UNEP

UNEP Global Environmental Alert Service (GEAS)

Taking the pulse of the planet: connecting science with policy

Website: www.unep.org/geas E-mail: geas@unep.org

IN THIS ISSUE OCTOBER 2011

Thematic Focus: Ecosystem Management, Climate Change

Drought, Fire and Deforestation in the Amazon: Feedbacks, Uncertainty and the Precautionary Approach

The Amazon is widely considered to be one of the world's most important natural areas and a high priority for conservation. Its importance to the global carbon cycle makes understanding its response to drought essential to modeling of the planet's future.

Drought, Fire and Deforestation in the Amazon: Feedbacks, Uncertainty and the Precautionary Approach

Why is this important?

A devastating drought across much of the Amazon region in late 2010 follows only 5 years after a drought which had previously been described as a "once-in-a-century" event (*1, 2*). More widespread and severe, the 2010 drought was accompanied by increased rates of fire, and research shows it to have decreased vegetation productivity and likely increased tree mortality (*3, 4*). In addition, re-evaluation of data from the 2005 drought has called into question some earlier research which had suggested that the Amazon forests showed greater than expected resiliency during that drought event (*5-9*). The importance of the Amazon to the global carbon cycle makes understanding its response to drought essential to modeling of the planet's future.

Figure 1: An aerial photo in central Amazonas State shows sand bars exposed by the record low water levels. © Rodrigo Baléia / Greenpeace

Figure 2: Record low water levels during the 2010 drought exposed sand bars along the river banks in Central Amazonas State (pink areas in the 2010 satellite image).

The Amazon is widely considered to be one of the world's most important natural areas and a high priority for conservation. The Amazon forest is the largest intact tropical forest landscape on the planet (*10*). Its biodiversity includes more than 40 000 plant species, 427 mammals, 1 294 birds, 378 reptiles, 427 amphibians and 3 000 fish species (*11*). Its enormous scale makes it one of the components in regional and global climate processes (*12-15*). Perhaps most important, is the Amazon Forest's widely acknowledged (if not yet definitively quantified) pivotal role in the global carbon cycle which makes its status a major factor in climate models (*16-21*).

In spite of its global and regional importance, the cumulative area deforested in the Brazilian Amazon since the early 1970s is estimated to be roughly equal to the area of France (*22*). The rate of loss has slowed over the past several years (*23*), but losses continue as new highways, roads, logging projects, fire leakage and settlement continue to fragment and degrade the forest (*24*). However, while limiting forest loss in the Amazon presents one of the best opportunities for decreasing anthropogenic carbon emissions (*12, 25, 14*) there is concern among some experts that a "tipping point" is already being approached that could lead to abrupt replacement of parts of the Amazon Rainforest with a more drought- and fire-adapted, savanna-like ecosystem (*26, 14, 4, 27, 15*). These two unusual droughts and what scientists are learning about them will help advance understanding of the Amazon forest and its interactions with climate. Among the most pressing areas of research is study of the feedbacks among several processes including climate change, increased fire and forest loss.

Two Droughts in Five Years

Analysis of the 2010 drought is ongoing; however, early results indicate that it was more widespread and severe than the 2005 drought (*3, 4*). The area of the Amazon with a rainfall deficit in 2010 was more than 1.6 times the size of the area affected in 2005 (Figure 4, next page) (*3, 4*). Several points along the Amazon River dropped to their lowest levels in 109 years of recordkeeping (Figure 1 and 2) (*3*).

