Autor: Philip M. Fearnside
National Institute for Reseach in Amazonia (INPA),
C.P. 478, 69.011-970 Manaus-Amazonas, Brazil, pmfearn@inpa.gov.br

Abstract

Climate and Changes in Brazilian Amazonia

Philip M. Fearnside
National institute for Research in Amazonia (INPA)
C.P. 478
69.011-970 Manaus-Amazonas
Brazil
pmfearn@inpa.gov.br

Global warming is caused by greenhouse gases that have been increasing beyond their "natural" levels in the atmosphere due to human activities over the past 200 years. About 70% of the total emission of these gases, and therefore of the warming that is already underway, is due to burning of fossil fuels such as coal, oil and natural gas. In Brazil, however, more than three-fourths of the emission comes from Amazonian deforestation. This fact represents an opportunity for Brazil because it would be much easier for Brazil to substantially reduce its emissions than would be the case for many other countries. Mitigation of global warming through reduction of deforestation represents an economic activity with much more potential value per hectare than does conversion of forest to pasture or to other uses. At the same time, Brazil is one of the countries that has the most to lose from continued global warming, including the possibility of losing the Amazonian rainforest itself. The forest faces serious threats to its survival due to climate changes that are projected to make Amazonia hotter and drier. This effect is much more intense in global climate simulations using models that include the connection between warming of the water in the Pacific Ocean and the occurrence of the El Niño phenomenon. Such events as the fires in Roraima in 1997/1998 and in 2003 indicate that the connection with El Niño is real. The impacts are worse in models that include biospheric feedbacks, with the death of the forest and the heating of the soil leading to carbon emissions that further warm the climate and kill more forest. Another factor that reinforces the same trend is the direct effect of deforestation, which reduces the recycling of water in the region and makes the climate even drier and hotter. These processes can cause the death of vast areas of forest, beginning on the eastern side of the region. Whether a scenario of this type becomes reality or not depends on human decisions concerning the limitation of greenhouse-gas emissions, both from fossil-fuel combustion and from continued deforestation.

Keywords: Amazonia, Carbon, Deforestation, El Niño, Global warming, Greenhouse effect, Water cycling

CLIMATE MODEL PREDICTIONS

Different climate models have produced a very wide range of results for future climate in Amazonia. One model in particular, the Hadley Center model of the U.K. Meteorological Office, indicates a catastrophic drying and warming in Amazonia, resulting in death of almost all of the forest by 2080 (Cox *et al*., 2000, 2004). Several other models indicate significant drying in Amazonia, including the NCAR model from the US National Center for Atmospheric Research (NCAR) and the ECHAM model from the Max Planck Institute in Germany. Some models, such as the CSIRO model from Australia indicate no change in Amazonia, while one model, from the Geophysical Fluid Dynamics Laboratory (GFDL) in the USA, even indicates more rain in Amazonia (see Kundzewicz *et al*., 2007, p. 183). Given these contradictory results, some thought is warranted in evaluating the different models for the specific purpose of representing future climate in Amazonia, as well as how to interpret the policy significance of the remaining uncertainty.

The Hadley Center's catastrophic results were first published in *Nature* in 2000. That eight years of intensive work by various research groups has failed to identify a specific error that would invalidate this result is extremely worrisome, the comparatively less-catastrophic outcomes of other models notwithstanding. Some comfort can be derived from the fact that the Hadley model indicates a present-day climate in Amazonia that is hotter and drier than the real climate is today (Cândido *et al*., 2007). This means that the numerical values for temperature and drought in the simulated future climate are probably also exaggerated. However, the simulated future climate is so far beyond the limits of tolerance of Amazonian forest trees that massive die-off would occur even if the changes are less extreme than the simulations indicate.

EL NIÑO AND GLOBAL WARMING

The central question with respect to the Hadley Center model's results for Amazonia is whether its representation of the effects of El Niño is correct. In the Hadley model, continued global warming leads the climate system to lock into a "permanent El Niño," resulting in severe drought and heat in Amazonia. Only part of this sequence is shown by other models.

