them into account.

*The authors agree with the referee. There was a lack of information regarding the water uses in the basin. In order to fill up this gap, the authors have added details about the water uses in the basin for 2007 (found in a report made by IPT (2008)) into the section **Study Area** (see previous remark).*

Calibration & validation: To avoid e.g. land use related biases in the calibration period, the authors could run the calibration for the 1993 conditions for instance from 1988 to 1997 (they claim to have all data since 1970), and the validation with year 2000 land use from 1995 to 2004 (or from 2002 to 2011 if you validate with 2007 land use).

The authors appreciate the suggestion given by the referee. However, as it is, the calibration and validation of parameters for sugarcane indicate a model performance of $NS \geq 0.92$ *and* 0.85, $RMSE \leq 380m^3/s$ *and* $508m^3/s$ *and* $RVE \leq 6.79\%$ *and* 12.3% *respectively. Compared to Immerzeel and Droogers (2008) or Poulin et al. (2011) or many other research articles, indicators of model performance revealed that the calibration and validation used in this study are by far better than those ones. Furthermore, the improvement in the calibration and validation related to such biases will not be relevant according to the large experience of the authors in applying the MGB-IPH model to large basins.*

In general terms, the authors need to address the issue of (i) land-use intensity and (ii) other water users potentially affecting runoff, as changes in (i) and (ii) may strongly influence results & conclusions.

*The authors completely restructured the sections **Results and discussions** and **Conclusions**. In their present form, these concerns raised by the referee have been addressed. See previous remarks.*

In the current version of the MS it is unclear whether 1993 land use is used for validation, which would make little sense given the partly large land-use change between 1993 and 2007.

The authors agree with the referee. The following sentence has been edited in order to let *clear the land use map used in the validation.*

"For the calibration of sugarcane parameters, Rio Grande basin was first divided into six smaller sub-basins where each sub-basin has a correspondent gauging station at its outlet. Also, as the land use map of 1993 was chosen as the control scenario, it has been used for both calibration and validation."

p. 5566 l 12: please replace last word river by Rio

Done.

p. 5567 l 9: Spatially distributed model??

The authors replaced the sentence:

"... Rio Grande Basin using a distributed hydrological model."

by

"... Rio Grande Basin using a spatially distributed hydrological model."

p. 5574 l 16: I consider the historical land-use constellation NOT to be scenarios, as the term scenario is usually used for potential (land use) constellations or plausible options of future developments. Thus, I suggest to use the term scenario only for the EMBRAPA case.

The authors fully agree with the terminology proposed by the referee. We replaced all occurrences of "land use scenario" by "historical land use" when referring land use maps of 1993, 2000 and 2007.

p. 5574 l 23: Please explain the "warming-up period".

The authors have added the following explanation:

"... All runs were preceded by a warming-up period of one year (January 1989 - December 1989), which means a period often used in simulations to let physical parameters reach realistic conditions..."

p. 5578 l 14 ff: In my understanding conditions and effects dont match. Please rephrase to explain the causal links much clearer.

This phrase has been taken away from the manuscript after restructuring the section of ***Results and discussions****. See previous remarks.*

p. 5579 top: Why would "the lower soil moisture content at this basin", lead

to "higher evapotranspiration rates"? To my knowledge, low water availability in soils LIMITS ET, assuming that water is a limiting factor. Unclear. Please rephrase and explain better.

*This phrase has also been taken away from the manuscript after restructuring the section of **Results and discussions**. See previous remarks.*

p. 5579 Furnas sub-basin: The logic of the explanantions seems wrong. For instance, why would humid soils keep ET down? see above.

The authors agree with the referee. This section has been rewritten. See previous remarks.

p. 5584 l 23: only Rembrapa presented, what about the others?

*Indeed. The section **Conclusions** has been rewritten. See previous remarks.*

Discussion: A serious discussion is lacking. The authors do not link their findings with similar field or simulation studies, making it almost impossible for the reader to interpret the significance of the findings.