The 2005 and 2010 droughts both coincided with higher than normal tropical North Atlantic sea surface temperatures (SST) which have been linked to the 2005 Amazon drought and are suspected in the 2010 drought (*2, 28, 4*). The 2010 drought also coincided with a La Niña event—associated with cooler than normal sea surface temperatures in the equatorial Pacific (*29*). While La Niña events are generally associated

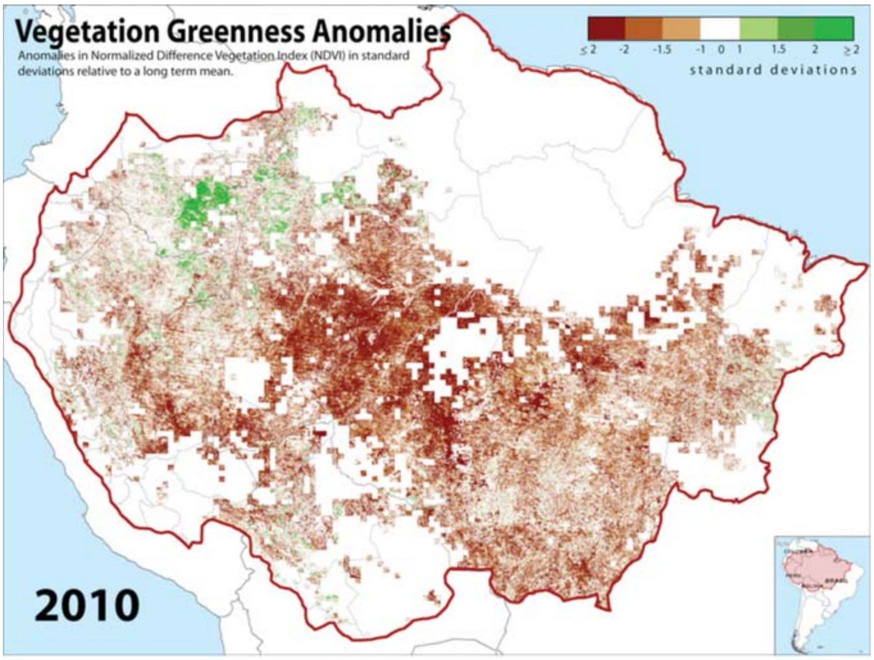


Figure 3: A map of anomalies in the Normalized Difference Vegetation Index (NDVI) during the 2010 drought shows the extent of the drought's impact. Red indicates areas that are 2 or more standard deviations below average dry season NDVI values. Redrawn by UNEP-GRID Sioux Falls from Xu and others 2010.