The Intergovernmental Panel on Climate Change (IPCC) noted in its 1995 Second Assessment Report that the frequency of El Niño events since 1976 has been much higher than was the case before that year, a highly significant statistical difference (Nicholls *et al,* 1996, p. 165). Recent events, such as the El Niños of 1997 and 2003, had substantial impacts in Amazonia.

The IPCC's 2007 Fourth Assessment Report (AR-4) concludes that continued global warming would lead to formation of "El Niño-like conditions" (Meehl *et al*., 2007, p. 779). This refers to the warmer surface waters in the Pacific Ocean that provide the trigger for El Niño. However, the IPCC report notes that the various climate models do not yet agree on a link between global warming and El Niño itself (Meehl *et al*., 2007, p. 780). This refers to the droughts and floods at different locations around the world.

Unfortunately, we know directly that El Niño-like conditions lead to drought and forest fires in Amazonia; this is not a conclusion that depends on the results of climate models. The El Niño droughts in 1982, 1997 and 2003 provide examples that most people in Amazonia remember. The graph of sea-surface temperatures in the Pacific (Hansen *et al.*, 2006; McPhaden *et al.*, 2006) is a striking portrait of drought events in Amazonia. The illustration used by Al Gore in his film “An Inconvenient Truth” is highly relevant: just as the continents of Africa and South America fit together too perfectly to be a coincidence, the graphs of atmospheric CO_2 and of global temperature mirror each other so well that there must be a relatioship between the two. The same applies to sea-surface temperature in the Pacific and Amazonian droughts. What this means is that a simple tabulation of the results of different climate models is not sufficient. If a model shows the surface water warming in the Pacific but nothing happening in Amazonia, then it means there is something missing from the model, not that we are safer in Amazonia.

El Niño is a phenomenon that is difficult to represent in global circulation models (GCMs), in part because of the coarse spatial resolution that is dictated by the processing capacity of most supercomputers today. It is disquieting, however, that the massive Earth Simulator in Yokohama, Japan also produces catastrophic results when programmed with climate physics similar to the Hadley Center model. Peak temperatures in central Amazonia in excess of 50°C are commonplace after 2050 in business-as-usual scenarios. The Earth Simulator represents the earth in 10 km × 10 km grid cells (pixels), whereas other computers running GCMs use grid cells of approximately 300 km × 300 km.

El Niño produces a pattern of floods and droughts around the world, with heavy rain on the coast of Peru, drought in northern Amazonia (for example the Great Roraima Fire of 1997-1998), floods in Santa Catarina, drought in Borneo (which also provoked fires in 1997-1998), drought in Ethiopia (which killed over 200,000 people in 1982) and heat in Europe (which killed approximately 40,000 people in 2003). Getting a climate model to represent all of these effects simultaneously when the Pacific water warms is a difficult task, and this difficulty explains why the different models currently fail to agree with each other. However, from the point of view of Amazonian drought, we only need to represent this part of the global pattern correctly – not the outcome at all of the other locations that are also affected by El Niño. In this, the Hadley Center model has done the best in reproducing the connection between warm water in the Pacific (*i.e.*, “El Niño-like conditions”) and Amazonian droughts. Of 21 models tested for this ability by the_ Coupled Model Intercomparison Project (CMIP2), the Hadley Center model was ranked number one (see Cox *et al*., 2004).

SAVANNIZATION OF AMAZONIA

It should be stressed that loss of large areas of Amazonian forest to climate change does not depend on the Hadley Center model being the best representation of future climate. Salazar *et al*. (2007) tested 15 different models for their implications regarding “savannization” in Amazonia. Over 75% of the models indicated a swath of what is now forest along the eastern and southern edges of the region becoming climatically inappropriate for forest by 2100 – leading to replacement of trees with some other vegetation loosely termed as “savanna.” At least 25% of the models indicate such a change in all of the area east of Manaus. The Hadley Center model, of course, would show the whole of Brazil’s Amazon forest succumbing in this time frame.