See previous remarks.

Conclusions: only here the authors provide a little bit of phenological information. This info is urgently needed in the results section. Please invest more efforts to critically discuss your study.

See previous remarks.

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Table 1: Minimum operating flow at the hydroelectric power plants used in this study (ONS, 2013).

Hydroelectric power plant	(m^3/s)
Funil	34.0
Camargos	34.0
Furnas	174.0
P Colômbia	251.0
Marimbondo	1100.0
A Vermelha	1600.0

Table 2: Fixed and adjustable parameters used (or assumed) in this study. The set of fixed and adjustable parameters for agriculture of grain crops, pasture lands and Atlantic Rainforest were assumed as defined via calibration and validation by Nóbrega et al. (2011) in the Rio Grande basin. On the other hand, for sugarcane fields, fixed parameters were adopted according to ranges obtained in the literature whereas adjustable parameters were calibrated and validated in this study.

Fixed Parameters													
Type of Land Use	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agriculture of grain crops	Albedo	0.13	0.13	0.13	0.13	0.16	0.16	0.17	0.17	0.16	0.15	0.14	0.13
	Leaf Area Index (m^2/m^2)	4.00	4.00	4.00	5.00	1.00	1.00	2.00	2.00	2.00	2.00	3.00	3.00
	Height of trees (m)	1.00	1.00	1.00	1.00	0.50	0.80	0.80	0.80	0.80	0.90	0.90	0.90
Pasture lands	Albedo	0.20	0.20	0.20	0.21	0.21	0.21	0.21	0.21	0.21	0.20	0.20	0.20
	Leaf Area Index (m^2/m^2)	2.00	2.00	2.00	3.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
	Height of trees (m)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Atlantic Rainforest	Albedo	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
	Leaf Area Index (m^2/m^2)	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
	Height of trees (m)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
Sugarcane fields	Albedo	0.28	0.28	0.29	0.31	0.31	0.24	0.25	0.25	0.25	0.27	0.27	0.27
	Leaf area index (m^2/m^2)	7.00	7.00	8.00	9.00	9.00	3.00	5.00	5.00	5.00	6.00	6.00	6.00
	Height of trees (m)	3.60	3.60	3.80	3.80	3.80	0.50	1.20	1.20	1.20	2.80	2.80	2.80

Adjustable Parameters			
Type of Land Use	Parameter	Unit	Value
Agriculture of grain crops	Maximum water storage	mm	625.0
	Mean percolation	mm d^{-1}	3.5
	Residual water storage	mm	62.5
Pasture lands	Maximum water storage	mm	446.0
	Mean percolation	mm d^{-1}	2.1
	Residual water storage	mm	44.6
Atlantic Rainforest	Maximum water storage	mm	711.0
	Mean percolation	mm d^{-1}	6.2
	Residual water storage	mm	71.1
Sugarcane fields	Maximum water storage	mm	654.0
	Mean percolation	mm d^{-1}	3.9
	Residual water storage	mm	65.4
Same for all types of land use	Mean groundwater flow	mm d^{-1}	146.0
	Upward flux of water	mm d^{-1}	0.0
	Shape parameter	-	0.10
	Hydraulic conductivity	mm d^{-1}	2268.0

Table 3: The portion of areas covered by sugarcane fields per sub-basin in 1993, 2000 and 2007.

Sub-basin		(%)	
	1993	2000	2007
Funil	0.0	0.0	0.0
Camargos	0.0	0.0	0.0
Furnas	1.5	1.5	1.5
P Colômbia	11.0	20.8	25.9
Marimbondo	27.9	31.1	42.0
A Vermelha	9.4	12.3	30.1

Table 4: 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 Colômbia	-1.39	0.082	Not rejected (Stationary)
Marimbondo	-1.33	0.092	Not rejected (Stationary)
A Vermelha	-1.82	0.035	Not rejected (Stationary)

