GEOPHYSICAL RESEARCH LETTERS, VOL. 36, L03807, doi:10.1029/2008GL036063, 2009

Reply to comment by W. Schroeder et al. on "Reversal of trend of biomass burning in the Amazon"

Ilan Koren,[1] Lorraine A. Remer,[2] Karla Longo,[3] Foster Brown,[4,5] and Rebecca Lindsey[6]

Received 18 September 2008; revised 20 November 2008; accepted 16 December 2008; published 6 February 2009.

Citation: Koren, I., L. A. Remer, K. Longo, F. Brown, and R. Lindsey (2009), Reply to comment by W. Schroeder et al. on ''Reversal of trend of biomass burning in the Amazon,'' *Geophys. Res. Lett.*, *36*, L03807, doi:10.1029/2008GL036063.

[1] The fate of the Amazonian rainforest is critically important to the well being of the planet. When studying questions related to the health of the forest and especially to human-induced effects on this fragile ecosystem, we must take special care to insure proper reporting and analysis. The comments of *Schroeder et al.* [2009] contribute to a welcomed scientific dialogue on important topics affecting the Amazon.

[2] *Koren et al.* [2007] (hereinafter referred to as K2007) analyzed seven biomass burning seasons of aerosol optical depth retrievals from the Moderate resolution Imaging Spectroradiometer (MODIS) satellite sensor and nine seasons of fire count observations from the Advanced Very High Resolution Radiometer (AVHRR) satellite sensor. The data showed a positive trend in both the fire counts and aerosol up until 2006 when a sharp reduction in both variables occurred. Although we acknowledged the fact that interannual variability in meteorology is important, we attributed the sharp reduction in the final year partially to human activities. In particular we suggested that part of the sharp decrease in the amount of fires and smoke in the dry season of 2006 can be attributed to actions done by a tri-national committee and a policy shift implemented by small rural farmers in 2006.

[3] *Schroeder et al.* [2009] (hereinafter referred to as S2009) address two issues in K2007. (1) They question the AVHRR fire count data and the resulting trend shown in K2007. We note that S2009 never question the validity of the data or the trends of the MODIS aerosol optical depth. Only the AVHRR fire count record is criticized. (2) They also question our interpretation that the reduction of the biomass burning in 2006 was in part due to deliberate changes in human activity.

[4] We will first address the comments on the fire counts and AOD trends. One of the remarkable points of K2007 is the close agreement between the measured aerosol optical thickness (AOD) and the fire counts. We note that MODIS also produces a fire count product. We found, but did not show in K2007, that the MODIS and AVHRR fire counts were tightly correlated, although offset from one another. Both the AVHRR and MODIS fire counts for the years 2001 through 2005 were correlated with the MODIS AOD ($R > 0.95$). Having the choice of either satellite's fire count data, we decided to show only the AVHRR record due to its longer time series. S2009 point out an inconsistency between the AVHRR fire counts in years 1998–1999 and the post-2000 record. We cannot rule out this inconsistency. However, even if we limit the analysis to the post-2000 MODIS era we see a clear and consistent increase in both smoke loading and fire counts, followed by a drastic decrease in 2006. The S2009 objections to the 1998 and 1999 data may be valid, but are immaterial to the main points or the conclusions of K2007. Figure 1 shows the time series in AOD for 2000–2006 and fire counts from MODIS for 2001–2005. The 2000–2005 trends and the correlations between fire counts and AOD are clearly demonstrated.

[5] The five years of MODIS fire counts shown in Figure 1 were all that were available to us during the analysis for K2007, due to MODIS reprocessing at that time. Today we have benefit of additional data. Figure 2 shows scatter plots between the monthly mean AOD over the Amazon forest (Latitude 3N to 16S; Longitude 52W to 72W) versus normalized monthly fire counts from MODIS from 2000 to 2008. The high correlation between the mean AOD and the fire counts is clearly seen in Figure 2. We also note a shift in the relationship between these variables when comparing the dry season (J,J,A) with the transition season (S,O,N). A lesser number of fires per AOD is seen in the wetter months, which can be explained by a higher cloud fraction in the transition season and a larger number of fires obscured by clouds. It is interesting to see that difference in the relationship between smoke and fires in the wetter and dryer parts of the season becomes smaller for the higher AOD cases. This can be explained by the effect of absorbing aerosols on the cloud fraction [*Koren et al.*, 2008]. There is an indisputable relationship between fires and smoke in the Amazon Basin dry season that showed a strong increasing trend in biomass burning activity from 2000 through 2005, then a drastic decrease in both fires and smoke in 2006.

