TIPPING POINTS IN CLIMATE MODELING: RISK OF AMAZON DIE BACK AND THE JMA-MRI-GSM0130. 60km - TL319L60 GLOBAL CLIMATE CHANGE PROJECTIONS

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1. INTRODUCTION

The Amazon region can be categorized as being at great risk from climate variability and change. The risk is not only due to projected climate change but also through synergistic interactions with existing threats not related to climate change, such as land clearance, forest fragmentation and fire. Some model projections (Betts et al. 2004, Cox et al, 2004, Oyama and Nobre 2004, and Sitch et al 2008) exhibit over the next several decades a risk of an abrupt and irreversible replacement of forests by savannah with large-scale loss of biodiversity and loss of livelihoods for people in the region. This process is referred as the Die-back of the Amazon, and it represents a process simulated by few climate models, where after reaching a "tipping point" in climate (CO2 concentration, air temperature) the forest stops behaving as a carbon sink and becomes a carbon source, and after that the forest enter in an state of collapse, being replaced by a savanna type vegetation ("savannization").

The main purpose of this study is to investigate and assess the risk associated with global warming and consequent climate change in the region and the feasibility of the die back of the Amazon and the savannization of the Amazon region, and to investigate if this possible scenario of future climate is depicted in the high resolution future climate change scenarios generated by the JAM-GSM0130-60km -TL319L60 climate model.

2. ON TIPPING POINTS AND CLIMATE CHANGE

Considering multiple equilibrium, persistence and climate, one could ask how does a system get from one equilibrium state to another? A shift in climate, due to natural or anthropogenic causes, can change the frequency and magnitude of disturbance. The change in a relative system stability might make a vegetation change irreversible from one state to another (e.g. Cox et al, 2001 and Oyama and Nobre 2004), but it might take a disturbance for the shift to occur. This leads to the concept of instability and to the idea of a "tipping pint" to be reached in order to the shift to occur.

In a complex system, "tipping point" represents a level, and if as a consequence of an imposed forcing (natural or anthropogenic) this level is over-passed, the system may suffer an abrupt change. In the case of the Amazon forest, if warming due to increase in concentrations of GHG (either natural or anthropogenic) is above 3.5 a 4 ^{o}C, there is a risk of a "tipping point" leading to savannization. A recent study by Sampaio et al. (2007) identified another "tipping point" when the deforested area reached 40-50% level, also leading also to savannization.

3. MODEL PROJECTIONS OF CLIMATE CHANGE IN THE AMAZON BASIN NA THE DIE BACK: PAST EXPERIENCES

Since the early 2000's new developments in atmosphere-ocean-biosphere coupled models by the Hadley Centre for Climate Research and Prediction in the UK, the Institute Pierre et Simon Laplace IPSL-University of Paris in France. Cox et al. (2000) ran the TRIFFID Dynamic Global Vegetation Model (DGVM) coupled with the low ocean resolution Hadley Centre General Circulation Model (GCM), HadCM3LC, in a fully interactive carbon cycle experiment for one future emission scenario (IS92a). They found a very large climate-carbon feedback, caused in particular by enhanced midlatitude soil decomposition in response to future warming, but also from 'dieback' of Amazon forests (Betts et al., 2004; Cox et al., 2004) in response to both future warming and drying. Dufresne et al. (2002) used the IPSL GCM and the simple land carbon cycle model SLAVE to perform a similar analysis and found a much smaller climate carbon feedback and therefore a very weak die back of Amazon forests.

Projections for future climate change from the Hadley Centre model have shown that an increase in the concentration of greenhouse gases in the atmosphere will produce changes in vegetation such that Amazonia will become a savanna by 2050's, and the region will become drier, warmer and most of the moisture coming from the tropical Atlantic, that normally produced rainfall in the region, will not find the environment to condensate above the savanna vegetation by 2050, and the moist air stream will move to southeastern South America producing more rainfall in those regions.