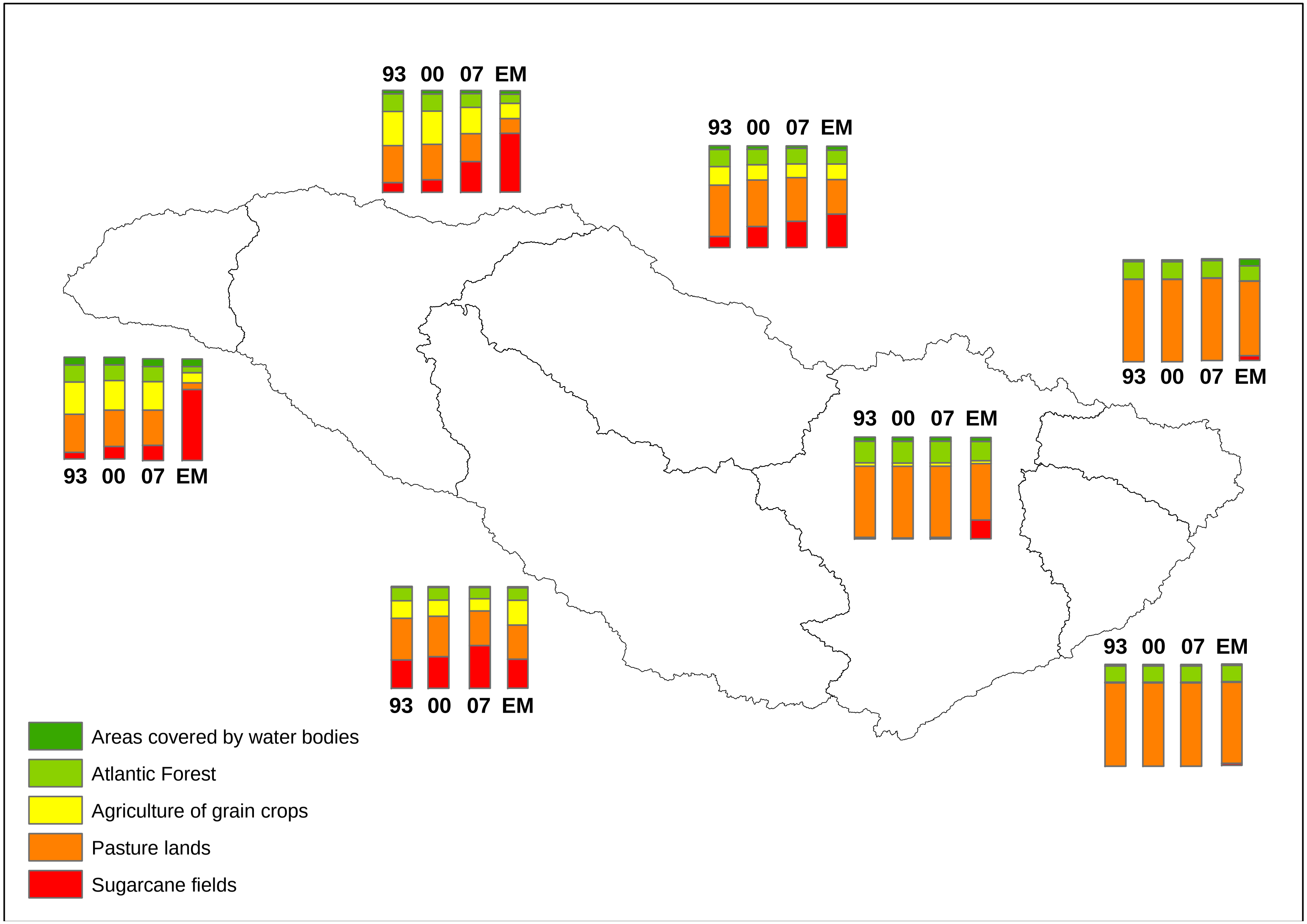
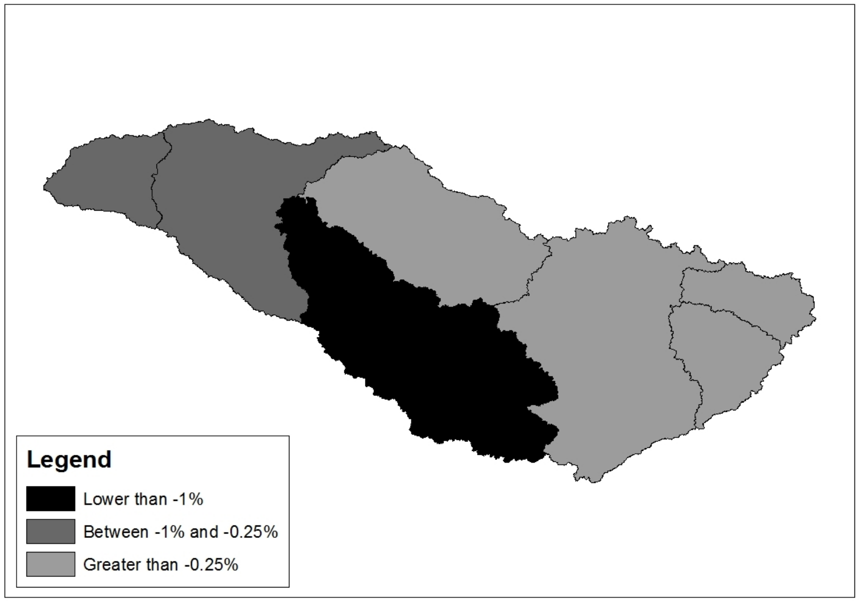
