Streamflow projections for the Brazilian hydropower sector from RCP scenarios
Cleiton da Silva Silveira, Francisco de Assis de Souza Filho and Francisco das Chagas Vasconcelos Júnior

ABSTRACT

Streamflow projections were estimated for river basins of relevance to the Brazilian hydroelectric sector from monthly precipitation projections from global models of the fifth report of the Intergovernmental Panel on Climate Change – IPCC-AR5 from 2010 to 2098 for RCP4.5 and RCP8.5 scenarios. Streamflow were computed using the Soil Moisture Accounting Procedure (SMAP) hydrological model, which was forced by bias-corrected precipitation from the monthly rain data of the Climatic Research Unit and by the estimation of potential evapotranspiration according to the Penman–Monteith method. The impacts on average annual streamflow were analyzed for the periods 2010–2039, 2040–2069 and 2070–2098 in comparison with the observational record (historical experiment) from 1950 to 1999. Most IPCC-AR5 models agree in terms of the impact on the electrical sector in the southeastern/midwestern and northern regions, showing that streamflow may be reduced up to 15% in each 30-year period on Furnas basin and approximately 30% by the end of the century in Tucurui basin under RCP8.5 scenario. In the northeastern sector, the divergence of the models suggests great uncertainty, emphasized in the Xingó basin. In the southern sector, results show increasing streamflow over southernmost Brazil and decreasing over intersection between southern and southeastern regions.

Key words | Brazilian hydropower sector, climate change, IPCC-AR5, Penman–Monteith, SMAP, streamflow

INTRODUCTION

The Brazilian electric system consists largely of ‘clean’ energy derived from hydroelectric sources. Consequently, careful analysis of the river systems and their temporal variation patterns is a requisite to management of Brazilian energy supply and economy. Significant changes in seasonality and quantity of streamflow in a reservoir are highly relevant to production of hydropower, and they can be intensified by changes in the climate system leading to problems for the planning, operation and viability of hydroelectric power stations (Harrison et al. 1998).

This has led to higher demand from the public and private sectors for climate information relevant to regional and local decision-making at short, medium and long timescales. Accurate predictions/projections of climate variability and changes can increase the efficiency of energy planning and minimize the potential impacts on the availability of energy supply on the economy (Quiggin 2008; World Bank 2010). The expansion of the electrical power supply must be fitted to the projections for energy consumption by considering the appropriate levels to ensure the supply at the lowest possible total cost (Marengo et al. 2011). In addition, Liu et al. (2015) have drawn attention to the problem of rising hydropower demand due to energy policies, add the anthropogenic impact on the climate and...
this increases the vulnerability of the hydrosystems and accentuates the fresh water scarcity.

The river basins relevant to the Brazilian electricity sector are regions with high spatial and temporal variability of precipitation (Reboita et al. 2010), driven by diverse rainfall-generating systems. Variability and climate change have been the subject of discussions and scientific research worldwide in order to understand both its occurrence (Marengo & Soares 2005; IPCC 2007, 2014; Marengo & Valverde 2007), as well as to identify and evaluate its potential environmental, social and economic impacts (IPCC 2007), and to draw up policies to minimize the adverse consequences thereof (Van Vilet et al. 2012, 2016; Mamoon et al. 2016). Climate changes and variability have been a topic of discussion and scientific research worldwide to understand their occurrence (Nobre 2005; IPCC 2007). The fourth and fifth reports produced by the Intergovernmental Panel on Climate Change (IPCC), released in 2007 and 2014, suggest increases in the average temperature of the atmosphere and altered precipitation patterns worldwide (Marvel & Bonfils 2013). This could lead to changes that directly affect the water cycle and can affect streamflow in the hydroelectric sector.

Silveira et al. (2015a) evaluated the performance of IPCC-AR5 models to represent precipitation on seasonal, interannual and decadal timescales and projections for the Amazon basin, La Plata basin and Northeastern Brazil, finding model agreement with decreased streamflow values over La Plata basin during the 21st century, and divergent signals in the Northeast and on the Amazon basins (Silveira et al. 2014). Lucena et al. (2010) indicate that Northern and Northeastern Brazil have vulnerabilities related to climate changes scenarios and suggest major impacts on the hydroelectric grid if the projections from the IPCC-AR4 models were to be achieved. Prado et al. (2016) point out that the expansion of hydropower generation designed for the northern sector of the country can lead to socioeconomic and environmental impacts in Brazil, and projects the need for increasing the participation of other renewable energy sources in the power grid of the country.