The various climate models, including the Hadley Center model, omit several critical processes that can be expected to make real events even more disastrous than those indicated by the models. The models only show the effects of global warming, whereas the Amazon forest is subject to other stressors. The most obvious is direct deforestation, with trees being cut down with chainsaws rather than dying of thirst. This not only eliminates the trees that are directly felled but also contributes to other climatic changes that reinforce the same trends to hotter and drier climate over the remainder of the forest, thereby contributing to the demise of the forest as a whole. Loss of trees reduces evapotranspiration, thereby reducing rainfall over the rest of the forest (eg, Lean *et al*., 1996). Two recent simulations indicate that continued forest loss would lead to hotter and drier climate over the remainder of the region (Foley *et al*., 2007; Sampaio *et al*., 2007). If deforestation follows the projected spatial patterns, a sharp drop in dry-season rainfall occurs after deforestation reaches 40% (Sampaio *et al*., 2007). As of 2007 deforestation had removed 18% of the original forest in Brazilian Amazonia (Brazil, INPE, 2007). The dry season is the critical period of the year when trees can die from lack of water.

Forest fires represent a major threat to Amazonian forests that is omitted from GCMs such as the Hadley Center model. Especially in El-Niño years, fires can move through the forest understory killing large trees. In the Great Roraima Fire of 1997-1998, an estimated 11-13,000 km^2 of forest burned (Barbosa and Fearnside, 1999). Large areas of forest also burned in Pará (Alencar *et al*., 2004; Cochrane *et al.*, 1999). The trees killed by the fires provide fuel for subsequent fires, leading to a positive feedback process that destroys the forest completely over a period of several years (eg, Nepstad *et al*., 2001). Since climate change can be expected to increase the frequency and severity of fires, the forest could be killed more quickly than the models indicate. A recent study indicates substantial forest loss to fire by 2030 under the optimistic assumption that the climate patterns of the last 10 years continue unchanged (Nepstad *et al*., 2007).

The Hadley Center model was the first to include "biotic feedbacks," where carbon released from forest dieback and from warming of the soil is included in calculating future global warming, which in turn leads to greater release of terrestrial biospheric carbon. With the Hadley Center model, the average global temperature in 2100 is 38% higher if the biotic feedbacks are included than if they are excluded. Because only about one-fifth of the roughly 20 models used by the IPCC AR-4 had the capacity to include biotic feedbacks, this portion of all of the models was deactivated in the runs used for the IPCC's estimates of global temperature (*i.e*., 4°C increase over pre-industrial temperature by 2100 under the "A-2" scenario that best approximates current trends). Undoubtedly future IPCC assessments will incorporate these feedbacks, in which Amazonia plays a major role.

RISK AND UNCERTAINTY

The predictions of future climate obviously indicate considerable risk for Amazonia, as well as substantial uncertainty. How these two factors are incorporated into policy decisions can make a great difference in the actions taken and, consequently, in whether Amazonian forest continues to survive.

Uncertainty refers to the lack of knowledge about parameter values or about what the true probabilities are that different outcomes will occur. The existence of uncertainty has repeatedly been used to avoid making difficult decisions on climate change. Most notorious has been the traditional refusal of US president George W. Bush to recognize the existence of global warming, with the result that he refuses to commit to specific reductions in emissions. Brazil took a similar position when the IPCC report on climate impacts was approved in Brussels in April 2007, making an unsuccessful attempt to have mention of savannization in Amazonia deleted from the report's summary for policy makers (*Folha de São Paulo*, 2007). As long as governments refuse to admit the existence of a problem there is no need for serious actions to avoid the problem.

In the case of Brazil's contribution to global warming from deforestation, there has been a long history of official estimates that understate or minimize its magnitude and importance (see Fearnside, 1997, 2000). Uncertainty is often used to justify omissions. For example, the official estimate of Brazil's emissions in the National Communication submitted to the United Nations Framework Convention on Climate Change (UNFCCC) in December 2004 does not count the carbon in the roots of the trees on grounds of uncertainty (Brazil, MCT, 2004, p. 148). This alone would increase emissions by approximately 20% in the case of Amazon forest, and by more than double in the case of *cerrado* (central Brazilian savanna). A series of factors are either omitted completely or for which improbably optimistic values are used.