Therefore, after 2050, the Amazon Basin would behave as a "source of moisture and carbon" rather than a sink as in present day's climate (Cox *et al.,* 2000, 2004; Betts *et al.,* 2004; Huntingford *et al.,* 2004). This issue has been discussed also in the SPM of the IPCC WG2 (IPCC 2007), where it is suggested that by mid-

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century, increases in temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia. There is a risk of significant biodiversity loss through species extinction in the Amazon and in many areas of tropical Latin America.

In synergy with the changes in moisture and carbon fluxes due to changes in climate, consequence of the increase on air temperature and GHG gases concentration, the forest coverage is projected to diminish in the HadCM3 model projections (Betts et al. 2004). In fact, since 2020, and the changes are more intense after 2050, where the area covered by trees in northern and central Amazonia starts to decrease. These changes are cconsequence of simulated future climate change and not direct deforestation due to human activities. The drying and forest die-back starts in North-East of Amazonia and die-back spread south and west over time, with the major ecosystem impact over Amazonia and North-East Brazil. However, we must consider the uncertainties in these model simulations.

When using potential vegetation models using the IPCC AR4 climate change projections (Salazar et al. 2007), particularly those for the last half of the 21th Century, when warming is more intense, the different models simulate different types of potential vegetation, and in some of them, especially the HadCM3 and the MIROC, the Amazon vegetation seems to be replaced by savanna, while caatinga (Brazilian savanna) in Northeast Brazil would be replaced by arid type vegetation. In reality, it would imply that the climate of the future, warmer/drier or warmer/wetter as simulated from some models, would affect the water balance and produce soil and near surface air dryness by means of large evapotranspiration (induced by large positive temperature anomalies). So, this new climate would not support tropical rain forest, and new vegetation types would appear, similar to the current savanna type vegetation, that requires less water. New vegetation would imply new recycling rates and therefore, the feedbacks of the new vegetation system would reduce rainfall in the region, affecting the regional climate, in and outside Amazonia. It should be clear that warming is the main driver in the potential vegetation models.

When using dynamic vegetation models, all of them forced with the global conditions of the HadCM3 and with each one of the vegetation models representing the carbon cycle differently, the TRI simulates the strongest Amazon dieback, with woody vegetation replaced by herbaceous plants, while the LPJ simulates only a moderate Amazon dieback. It will be interesting to see the simulation of vegetation from the LPJ after being forced with the model output from the MRI-JMA global model.

In both experiments, savannization appears in here as a product of the vegetation model. However, the die back is generated mainly by the HadCM3 model, leading to savannization due to this die back. Both savannization processes are different in nature, and are dependent on the type of vegetation model used (dynamical or equilibrium-potential models), the way each model handles the carbon balance, and how the characteristics of vegetation are parameterized on the models.

The study by Cox et al (2008) suggest that intense droughts as in 2005 (Marengo et al. 2008a, b, Zeng et al. 2008) could be more frequent and intense in a warmer climate in the second half of the 21th century. This could exacerbate the risk of Die Back of the Amazon and savannization.

4. AMAZON DIE BACK IN THE HIGH RESOLUTION JAM-GSM0130-60km TL319L60 CLIMATE MODEL?.

A super-high resolution atmospheric general circulation model (AGCM) with the horizontal grid size of about 20 km has been developed for use in climate change study (Mizuta et al. 2006), and has been used for climate change projections under increasing atmospheric concentrations of greenhouse gases and aerosols (e.g. Kusunoki et al. 2006; Oouchi et al. 2006). The grid size of this model is several times higher than that previously used in climate model simulations. Kitoh and Kusunoki (2008) evaluated the East Asian summer climate in its present-day climate simulation in comparison with observations as well as lower resolution versions of the same model. Yun et al. (2008) and Kitoh et al. (2008) investigated future climate projections at the end of the 21st century with this 20-km mesh AGCM over East Asia, India and Middle East, respectively. The 20-km and 60-km model simulations are done by the Earth Simulator of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) located in Yokohama. The Earth Simulator was the fastest supercomputer in the world from 2002 to 2004 with capability of 35.86 TFLOPS. The analysis is made for the A1B scenario, using the 60 km version, referred as JAM-GSM0130. 60km -TL319L60.