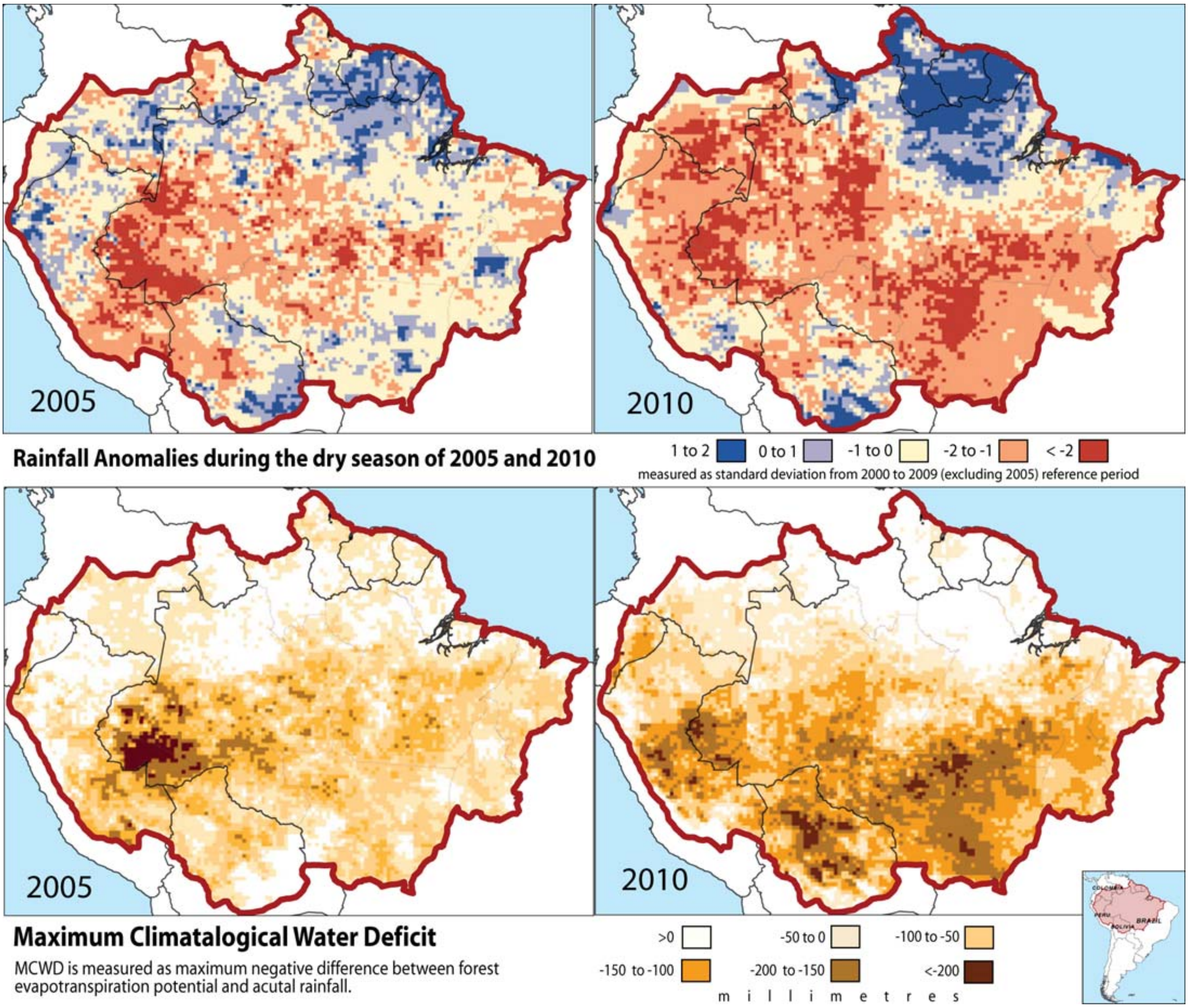


Figure 4: Top left and top right: Rainfall anomalies calculated from NASA's Tropical Rainfall Measuring Mission (TRMM) data show the spatial extent of the 2005 and 2010 droughts. Based on the size of the area that experienced negative rainfall anomalies, the 2010 drought was over 1.6 times larger than the 2005 drought. Bottom left and right: Maximum climatological water deficit (MCWD) is an alternative measure of drought intensity and has been shown to correlate with Amazon forest tree mortality. Based on this relationship it is believed that the Amazon forest lost roughly 38 percent more biomass from the 2010 drought than was lost to the 2005 drought. Graphic redrawn by UNEP/GRID Sioux Falls from Lewis and others 2011.

with wetter than normal weather over the northern parts of the Amazon Basin, including some areas impacted by the 2010 drought, it has also been associated with drying over much of the southern half of the basin (*30*). It seems likely that the 2010 drought was influenced by both Pacific and Atlantic SSTs. Furthermore, both droughts are consistent with climate modeling that projects drying of the Amazon (*31*), although researchers concede that significant uncertainty still remains in these linkages (*32*).

To quantify the impact of the drought, Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI), two satellite metrics of vegetation's photosynthetic activity, were compared for drought years and non-drought years (Figure 3, previous page) (*3*). The comparison showed lowered "greenness" across four times as much area in 2010 compared to the 2005 drought, suggesting that the 2010 drought had a more widespread and damaging impact on the forest (*3*). The research showed these declines in more than half of the drought-stricken area and found that, unlike 2005, the declines in "greenness" persisted beyond the end of the dry season (*3*).

An analysis of the forest's response to the 2005 drought estimated that the total loss of aboveground biomass translated to between 1.2 to 1.6 petagrams of carbon (*7*) (1 petagram = 1000 million tonnes). The research by Lewis and others (2011) extrapolated from that observed relationship between drought and biomass loss, to the 2010 drought, and gives a "first approximation" of carbon lost as 2.2 petagrams from loss of biomass (*4*). The Lewis article suggests that continued drought events would turn the Amazon from a carbon sink to a carbon source. Similarly, the article by Xu and others states that, "Overall, the widespread loss of photosynthetic capacity of Amazonian vegetation due to the 2010 drought may represent a significant perturbation to the global carbon cycle."