The development of new convection parameterization schemes and the reduction of the grid spacing driven by the continuous increasing of computational processing allow improvements in the representation of dynamical and physical processes by Coupled Global Climate Models in the fifth IPCC report which may lead to better results on the present climate and minimize the uncertainties of projections (IPCC 2014).

The objective of this study is to analyze the projections of the global models of the CMIP5 (published in the fifth report of the IPCC-AR5) for the RCP 4.5 and 8.5 scenarios for the 21st century to identify changes in the seasonality and trends of streamflow values over the basins, which provide water to the Brazilian hydropower sector. The rest of the paper is organized as follows. The following describes the Brazil National Hydrosystem, followed by a section presenting the methodology utilized as well as the dataset. The results and discussion section is followed by the conclusion and remarks.

**NATIONAL INTERCONNECTED SYSTEM (SISTEMA INTERLIGADO NACIONAL)**

The river basins monitored by the National Systems Operator (Operador Nacional de Sistemas) are shown in Figure 1. With the exception of the Santo Antonio basin, all studied basins are completely within the Brazilian territory. The extensive system for the production and transmission of electrical energy in Brazil – the National Interconnected System (Sistema Interligado Nacional, SIN) – involves many different regions, which have climatic influences from various meteorological phenomena. Thus, different basins have distinct seasonal behaviors, which necessitate detailed operational plans to make the best use of the energy resources in the country and the hydrological seasonality of each region. SIN is divided into four subsystems: the Southeastern/Midwestern, the Southern, the Northern and the Northeastern sector. These subsystems are interconnected by an extensive transmission network that makes the transfer of surplus energy possible and enables the optimization of water stored in the reservoirs of the hydroelectric plants.

There is a hydrological complementarity of the affluent natural energy through the two SIN subsystems due to the spatial seasonality of precipitation on the Southeast/Midwest and the South regions. It means that there are spatial
and temporal coupling of the decisions making in energy operations.

The Sobradinho and Xingó basins compose the Northeastern sector. The Northeastern region of Brazil presents a well-defined annual precipitation cycle with two distinct periods: the rainy and dry season (Reboita et al. 2010). The wet period occurs between December and July, its main rainfall-producing system is the Intertropical Convergence Zone (Uvo & Nobre 1987) followed by secondary systems, including upper tropospheric cyclonic vortices, mesoscale convective systems and easterly wave disturbances (Reboita et al. 2010).

The Northern sector consists of the Serra da Mesa, Lajeado Tucurú, Belo Monte, Teles Pires, São Luiz do Tapajós, and Santo Antônio basins. The seasonality of the North Region is essentially identical to that of the Northeast Region. During the wet season, the streamflow from the Tucurú is extremely high, indicating that a part of the energy generated can be exported to another region. Rainfall amounts in this region are driven by local convection as part of the South America Monsoon System (Marengo et al. 2012).

The Southeastern/Midwestern region has the highest demand of the country and imports energy from other regions most of the year. The Basins of Emboicação, Nova
Ponte, Itumbiana, São Simão, Furnas, Água Vermelha, Nova Avanhandava, Porto Primavera, Rosana, Santa Cecília, and Três Marias form the South sector. Its main rainfall-producing system is the South Atlantic Convergence Zone, which is also part of the summer monsoon system in South America, and contributes to the majority of annual total rainfall (Carvalho et al. 2004).

The Southern Region is composed of the Itaipú, Salto Caxias, Itá and Dona Francisca basins. Its high variability is driven by the dependence of precipitation on stationary cold fronts (Rao et al. 2015). The demand of the Southeast/Midwest region is extremely dependent on this region.

**METHODOLOGY**

The methodology of this study is divided into three steps. First, we obtained the potential evapotranspiration from the models of the IPCC-AR5 using the Penman–Monteith method. Next, monthly precipitation time series were obtained from the models for the basins of interest using interpolation on a grid of pre-defined points in each basin for subsequent statistical correction for bias removal using the gamma distribution function. Finally, streamflow projections were computed by using the Soil Moisture Accounting Procedure (SMAP) hydrological model with input data from the evaporation and the bias-corrected precipitation. Thus, from the estimation of the evaporation, precipitation and flow variables, it is possible to quantify the sensitivity of the supply to the climate variability and change.