[6] We now address the second criticism of S2009. What causes this interannual variability and the trends in biomass burning in the Amazon? First we need to clarify an ambiguity from K2007 that created a concerned response in S2009. There was a severe drought during the 2005 dry season that affected the western Amazon, which is a tri-national region consisting of parts of Brazil, Peru and Bolivia. The policy

[1]Department of Environmental Sciences, Weizmann Institute of Science, Rehovot, Israel.
[2]Laboratory for Atmospheres, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.
[3]Divisão de Geofísica Espacial, Instituto Nacional de Pesquisas Espaciais, Cachoeira Paulista, Brazil.
[4]Woods Hole Research Center, Falmouth, Massachusetts, USA.
[5]Parque Zoobotanico, Federal University of Acre, Rio Branco, Brazil.
[6]NASA Earth Observatory, Science Systems and Applications, Lanham, Maryland, USA.

0094-8276/09/2008GL036063$05.00

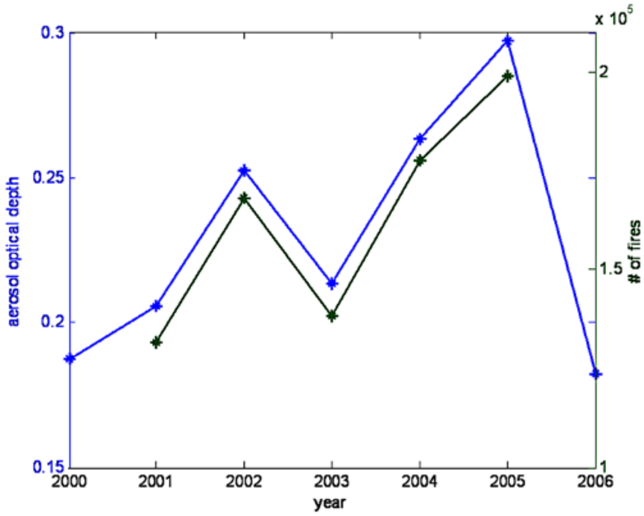

Figure 1. Time series of MODIS-derived aerosol optical thickness (blue) and MODIS-derived fire counts (green) for the biomass burning season in each year. The five years of MODIS fire counts were all that were available to us at the time of the analysis for K2007 due to MODIS reprocessing at the time. Analysis of additional data 2000 to 2008 is shown in Figure 2, and a similar tight correlation is seen.

shift to reduce burning was implemented only in the Brazilian state of Acre, not the neighboring countries. In Table 1 we show the results of that policy shift in Acre, as compared to Acre's neighboring jurisdictions. S2009 was correct to question the misleading statement in K2007 that suggested that Peru and Bolivia implemented similar policy as Acre. However, K2007 did correctly identify an anthropogenic factor in the drastic decrease in burning in 2006 as compared to the previous six years.

[7] Three main independent factors dominate the fire scenario in the region: weather, economics and policy. The last two factors fall within the category of human discretion. Without doubt weather plays an important role in modulating biomass burning. 2006 was a wet year in the Amazon, and was partially the reason for the dramatic reversal of the trend witnessed during the previous six years. However, human discretion also played a significant role.

Table 1. Total Seasonal Fire Counts From GOES-12, GOES-10 (2007), NOAA-12, NOAA-15 (2007), MODIS-Aqua and MODIS-Terra for Three Amazonian Jurisdictions[a]

	Madre de Dios	Acre	Pando	Total
2003	301	3570	663	4534
2004	227	2470	610	3307
2005	626	12670	2336	15632
2006	310	2573	1349	4232
2007	555	1906	1589	4050

[a]Madre de Dios Peru, Acre Brazil and Pando Bolivia. Source www.cptec.inpe.br/queimadas, from *Vasconcelos et al.* [2008].

[8] Table 1 shows the combined fire counts from three jurisdictions in western Amazonia. Here we see the trends described in K2007 with the addition of an extra year of data. The biggest change from 2005 to 2006 is for Acre, where the Public Ministry recommended prohibition of fires in 2006, and the population mostly adhered to the policy. The drop is 5-fold, and represents 10,000 fewer fire counts. Pando and Madre de Dios, where similar fire suppression actions were not implemented, saw only a 2-fold decrease in fires. In 2007, a dry year as compared with 2006, Acre continues to show a decrease of fire counts, while its neighbors show an increase. The continued drop in fire counts in Acre mirrors a change both in public policy and possibly in the behavior of small rural producers who had suffered major economic losses during the fires of 2005.

[9] International economic pressures counteract the best intentions of public policy. As demand for beef, soybean, sugarcane and other biofuel and agricultural products increase on the world market, the incentive for local farmers to disregard the law to clear land with fire and plant these crops also increase. Links between international agricultural markets and the fate of the Amazon forest are well documented [*Malhi et al.*, 2008; *Fargione et al.*, 2008; *Laurance*, 2007; *Morton et al.*, 2006; *Fearnside*, 2005]. However for a given season it is true that it is difficult to isolate the direct impact of manmade activity from fluctuations in the meteorological conditions.