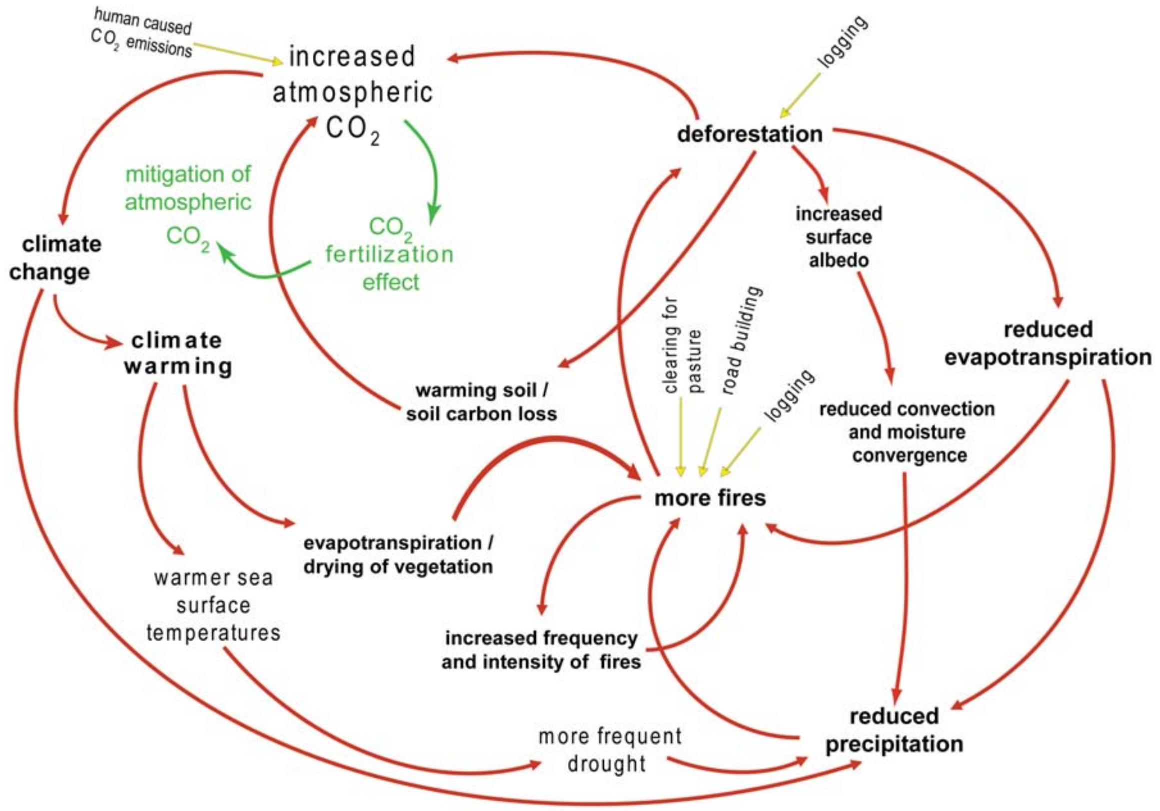
Feedback Loops and Uncertainty

Several feedback relationships linking climate, ecosystems and human activities have been identified, and to a degree quantified (*33*, *34*, *26*, *12*, *35*). The complexity of their interaction, however, makes predicting the future impact on changes in Amazonian forests status uncertain in both time and scale. Figure 5 schematically illustrates some of the many factors and relationships mentioned in the scientific literature. Because of this complexity it is not yet possible to state with certainty that recent droughts are the result of global climate change as modeled by many global circulation models. However, those models have correctly predicted both the increase in Pacific and Atlantic sea surface temperatures from anthropogenic CO_2 emissions, as well as increased frequency of droughts in the Amazon region (*4*).

Added to the complexity of the interaction of natural systems is the uncertainty of future human influence on these interactions (*15*). Road building, clearing for agriculture, settlement and logging are some human activities that directly affect the Amazon Forest ecosystem. These direct impacts on the forest are also drivers of several of the factors in the complex web of feedbacks within regional and global climate systems. One of the most obvious ways these activities enter the regional and global climate system is through increased incidence of fire.