Time series of some variables derived fro the long term runs of the JAM-GSM0130. 60km -TL319L60 for the central-northern Amazon region are shown in Fig. 1 for the period 1979-2099. The region was selected because its exhibits the die back of he Amazon in the HadCM3. The available time slices are 1979-2005 (assumed as present climate), 2015-39 and 2075-99. The models show a warming of about 1 ^{o}C in the middle of the century and up to 3 ^{o}C at the end of the century, and are similar to that projected by the HadCM3. In terms of precipitation, there is a strong year-to-year variability until the end of the XXI Century and by the end of the century rain seems to increase in the region, alternating dry and wet years, and possible extreme rainfall events may occur significantly in the region. The relative humidity signal is clear, it will get drier in the region especially by 2099, on the order of 1.5% lower than in the present, but this does not mean that Amazon´s climate would become semi arid or arid future

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climate in Amazonia. Because of higher temperatures and low humidity, transpiration from the canopy and grass is much higher in the future as compared to the present. The water vapor flux shows large increases, mainly due to an intensification of the winds in a warmer climate, and this flux may indicate larger moisture transport from northern to southern Amazon. This would be consistent with the tendency for rainfall extremes projected by southern Brazil in the future, as shown by Marengo et al (2008) from the donwscaling of the HadCM3 future climate change projections, both in western Amazonia and southeastern and southern Brazil.

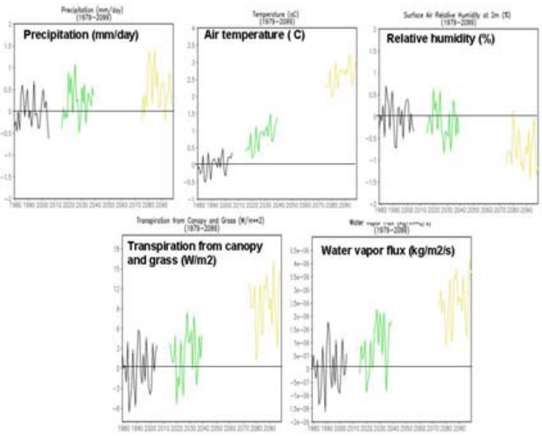

Figure 1. Time series o precipitation, air temperature, relative humidity, transpiration from canopy and grass and water vapor flux for 1979-2099 for the A1 scenario, derived from the JAM-GSM0130-60km TL319L60 climate model for Amazonia.

Projections of rainfall show an increase in rainfall in the Amazon region, especially in the central and eastern Amazonia, by about 5-15%, especially in 2075-2099 (Fig. 2). This is in contrast of the projections from the HadCM3 that shows rainfall reductions in eastern Amazonia by the end of the XXI Century in central and eastern Amazonia. However, both models show rainfall increases in western Amazonia, particularly during autumn and winter. This increase seems to be consistent with the increase frequency of intense rainfall events in the future, as shown in the downscaling of the HadAM3P using the HadRM3-PRECIS (Marengo et al. 2008). Therefore, this results imply that the regional precipitation features of the western Amazonia will increase in disagree with most of the global models and downscaled projections that show the rainfall anomalies decrease in western Amazonia. However, this can be interpreted in the form of reductions of precipitation in the west Amazon in a future warmer climate, and that the rainfall that still may fall on the region would be in the form of intense rainfall events (Fig. 2).

Projections of air temperature (Fig. 3) are consistent with those of the IPCC AR4 models, with increases of about 1-1.5 °C in 2015-2039 and about 3-3.5 °C in 2075-2099. The warming is much higher in southern Amazonia, where less rainfall and large reductions in relative humidity are consistent with temperatures increases of the order of 4 °C. Projections of transpiration from forest and grass show increases in a warmer and drier climate, especially in southern Amazonia and extending into the entire Amazonia during spring and summer during the 2075-2099 period, by about 12 W/m2 (Fig. 4).