**Observational data**

The observational database was used as a comparison for future climate projections from the University of East Anglia/Climate Research Unit (CRU) (New et al. 2001). This dataset corresponds to monthly precipitation from 1901 and 1999 with a spatial resolution of 0.5 × 0.5 degrees for the continent (CRU TS 3.0).

**IPCC-AR5 models**

Monthly data from the IPCC-AR5 global models simulations are considered in this work. For this experiment, only models that had the maximum and minimum temperature of the air were used because the calculation of the potential evapotranspiration suggested in this work is only possible with this information. Several models from research centers worldwide that contributed to the AR5 report are listed in Table 1. These models were forced by observed concentrations of greenhouse gases during the 20th century (historical simulations). Additionally, sets of projection simulations with emission scenarios of these gases (representative concentration pathways, RCP) to 21st century were also performed (RCP simulations). These scenarios are related to total radiative forcing in 2100. This work analyzes the RCP4.5 and RCP8.5 projections, which assume an increase in radiate forcing of 4.5 and 8.5 W/m² by the end of the century relative to pre-industrial period.

**Scenarios for the 21st century**

The RCP4.5 and RCP8.5 scenarios are considered for the evaluation of the projections for the 21st century for the Brazilian hydropower sector. Ten models were considered for the RCP4.5 simulations, whereas for RCP8.5 projections 14 models were utilized.

The RCP4.5 scenario assumes that forcing stabilizes shortly after 2100 without overshooting the long-run radiative level of 4.5 W/m² (Clarke et al. 2007). These projections are consistent with low energy intensity, strong reforestation programs and decreasing use of agricultural lands, stringent climate policies, stable methane emissions and CO₂ emissions peaking around 2040 and reaching a target value of 650 ppm CO₂ equivalent in the second half of the 21st century (Van Vuuren et al. 2011).

The RCP8.5 scenario suggests a continuous growth in the population associated with slow technological development, resulting in accentuated carbon dioxide emissions. This scenario is considered the most pessimistic for the 21st century in terms of greenhouse gas emissions, and is consistent with a scenario lacking policy change to reduce emissions, rapid increase in methane emissions and heavy reliance on fossil fuels (Riahi et al. 2007).

**The SMAP model**

The SMAP rain-streamflow model (Lopes et al. 1982; Souza Filho & Porto 2003) is conceptual, deterministic and limited...
in its structure. This model is part of the wide family of hydrological models used for calculating soil moisture. Its structure is relatively simple, and its parameters are related to the average physical parameters of the basin.

The monthly version of SMAP contains four calibration parameters: soil saturation capacity (Sat); surface runoff parameter (PE); recharge coefficient (Crec), which is related to permeability of non-saturated soil zone; drawdown rate (K) of the level (Rsub) that generates baseflow (Eb) (see Figure 2). Two other state variables are set at initialization of the model: moisture soil rate (TUin) that determines the initial level of the reservoir in the soil and baseflow (EBin) that defines the initial value of the underground reservoir.

On monthly timescales, the model receives accumulated rainfall, whereas the most important factor is the quantitative character of average precipitation over the basin instead of its spatial distribution of each rainfall event. For this reason, its use in large basins is appropriate and the results correspond well to the average characteristics of the basins. The model calibration was performed for the period from September 1997 to August 2002 and validation from September 2002 to August 2007. The initial state variables of the soil water reservoirs TUin and EBin were manually set from the equivalence between modeled and observed streamflow at the first time step for each calibration period. The parameter K was estimated by the behavior of the observed hydrographs. The parameters Sat, Pes, and Crec were calibrated by the semiautomatic procedure by using the Solver tool from Microsoft Excel.
followed by manual refinement of trial and error. The aim of use Solver tool was to maximize the Nash–Sutcliffe efficiency coefficient, and the final manual adjustment was based on a comparison between observed and computed streamflow. This procedure was performed for each sub-basin and in the period of validation was required a Nash–Sutcliffe coefficients above 0.8.

This rain-streamflow model requires inputs of precipitation and evaporation rate on the basin. The monthly precipitation time series of the projections from IPCC-AR5 models was statistically corrected by the gamma cumulative distribution function (see below in the following subsection) based on historical experiment. The input evaporation is obtained using the Penman–Monteith method detailed in Allen et al. (1998) and adapted by Silveira et al. (2014).