While many factors play roles in deforestation in the Amazon, fire, from deliberate burning and fire leakage is one of the main proximal causes of forest loss (Figure 6). In addition, fire frequency and severity have been linked to previous occurrence of fire (*35*). In other words, areas that have burned once are more likely to burn in the future and experience more intense fires when they do burn. In addition, forest fragmentation, which creates more forest edges, has been found to reduce fire-return intervals to less than 20 years—below the length of time needed to maintain rain-forest

Figure 5: The complexity of the climate-ecosystem relationship is illustrated by this schematic representation of some of the many established and theorized feedbacks found in the scientific literature. Graphic: UNEP/GRID Sioux Falls; Feedbacks (*35, 2, 16, 35, 33, 4, 7, 42*)



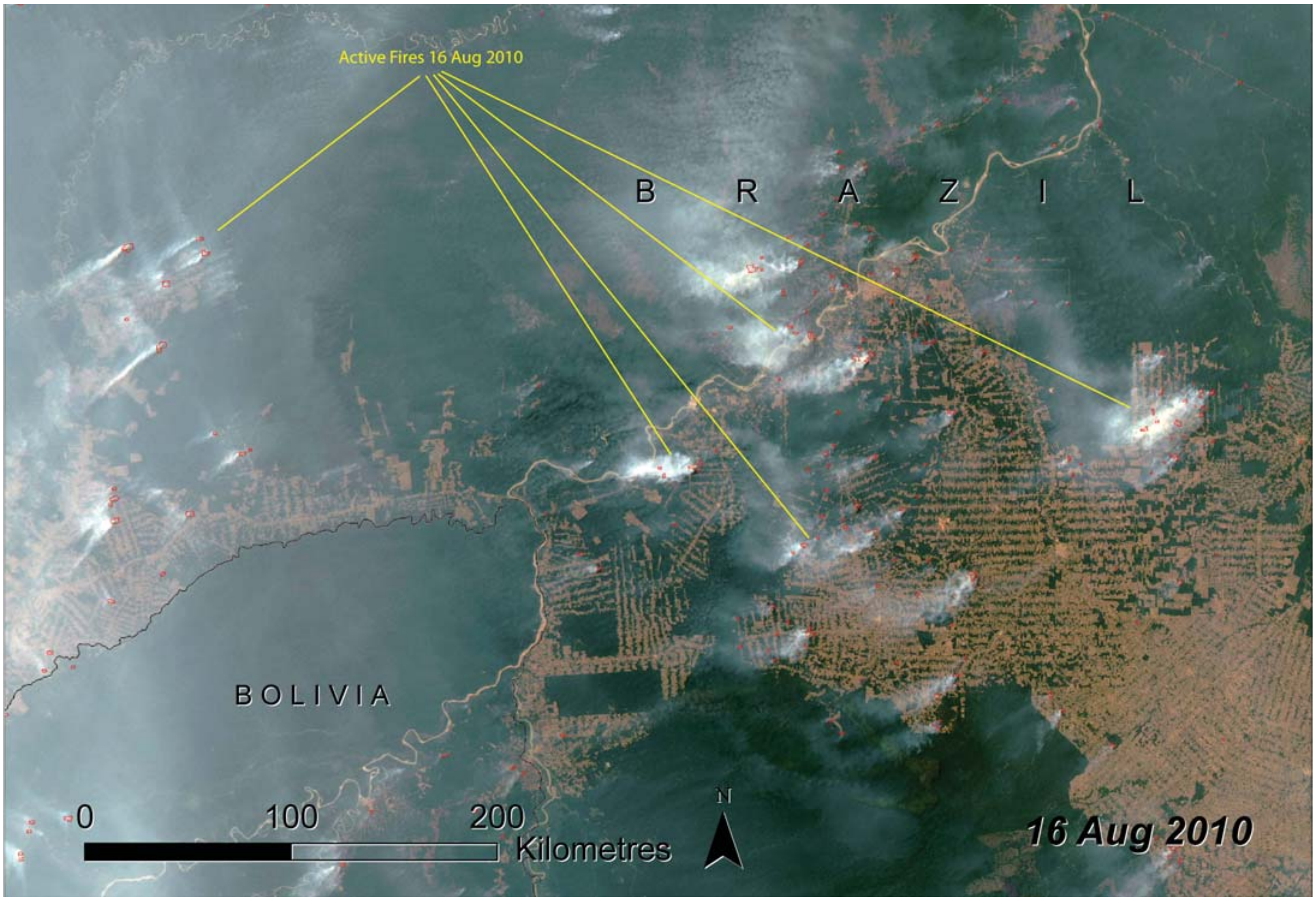


Figure 6: Fires burned across Bolivia and Brazil throughout much of the drought. This MODIS image shows many active fires on 16 August 2010 along the Bolivia-Brazil border.

vegetation *(36)*.The potential volatility of this feedback cycle suggests that burning in the Amazon would become increasingly common as these feedbacks accelerate—potentially leading to a dieback of the rainforest, converting it to a more grassland or savanna-like ecosystem *(14, 15)*.

Major Findings and Implications

The 2010 drought, measured by water levels in the Amazon, is the most severe in the 109 years of available data (*3*). Its severity is corroborated by remote sensing measures of precipitation and vegetation response (*3, 4*). There is evidence that the 2005 and 2010 droughts and drought in general over the Amazon are linked to high SSTs for the Pacific and North Atlantic Oceans (*4, 24, 2*). SST