Most of what is discussed regarding climate change, including the IPCC reports, is based exclusively on average or "most likely" estimates. The most likely case means that there is a 50% probability of the real value being equal to or less than the estimate. However, the other side of this coin is that there is a 50% chance of the real value being higher – perhaps much higher. What should the response to this uncertainty be in terms of policy? The precautionary principle would indicate that policies should be conservative in order to assure that critical thresholds are not surpassed. In other words, less deforestation should be allowed to take place and global greenhouse-gas emissions should be held at lower levels than would be indicated by "average" or "most likely" values.

In addition to the uncertainty associated with climate in Amazonia, there is considerable uncertainty concerning the global climate system. A key factor determining the severity of global-warming impacts is the "climate sensitivity," or the amount by which global mean equilibrium temperature would increase in response to a doubling of the pre-industrial CO_2 concentration of 280 ppmv. Under business-as-usual scenarios this doubling is expected to occur by 2070. The "most likely" value for climate sensitivity is approximately 3°C, but there is a 50% chance that the true value is higher than this and the possibility that it is much higher is significant. A value of 6.2°C would need to be used in order to have 95% certainty that the real value is included (Hegerl *et al*., 2006). Projections such as a 4°C rise in global mean temperature over pre-industrial levels by 2100 are based on a climate sensitivity of about 3°C. This is also true for the various simulations of savannization in Amazonia.

The danger of using average or "most likely" values in decision making about catastrophic events can be illustrated by a simple example. Imagine that someone who lives in an apartment building were to ask an engineer if the building will collapse and fall to the ground like the Palace-II building that collapsed in Rio de Janeiro in 1998. If the engineer were to answer that it is "most likely" that the building will continue standing, would the worried resident be satisfied? Clearly the answer is no, since there may be, for example, a 51% chance that the building will continue standing but a 49% chance that it will collapse! The person who lives in the building, for whom a collapse would be catastrophic, would surely want a probability of much more than 99% that the building will stay standing. The more catastrophic the outcome, the more assurance is required that the catastrophe will not occur. Events such as a die-off of the Amazon forest would be catastrophic for Brazil, and Brazil should therefore be demanding deeper cuts in total global emissions. However, Brazil's positions have instead been a refusal to specify a limit on global emissions.

The UNFCCC, signed in 1992 in Rio de Janeiro at the ECO-92 or UNCED meeting, has as its objective stabilizing atmospheric greenhouse-gas concentrations at levels that would avoid "dangerous" interference with the global climate system (UNFCCC, 1992, Article 2). Negotiations are now underway to define "dangerous" in terms of a maximum concentration of CO_2-equivalent greenhouse gases or as its corresponding maximum global temperature rise. The European Union has adopted 2°C above pre-industrial average global temperature as the definition of "dangerous." This approximately corresponds to the limits of tolerance of the Amazon forest. Why, then, does Brazil continue to refuse to support defining 2°C as "dangerous"? The answer, of course, is that adopting a limit means that all countries, including Brazil, will have to make real reductions in their emissions. A global limit on concentration or on temperature means that <u>all</u> emissions have to stay within the limit, regardless of whether they are anthropogenic or natural, whether they are intentional or accidental, and whether they come from rich or poor countries.

Brazil should be leading the way in making commitments to reducing emissions because it is one of the countries most heavily affected by projected climate change and because of its virtually unique position in having the bulk of its emissions coming from deforestation, which contributes little to the economy. Instead, Brazil's foreign ministry has steadfastly refused to take on any binding international commitment to reduce emissions – or even to set internal targets for emissions reduction. The government's repeated claims that deforestation is under control should translate into willingness to commit to reducing deforestation and its associated emissions. While deforestation is less "under control" than implied by the drop in deforestation rate by 50% between 2004 and 2007, much could be done to reduce clearing if this were given the priority it deserves (*eg*, Fearnside, 2005). The cost of such actions could be easily met by the value of the emissions that would be avoided were deforestation reduced and were Brazil willing to sell carbon credits from this source that would be valid for international commitments (*eg,* Fearnside, 2006). The Brazilian contributions at the UNFCCC conference of the parties in Nairobi in 2006 and in Bali in 2007 have at least opened the door to discussion of this previously taboo subject. Because the climate system takes decades to respond to emissions reductions there is no time to waste if the threat to the Amazon forest posed by climate change is to be contained.

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