**Statistical correction of the precipitation using gamma cumulative distribution function**

The statistical correction via gamma cumulative distribution function is performed on the monthly mean precipitation time series from the IPCC-AR5 models over the 24 basins of the Brazilian hydropower sector. For the gamma correction, an adjustment for bias removing was performed according to the following steps:

(a) A gamma distribution was fitted to the observed precipitation data for each basin to identify the parameters that represent the monthly frequency distribution of rainfall, saving the form and scale parameters;

(b) A gamma distribution was fitted to the precipitation time series from the IPCC models for the 20th century (historical simulations) for each basin, saving the form and scale parameters;

(c) Bias removing for the 20th century: for a given simulated precipitation, its probability of occurrence is obtained from the frequency distribution in the model simulation for the historical experiment (estimated at step b). The frequency distribution of observed precipitation was also looked up to identify the quantile with the same probability. The latter represents the bias removed precipitation, as shown in Figure 3.

(d) Bias removing for the 21st century: the bias removing process is the same described at step c, except the mapping procedure from the cumulative distribution function is performed in frequency distribution of the 20th century simulations.

To calculate the bias-removed precipitation two cumulative distribution functions (CDF) are used: (1) historical observed precipitation and (2) historical modeled precipitation from CMIP5 models. This approach is utilized to compute the monthly precipitation for the 20th and 21st centuries.

The probability mapping is selected for bias correction of the monthly IPCC-AR5 precipitation data, based on two CDF: (1) the historical IPCC-AR5 data and (2) the observed data (from 1950 to 1999) pooled by months. The correction of a given monthly model precipitation value is performed by mapping it from the corresponding pooled IPCC-AR5 models to underlying observed CDF, as described in Figure 3.

**RESULTS**

Figure 4 shows boxplots of annual mean streamflow, as percent anomaly, for IPCC-AR5 models for the periods 2010–2039, 2040–2069 and 2070–2098 from RCP4.5 and RCP8.5 scenarios in relation to the historical period of 1950–1999 for the main basins of the Brazilian hydropower sector. The models present greater spread in the third period.
Figure 4  |  Annual mean streamflow percent anomaly from IPCC-AR5 models for basins of the Brazilian hydropower sector under RCP 4.5 and RCP 8.5 scenarios.
at the end of the century for both scenarios, indicating more uncertainty for this period.

The global model projections suggest greater reductions of streamflow in RCP8.5 scenario than RCP4.5 for most of the basins in all periods; this characteristic could be associated with the sharp increase of air temperature in RCP8.5 and consequently an increase in the potential evapotranspiration over the 21st century.

The annual streamflow projections over the Southern sector show a slight increase in the periods 2010–2039 and 2040–2069 for both RCP scenarios (Figure 4(a)–4(d)). However, RCP8.5 presents greater positive anomalies than RCP4.5 (null median) at the end of the century (Figure 4(e) and 4(f)). This could be explained by the stabilization of greenhouse gases forcing from 2070 in the RCP4.5 scenarios.

For the Southeastern and Midwestern basins, most models suggest a reduction in annual streamflow values of approximately 10–20%, with negative median for all periods. They also project an increase in the spread of projected streamflow for the end of the 21st century (2070–2098) for most basins and both scenarios (Figure 4(e) and 4(f)).

In the Northeastern sector, in Xingó basin, the results indicate a large divergence from model projections and depict large uncertainty in the future streamflow (Figure 4) in accordance with previous studies that showed the spreading of precipitation projections over Northeast Brazil (e.g. Silveira et al. 2035). Nevertheless, in the Sobradinho basin, where the major Northeast hydropower generation is established, models project a reduction in annual streamflow with a median of about 15% in RCP4.5 and 20% in RCP8.5 for 2070–2098 (Figure 4).

There is convergence of the projections for the Northern sector in both scenarios, the models indicate a reduction in annual streamflow for all basins, which is emphasized in the mid-21st century (Figure 4(c) and 4(d)). For Belo Monte and Santo Antônio basins, the RCP8.5 projections show enhanced reduction in streamflow values, with the median reaching values below 40 and 30% at the end of the century, respectively. These projections may have a huge impact on the growth of the Brazilian electric sector, as this region represents the greatest energy potential of the country and currently is under exploitation in terms of power generation. The expansion of the SIN is planned considering the water availability in the present and major future investments in this region associated with the construction of a hydroelectric power plant.

In Figure 5, the impact on the average annual streamflow in the 21st century within three periods (2010–2039, 2040–2069 and 2070–2099) for the IPCC-AR5 models under RCP 4.5 scenario in relation to the 20th century (1950–1999) for the Furnas, Itaipú, Sobradinho, and Tucuruí basins is shown. They are considered the largest basins of the Brazilian hydropower system.