warming in turn has been linked to warming climate by some research (37, 38), although this remains an area of debate (39). Warming climate is widely accepted as an outcome of increasing CO_2 concentrations in the atmosphere. Drought in the Amazon, and the resulting increase in fires and increased tree mortality, release large amounts of CO_2 into the atmosphere creating a feedback between Amazon Forest loss and warming climate (*15*). Human activities such as conversion of forest for agriculture, logging, road building and settlement act as a catalyst in this system (*15, 40*).

The major mechanisms of interaction between climate change, human activity and terrestrial ecosystems such as the Amazon are generally agreed upon among those studying the global climate system. Quantifying those interactions and modeling future outcomes for climate and the natural environment is an ongoing process. Nevertheless, emerging agreement on possible and probable outcomes is the best information available to inform policy actions. Among the most widely advocated of options is preserving the Amazon Forest, which can be justified for several reasons beyond its influence on the global climate system. The opportunity and practicality of preserving the remaining forest decreases as the forest decreases, and the opportunity may quite quickly disappear or dramatically diminish if the theorized tipping points for global warming or deforestation are exceeded (*26*).

One of the principles from the UN Rio Declaration on Environment and Development addresses the issue of balancing scientific uncertainty against taking action (*41*).

"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

– Rio Declaration on Environment and Development, United Nations Conference on Environment and Development, June 1992