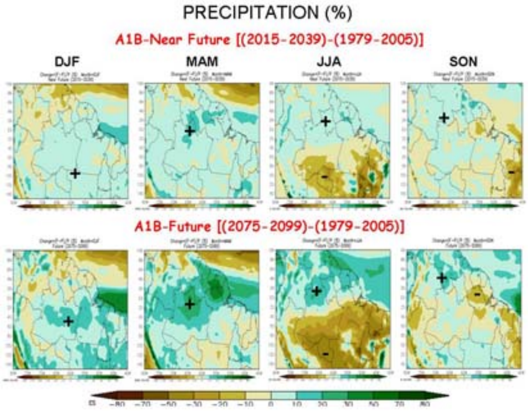

Figure 2. Seasonal projections of precipitation (%) for 2015-2039 and 2075-2099 relative to the present (1979-2005) in tropical South America, derived from the JAM-GSM0130-60km TL319L60 climate model for the A1B scenario.

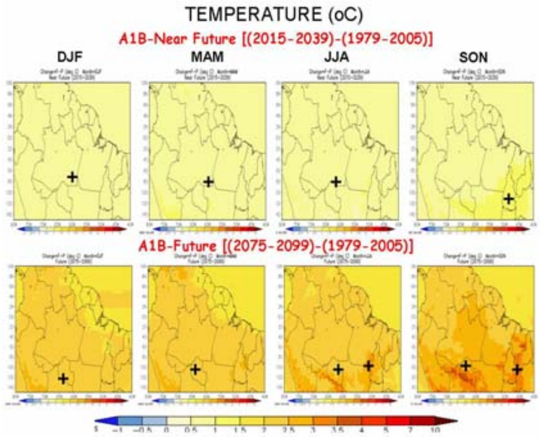

Figure 3. Seasonal projections of air temperature (°C) for 2015-2039 and 2075-2099 relative to the present (1979-2005) in tropical South America, derived from the JAM-GSM0130-60km TL319L60 climate model for the A1B scenario.

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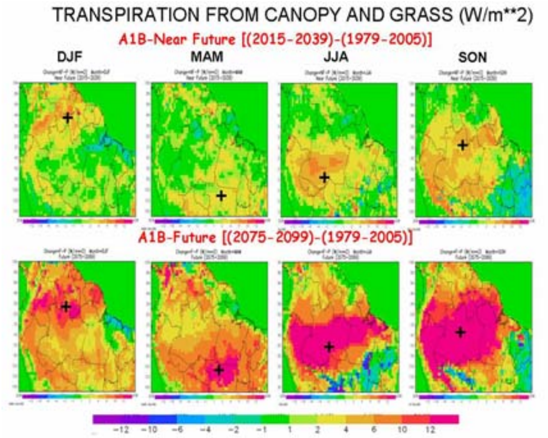

Figure 4. Seasonal projections of transpiration from canopy and grass (W/m2) for 2015-2039 and 2075-2099 relative to the present (1979-2005) in tropical South America, derived from the JAM-GSM0130-60km TL319L60 climate model for the A1B scenario.

5. FINAL REMARKS

For the Amazon forest, if warming due to increase in concentrations of CO2 (either natural or anthropogenic) above 700 ppm and the projected warming is above 3.5 a 4 ^{o}C, there is a risk of a "tipping point" leading to the Amazon Die Back, that according to climate models may occur during 2040-50, as shown by Cox et al (2000, 2004). However, this is a concept used in climate modeling, and should consider model uncertainties, and so far only two models show this tipping point that may lead to the die back, and these models are the HadCM3 of the UK Hadley Centre and IPSL from France. However, when analyzing the model output of the high resolution JMA climate model, we can not detect the die back of the Amazon as shown in the HadCM3 model. The non availability of carbon fluxes in the JMA model data sets does not allow us to detect the possible change in nature of the carbon fluxes, from a sink behavior in the tropical rain forest to the source behavior after the collapse of the forest after 2040-2060.