In Furnas and Itaipú, models diverge regarding the projected future annual streamflow (Figure 5(a) and 5(b)). The analyzed models converge in relation to the impact on Tucuruí and indicate that the streamflow tends to decrease in this basin. MIROC_ESM, BNU-ESM, IPSL-CM5A-LR, and CANESM2 show annual streamflow reductions for basins of the southeastern sector for all periods (Figure 5(d)). The final figure indicates an increase in annual streamflow of over 20% for the 21st century. While the HadGEM2-AO shows increased annual streamflow above 15% for the Furnas basin at the end of the century, IPSL-CM5A-MR projects decreased streamflow values in the two first periods. On the other hand, BCC-CSM1-1 shows favorable conditions of annual streamflow on the Furnas basin in the first period, normality in the second one, followed by another increase at the end of the century (Figure 5(b)).

BNU-ESM, CESM1-BGC and IPSL-CM5A-LR project decreasing streamflow on Itaipú basin (Figure 5(b)). In contrast, the results from MIROC5 and HadGEM2-AO indicate increases in annual streamflow over the Itaipú basin. The values reach levels greater than 15% of anomaly over Itaipú at the end of the century. CANESM2 and MIROC_C_ESM also indicate reductions lower than –10% in the Itaipú basin. Further, BCC-CSM1-1 also shows a reduction in streamflow, but with lower magnitudes.

For the Sobradinho basin, most models project a reduction in annual mean streamflow (Figure 5(c)), of which the MIROC-ESM and CanESM2 models show the greatest reductions. CanESM2 indicates a decrease of less than 30% for each period, while HadGEM2-AO indicates variation near normality in three periods. Moreover, MIROC5 projects increases of 10% in 2010–2039, and IPSL-CM5A-MR shows a reduction of 40% for 2070–2098.

For Tucuruí basin, most models indicate a strong impact on annual mean streamflow, with reductions greater than 10% over
the 21st century. The models differ only in magnitude of the reductions, as shown in Figure 5(d), reiterating that the decrease in streamflow over the Northern sector is the most likely.

Figure 6 shows the impact on the average annual flow in the 21st century in the three periods (2010–2039, 2040–2069 and 2070–2099) for the CMIP5 models for the RCP 8.5 scenario in relation to the 20th century (1950–1999) for the Itaipú, Furnas, Sobradinho and Tucuruí basins.

MIROC_ESM, BNU-ESM, IPSL-CM5A-LR and CANESM2, as well as the RCP 4.5 scenario, indicate reductions in major basins in the Southeast sector for all periods. These reductions are significantly greater in the RCP 8.5 scenario. In the Furnas basin, the values are higher than 20% in each analysis period (Figure 6(a)). Likewise, GFDL-ESM2M and GISS-E2-R (data unavailable for RCP 4.5 scenario) also indicate negative anomalies during the three periods for all basins of the Southeastern sector, including Furnas (not shown). The IPSL-CM5A-MR model shows reductions in annual mean streamflow in the period 2010–2039, followed by a likely increase in the periods 2040–2069 and 2070–2098. The bcc-csm1-1 model shows a slight increase in streamflow of this sector in the early and mid century, followed by a period with no change.

Most models project reductions in streamflow over Itaipú basin, however most also indicate increases for other basins of the Southern sector, as in Figure 4. GFDL-ESM2M and CanESM2 show reductions in all basins of that sector and in all periods. Further, MIROC5 also indicate an increase in streamflow over Itaipú, reaching values higher than 10% in the period 2070–2098.

For Sobradinho basin, most models indicate reductions in annual streamflow. GISS-E2-R and CanESM2 project negative anomalies around 30% in each period (Figure 6(c)). IPSL-CM5A-MR shows increases over Sobradinho in the
periods 2040–2069 and 2070–2098, indicating a negative trend over the 21st century.

As in the RCP4.5 scenario, the projections under the RCP8.5 scenario also show reductions in streamflow in the northern sector basins, as seen in Figures 4 and 6(d). IPSL-CM5A-LR and IPSL-CM5A-MR are the unique models that point out an increase in streamflow over the Tucuruí basins in the mid and late 21st century. The other models suggest reductions in annual streamflow of at least 10% in each basin for all periods.