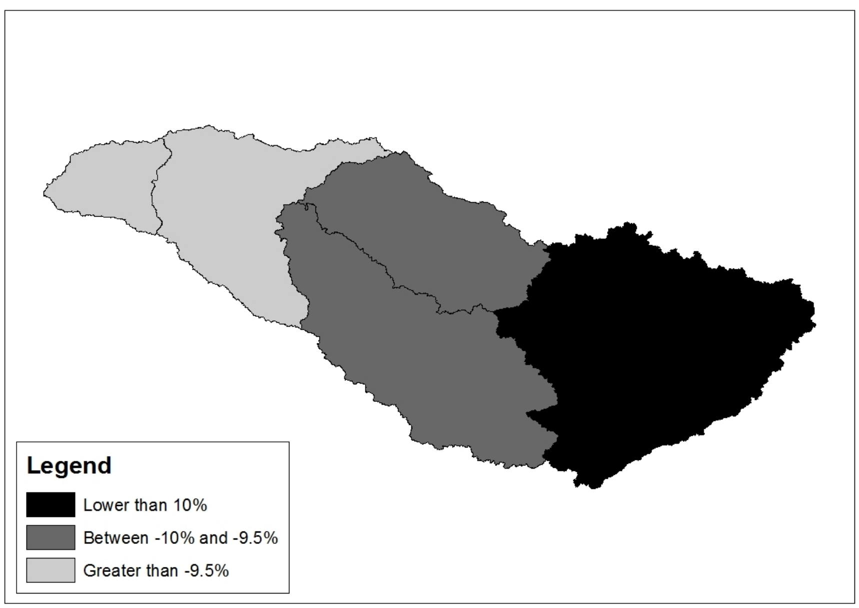