References

1. Tollefson, J. (2010) Amazon drought raises research doubts. Nature 466:423 doi:10.1038/466423a
2. Marengo, J., Nobre, C. and Tomasella, J. (2008) The Drought of Amazonia in 2005. Journal of Climate 21:495-516. doi: 10.1175/2007jcli1600.1
3. Xu, L., Samanta, A., Costa, M., Ganguly, S., Nemani, R. and Myneni, R. (2011), Widespread decline in greenness of Amazonian vegetation due to the 2010 drought. Geophysical Research Letters. 38: L07402, doi:10.1029/2011GL046824.
4. Lewis, S., Brando, P., Phillips, O., van der Heijden, G. and Nepstad, D. (2011) The 2010 Amazon Drought. Science 331:554.
5. Saleska, S. R., K. Didan, A. R. Huete, and H. R. da Rocha (2007), Amazon forests green-up during 2005 drought. Science 318(5850):612 doi:10.1126/science.1146663.
6. Samanta, A., Ganguly, S., Hashimoto, H., Devadiga, S., Vermote, E., Knyazikhin, Y., Nemani, R. and Myneni, R. (2010) Amazon forests did not green-up during the 2005 drought. Geophysical Research Letters 37: L05401, doi:10.1029/2009GL042154.
7. Phillips, O. and others (2009) Drought Sensitivity of the Amazon Rainforest. Science 323(5919):1344-1347, doi:10.1126/science. 1164033.
8. Brando, P., Goetz, S., Baccini, A., Nepstad, D., Beck, P. and Christman, M. (2010) Seasonal and interannual variability of climate and vegetation indices across the Amazon. Proceedings of the National Academy of Science USA., 107(33):14685-14690.
9. Asner, G. and Alencar, A. (2010) Drought impacts on the Amazon forest: the remote sensing perspective. New Phytologist 187:569-578.
10. Hansen, M., Stehman, S. and Potapov, P. (2010) Quantification of global gross forest cover loss. Proceedings of the National Academy of Sciences. 107:8650-8655
11. Rylands, A, et al. 2002. Amazonia. Pages 56–107 in R. A. Mittermeier, C. G. Mittermeier, P. Robles Gil, J. Pilgrim, G. A. B. da Fonseca, T. Brooks and W. R. Konstant, editors. Wilderness: Earth's last wild places. CEMEX, Agrupaci´on Serra Madre, S. C., Mexico. Cited in Da Silva, J., Rylands, A. and Da Fonseca, A. (2005) The Fate of the Amazonian Areas of Endemism. Conservation Biology 19(3):689-694.
12. Betts, R., Sanderson, M. and Woodward, S. (2007) Effects of large-scale Amzaon forest degradation on climate and air quality through fluxes of carbon dioxide, water, energy, mineral dust and isoprene. Philosophical Transactions of the Royal Society-Biological Sciences. 363:1873-1880.
13. Coe, M., Costa, M. and Soares-Filho, B. (2009) The influence of historical and potential deforestation of the stream flow of the Amazon River-Land surfaces processes and atmospheric feedbacks. Journal of Hydrology. 369:165-174.
14. Malhi, Y., Aragão, L., Galbraith, D., Huntingford, C., Fisher, R., Zelazowski, P., Sitch, S., McSweeney, C and Meir, P. (2009) Exploring the likelihood and mechanism of a climate-change-induced dieback of the Amazon rainforest. Proceedings of the National Academy of Sciences 106(49):20610-20615.
15. Nepstad, D., Stickler, C., Soares-Filho and Merry, F. (2008) Interations among Amazon land use, forests, and climate: prospects for a near-term forest tipping point. Philosophical Transactions of the Royal Scociety-Biological Sciences. 363:1737-1346.
16. Houghton, R., Skole, D., Nobre, C. Hackler, J., Lawrence, K. and Chomentowski, W. (2000) Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. Nature 403:301-304.
17. Ometto, J., Aguiar, A. and Nobre, C. (2010) Reducing uncertainties on carbon emissions from tropical deforestation: Brazil study case. 3rd International Workshop on Uncertainty in Greenhouse Gas Inventories, Lviv, Ukraine, September 22-24, 2010. Accessed May 16, 2011 at: http://ourplanetaryskin.org/ps/is/content/INPE4.pdf
18. Soares-Filho, B., Moutinho, P., Nepstad, D., Anderson, A., Rodrigues, H., Garcia, R., Dietzsch, L., Merry, F., Bowman, M., Hissa, L., Silvestrini, R and Maretti, C. (2010) Role of Brazilian Amazon protected areas in climate change mitigation. Proceedings of the National Academy of Sciences 107(24):10821-10826.