[10] K2007 (paragraph 17) state "The reduction in biomass burning in 2006 also had a meteorological component. The precipitation in the Brazilian states of the deforestation arc (Acre, Rondonia, Mato Grosso, Southern Amazonas and Southwestern Para) was indeed above the climatologic mean

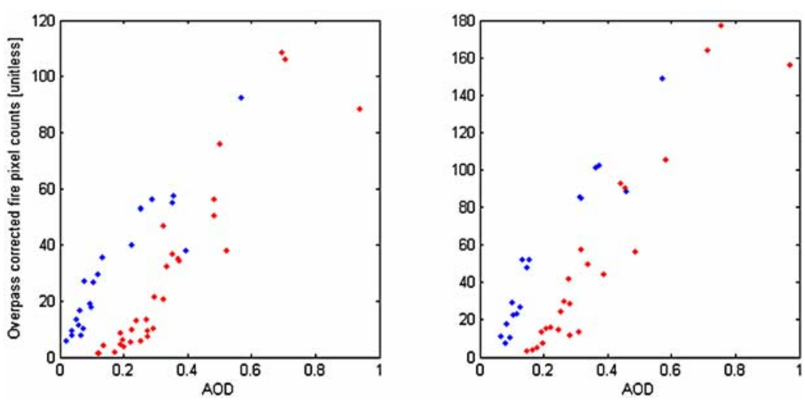

Figure 2. Monthly mean AOD over the Amazon forest vs. monthly normalized fire counts from MODIS from 2000 to 2008. Blue for the early dry season (J,J,A). Red for the late dry season and transition to rainy conditions (S,O,N). (left) Data collected during the morning overpass (Terra). (right) During the afternoon overpass (Aqua).

for 2006 but these rains came late in the season. Before September, Acre was most likely the only state of the deforestation arc where weather could have affected the burning activity. Even so, the strong reduction over all Brazil and specifically in Acre before the onset of the rains points to the critical role human activity plays in creating, controlling and mitigating biomass burning and deforestation.'' We stand by this statement.

[11] **Acknowledgments.** We thank Alberto Setzer for his help in clarifying the AVHRR fire count time series and for sharing his perspective on biomass burning in the Amazon.

References

Fargione, J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne (2008), Land clearing and the biofuel carbon debt, *Science*, *319*, 1235, doi:10.1126/science.1152747.

Fearnside, P. M. (2005), Deforestation in Brazilian Amazonia: History, rates and consequences, *Conserv. Biol.*, *19*, 680–688.

Koren, I., L. A. Remer, and K. Longo (2007), Reversal of trend of biomass burning in the Amazon, *Geophys. Res. Lett.*, *34*, L20404, doi:10.1029/2007GL031530.

Koren, I., J. V. Martins, L. A. Remer, and H. Afargan (2008), Smoke invigoration versus inhibition of clouds over the Amazon, *Science*, *321*, 946–949, doi:10.1126/science.1159185.

Laurance, W. F. (2007), Switch to corn promotes Amazon deforestation, *Science*, *318*, 1721, doi:10.1126/science.318.5857.172b.

Malhi, Y., J. T. Roberts, R. A. Betts, T. J. Killeen, W. Li, and C. A. Nobre (2008), Climate change, deforestation, and the fate of the Amazon, *Science*, *319*, 169–172, doi:10.1126/science.1146961.

Morton, D. C., R. S. DeFries, Y. E. Shimabukuro, L. O. Anderson, E. Arai, F. del Bon Espirito-Santo, R. Freitas, and J. Morisette (2006), Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon, *Proc. Natl. Acad. Sci. U.S.A.*, *103*, 14,637–14,641, doi:10.1073/pnas.0606377103.

Schroeder, W., L. Giglio, and J. A. Aravéquia (2009), Comment on "Reversal of trend of biomass burning in the Amazon" by Ilan Koren, Lorraine A. Remer, and Karla Longo, *Geophys. Res. Lett.*, *36*, L03806, doi:10.1029/2008GL035659.

Vasconcelos, S. S., I. F. Brown, and A. W. F. de Melo (2008), Fires and their trends in recent years in Acre State (in Portuguese), technical report, Ecol. and Environ. Zoning of Acre State, Rio Branco, Acre, Brazil.

F. Brown, Parque Zoobotanico, Universidade Federal do Acre, Rio Branco, Acre 69.915-900, Brazil. (fbrown@uol.com.br)

I. Koren, Department of Environmental Sciences, Weizmann Institute of Science, 76100 Rehovot, Israel. (ilan.koren@weizmann.ac.il)

R. Lindsey, NASA Earth Observatory, Science Systems and Applications, Greenbelt Road, Code 613.2, Lanham, MD 20706, USA. (eoeditor@yahoo.com)

K. Longo, Instituto Nacional de Pesquisas Espaciais, Avenida Dos Astronautas, 1758, Jd. da Granja, São José dos Campos, SP, Brazil, 12227-010. (karla.longo@dge.inpe.br)

L. A. Remer, Laboratory for Atmospheres, NASA Goddard Space Flight Center, Code 613.2, Greenbelt MD 20771, USA. (Lorraine.A.Remer@nasa.gov)