Figure 1: Land use distribution of each sub-basin of the Rio Grande basin for all four land use scenarios used in this study: 1993, 2000, 2007 and EMBRAPA.



(a) 1993 - 2007



(b) 1993 - EMBRAPA

Figure 2: Results from bootstrap analysis of the percentage differences of daily surface runoff between CR1993 and R2007 (a) and CR1993 and EMBRAPA (b).

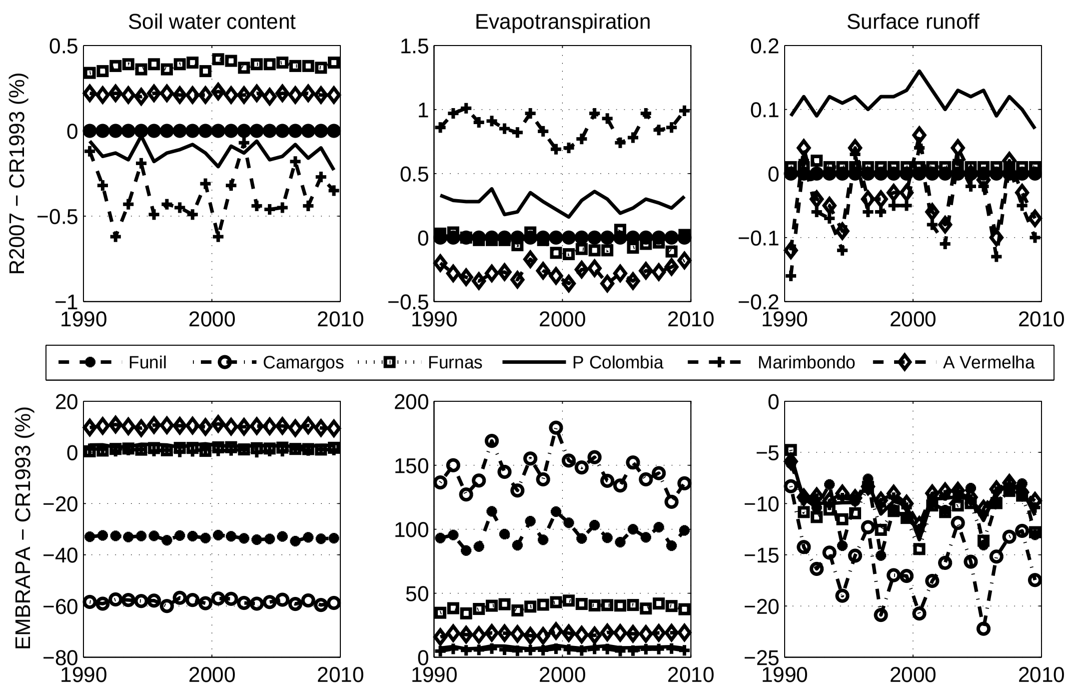
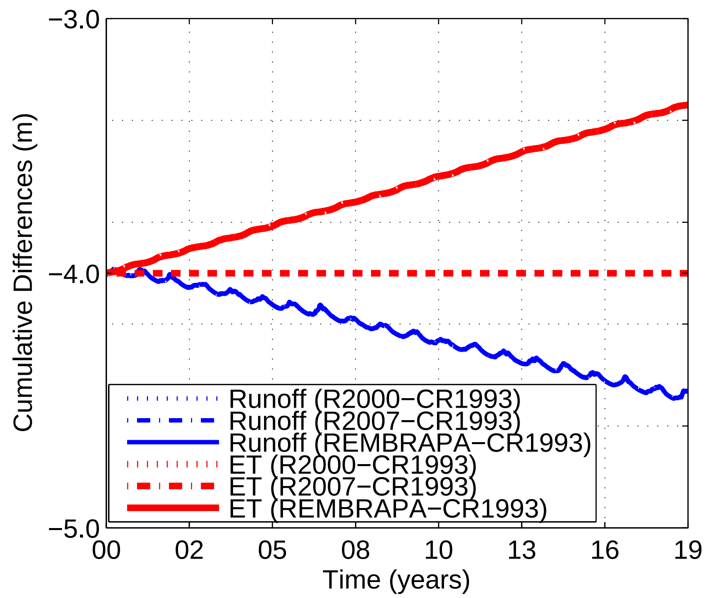
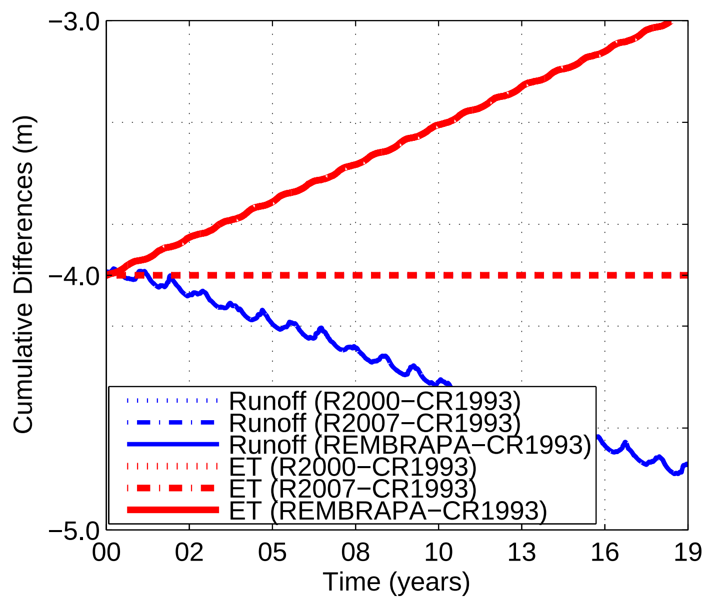