**DISCUSSION**

As mentioned above under ‘National Interconnected System (SIN)’, the SIN is divided into four major subsystems. The North sector has a growing demand but has greater expandability. The Northeast sector has shown a growth in the consumption of hydropower and import part of it from the Southeast sector. The Southeast/Midwest has the largest supply and the largest power demand of the country, exporting to various regions and in recent years has received a greater contribution from the North sector. The South region has a well-defined seasonality and periodically imports (exports) power from (to) the Southeast/Midwest. The IPCC-AR5 models show different impacts on the mean annual streamflow according to the selected subsystems of SIN, its intensity is likely to increase in the South region, while in the North sector there is more likely a reduction. In the Northeast sector the models show huge divergence, indicating significant uncertainty of the impacts from climate change on this region. The results for the Northern sector agree with those obtained by Lucena et al. (2010) which obtain Brazil’s hydropower grid scenarios.
from IPCC-AR4 output and point out increasing vulnerabilities in Northern and Northeastern Brazil.

The reduction of water availability in the North and Southeast sectors, shown in this work, could lead to an increase in conflicts among multiple uses of water, a possible economic downturn due to water reduction for agriculture and industry as well as the shortage of cities. The expansion of the Brazilian hydropower for the Northern sector needs to consider a possible reduction of energy supply in the region in its Climate Change adaptation plan. In addition, Soito & Freitas (2011) mention issues arising from large projects such as inundation of tropical forest areas, intensification of disputes between farmers and indigenous populations, and biodiversity loss in the region. According to Prado et al. (2016), the policies for growth power in Brazil need to be revised, ensuring energy security in the long term under climate change. It is necessary to make efforts focused on improving energy efficiency and investments in wind and solar power. On the other hand, they point out that to ensure the economic growth with energetic security, construction of some hydroelectric projects is necessary, however they also note that plants in northern Brazil need to be postponed to avoid and minimize socioeconomic and environmental damage to the region.

**CONCLUSIONS**

We performed an analysis of streamflow projections on the main basins of the Brazilian hydropower system using data from the IPCC-AR5 models under RCP 8.5 and RCP 4.5 scenarios for the 21st century. Using historical simulations and observations, statistical bias correction of model projections was applied. Evapotranspiration was calculated by the Penman–Monteith method, and monthly rainfall data were obtained from IPCC-AR5 models, which were utilized as input variables into the rainfall-runoff SMAP model. The SMAP model was calibrated to the basins of interest considering the period from September 1997 to August 2002 and validated from September 2002 to August 2007. The set of calibrated SMAP parameters in each basin remained the same throughout the simulation of the streamflow over the 21st century.

Model projections of annual streamflow in the main basins of the Brazilian hydropower system diverge in magnitude. This divergence can be associated with the uncertainty in the meteorological phenomena solved by the coupled global models. However, most models indicate that the Brazilian hydropower system could suffer reductions in annual mean streamflow for most basins over the 21st century.

In the Southern sector, there are latitudinal contrasting signals regarding projected streamflow anomalies over those basins. Our results show increasing streamflow over the southernmost parts of Brazil and decreasing over the intersection between the Southern and Southeastern regions.

Reduction in annual mean streamflow is more likely to happen over the Southeastern/Midwestern sector. The models indicate decreases of about 10–20%. In the Northeast sector there is also a trend of reductions, but there is much less model agreement. This behavior is most evident over the Xingó basin, which presents major differences in annual mean streamflow anomalies in the early, mid and 21st century.

For the Northern sector, the models project small or no streamflow reductions from 2010 to 2039 under the RCP4.5 scenario. Under the RCP8.5 scenario, models indicate significant reductions in annual mean streamflow, especially in Belo Monte, differing in magnitude only.

The possible reduction in annual streamflow indicated by most models suggests that climate change, added to the growth of energy demand in Brazil, could lead to investments in non-renewable energy (fossil fuel derived) because of the risk of failing to meet electrical demand. This kind of action could create a positive global warming feedback and intensify the impacts on the whole earth system, and, consequently, over the country.

The divergences of the projections of the IPCC-AR5 global models demonstrate that there is a high level of uncertainty in these projections. This information defines ranges for possible future flow scenarios in the Brazilian hydro sector, and it can be used for the adoption of policies and management.

Obviously, projections with less uncertainty would be more interesting for decision makers. However, the projections of the IPCC-AR5 models for this region are not clear. Robust strategies must consider the uncertainties in the current level of knowledge.
REFERENCES


First received 10 February 2016; accepted in revised form 2 September 2016. Available online 31 October 2016