When using potential vegetation models using the IPCC AR4 climate change projections, particularly those for the last half of the 21th Century, when warming is more intense, the different models simulate different types of potential vegetation, and in some of them, especially the HadCM3 and the MIROC, the Amazon vegetation seems to be replaced by savanna, while caatinga (Brazilian savanna) in Northeast Brazil would be replaced by arid type vegetation. In reality, it would imply that the climate of the future, warmer/drier or warmer/wetter as simulated from some models, would affect the water balance and produce soil and near surface air dryness by means of large evapotranspiration (induced by large positive temperature anomalies). So, this new climate would not support tropical rain forest, and new vegetation types would appear, similar to the current savanna type vegetation, that requires less water. New vegetation would imply new recycling rates and therefore, the feedbacks of the new vegetation system would reduce rainfall in the region, affecting the regional climate, in and outside Amazonia. It should be clear that warming is the main driver in the potential vegetation models.

When using dynamic vegetation models, all of them forced with the global conditions of the HadCM3 and with each one of the vegetation models representing the carbon cycle differently, the TRIFFID simulates the strongest Amazon dieback, with woody vegetation replaced by herbaceous plants, while the LPJ model from Germany simulates only a moderate Amazon dieback. It will be interesting to see the simulation of vegetation from the LPJ after being forced with the model output from the MRI-JMA global model.

In both experiments, savannization appears in here as a product of the vegetation model. However, the die back is generated mainly by the HadCM3 model, leading to savannization due to this die back. Both savannization processes are different in nature, and are dependent on the type of vegetation model used (dynamical or equilibrium-potential models), the way each model handles the carbon balance, and how the characteristics of vegetation are parameterized on the models.

As a process, savannization generated in climate models is still uncertain, but as a product of climate change scenarios combined with potential vegetation models, savannization is a consequence of climate change. These are projections only, and hardly reflect a definitive outcome of climate change and impacts in Amazonia. A simplified mechanism for Amazon die back, the possible savannization and the relevant consequences on regional climate are shown on Fig. 5.

In any case, synergistic interactions with the effects of forest clearing and fragmentation could flip the ecosystems of this region from forest to savanna, with large impacts in biodiversity, human livelihoods, and economic development.

When analyzing the model output of the high resolution JMA climate model, we can not detect the die back of the Amazon as shown in the HadCM3 model. The non availability of carbon fluxes in the JMA model data sets does not allow us to detect the possible change in nature of the carbon fluxes, from a sink behavior in the tropical rain forest to the source behavior after the collapse of the forest after 2040-2060. In sum, if we think in the Amazon die back as depicted by the HadCM3 model, we conclude that in the climate change projection produced by the JMA model it is hard to see something similar to the Amazon die Back. The JAM model shows increases in temperature and transpiration, and reduction in atmospheric humidity, mainly in south-central Amazonia, while similar changes are noticed over northwestern Amazonia in the HadCM3 attributed to the dieback. In the later time slice 2075-99

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A1B scenario temperature increases by 2.5-3.5 C, and relative humidity drops by about 1-2%, and transpiration increase by 9-12 W/m2 in southern Amazonia. We do not know if that would produce a risk of a "tipping point" in the southern Amazon region in the JAM-GSM0130-60km TL319L60 climate model.

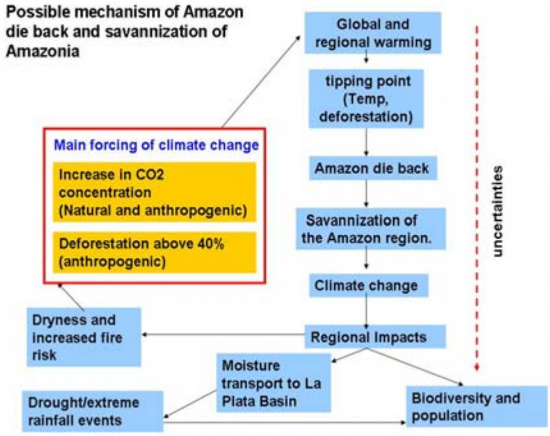

Figure 5. Simplified mechanism of the Amazon die back and possible impacts on regional climate

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