19. Clark, D. (2002) Are Tropical Forests an Important Carbon Sink? Reanalysis of the Long-Term Plot. Ecological Applications 12(1):3-7.
20. Eva H., Achard F., Stibig H. and others (2003) Response to comment on 'determination of deforestation rates of the world's humid tropical forests'. Science, 299:(1015).
21. Fearnside P. and Laurance W. (2003) Comment on 'determination of deforestation rates of the world's humid tropical forests'. Science, 299(5609):1015
22. Fearnside, P. (2005) Deforestation in Brazilian Amazonia: History, Rates, and Consequences. Conservation Biology 19(3):680-688.
23. INPE (2010) Specific Data of PRODES/INPE confirms the range of the Amazon deforestation. April 29, 2010. Accessed June 18, 2011 at: http://www.inpe.br/ingles/news/news_dest117.php
24. Malhi, Y., Robers, J., Betts, R., Killeen, T., Li, W. and Nobre, C. (2008) Climate Change, Deforestation and the Fate of the Amazon. Science 319:169-172.
25. Loarie, S., Asner, G., Field, C. (2009) Boosted carbon emissions from Amazon deforestation. Geophysical Research Letters 36:L14810.
26. Nobre, C. and Borma, L. (2009) 'Tipping points' for the Amazon forest. Current Opinon in Environmental Sustainability. 1:28-36.
27. Cox, P., R. Betts, M. Collins, P. Harris, C. Huntingford, and C. Jones (2004), Amazonian forest dieback under climate-carbon cycle projections for the 21st century, Theoretical and Applied Climatology, 78(1–3), 137–156, doi:10.1007/s00704-004-0049-4.
28. Cox, P., Harris, P., Huntingford, C., Betts, R., Collins, M., Jones, C., Jupp, T., Marengo, J. and Nobre C. (2008) Increasing risk of Amazonian drought due to decreasing aerosol pollution. Nature 453:212-215.
29. NOAA (2010) Current La Niña Conditions and the Upcoming 2010-2011 Winter Season. Accessed June 22, 2011 at: http://www.crh.noaa.gov/images/bou/showimages/Lanina_Winter1011_outlook.pdf
30. Foley, J., Botta, A., Coe, M. and Costa, M. (2002) El Niño-Southern oscillation and the climate, ecosystems and rivers of Amazonia. Global Biogeochemical Cycles 16(4): 1132, doi:10.1029/2002GB001872
31. Cox, P., Betts, R., Jones, C., Spall, S. and Totterdell, I. (2001) Modelling Vegetation and the Carbon Cycle as Interactive Elements of the Climate System. In: Pearch R (ed) Meteorology at the millennium. Academic Press. Pp 259-279.
32. Guardian Feb 3, 2011: Mass tree deaths prompt fears of Amazon 'climate tipping point.' Accessed August 8, 2011 at: http://www.guardian.co.uk/environment/2011/feb/03/tree-deaths-amazon-climate
33. Laurance, W. and Williamson, G. (2001) Positive Feedbacks among Forest Fragmentation, Drought and Climate Change in the Amazon. Conservation Biology 15(6):1529-1535.
34. Field, C., Lobel, D., Peters, H. and Chiariello, N. (2007) Annual Reviews of Environment and Resources 32:1-29.
35. Cochrane, M., Alencar, A., Schulze, M., Souza, C., Nepstad, D., Lefebvre, P. and Davidson, E. (1999) Positive Feedbacks in the Fire Dynamic of Closed Canopy Tropical Forests. Science 284:1832-1835.

36. Cochrane, M. and Laurance, W. (2002) Fire as a large-scale edge effect in Amazonian forests. Journal of Tropical Ecology 18:311-325.
37. Wang, C. and Dong, S. (2010) Is the basin-wide warming in the North Atlantic Ocean related to atmospheric carbon dioxide and global warming?. Geophysical Research Letters, 37:L08707.
38. Latif, M. and Keenlyside, N. (2009) El Niño/Southern Oscillation response to global warming. Proceedings of the Academy of Sciences 106(49):20578-20583.
39. Vechi, G., Clement, A. and Soden, B. (2008) Examining the Tropical Pacific's Response to Global Warming. Eos 89(9):81-83.
40. Cochrane, M. and Barber, C. (2009) Climate change, human land use and future fires in the Amazon. Global Change Biology 15:601-612
41. UN (1992) UN General Assembly 'Rio Declaration on Environment and Development' Accessed May 16, 2011 at: http://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm
42. Davidson, E. and Janssens, I. (2006) Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature 440(9):165-173.