Figure 3: Percentage differences of accumulated annual values of soil water content, evapotranspiration and surface runoff for all sub-basins during the entire simulation period between CR1993 and R2007, and CR1993 and REMBRAPA. Accumulated annual values were accumulated along the annual cycle of sugarcane phenology.

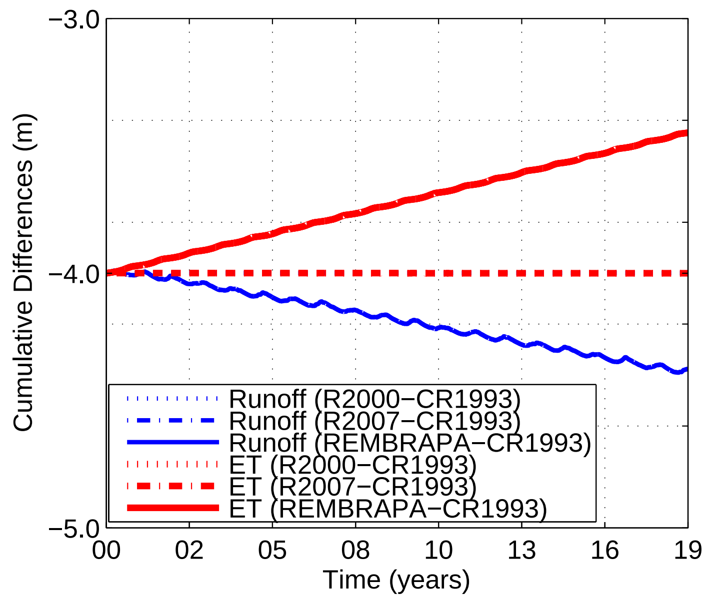


(a) Funil

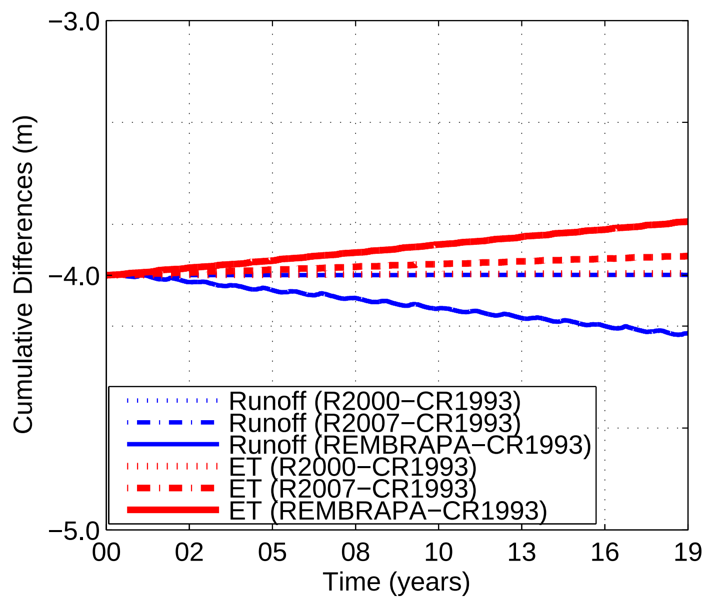


(b) Camargos

Figure 4: Cumulative differences in surface runoff and evapotranspiration between CR1993, R2000, R2007 and REMBRAPA for Funil (a) and Camargos (b) sub-basins.

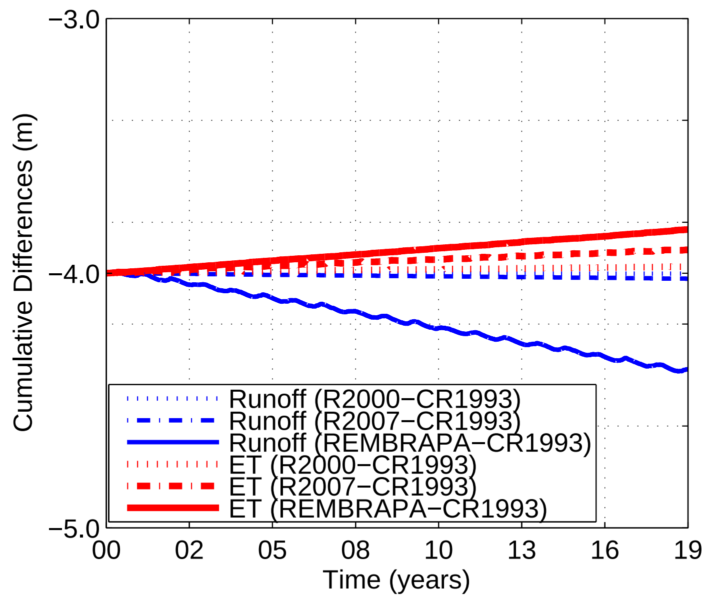


(a) Furnas

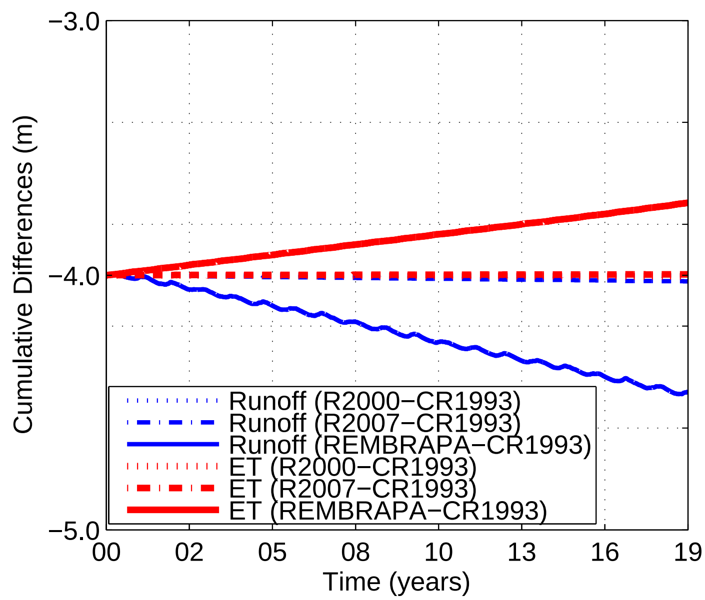


(b) P Colômbia

Figure 5: Cumulative differences in the local water balance of Furnas (a) and P Colômbia (b) sub-basins over a 20-year period.



(a) Marimbondo



(b) A Vermelha

Figure 6: Differences in surface runoff and evapotranspiration accumulated over 20 simulation years for Marimbondo (a) and A Vermelha (b) subbasins.