EOS

EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 87 NUMBER 26

27 JUNE 2006

PAGES 253–264

Monitoring Fires in Southwestern Amazonia Rain Forests

PAGES 253, 259

From mid-July to mid-October 2005, an environmental disaster unfolded in the trinational region of Madre de Dios, Peru; Acre, Brazil; and Pando, Bolivia (the MAP region), in southwestern Amazonia. A prolonged dry season and human-initiated fires resulted in smoke pollution affecting more than 400,000 persons, fire damage to over 300,000 hectares of rain forest, and over US$50 million of direct economic losses. Indicatorrs suggest that anomalous drought conditions could occur again this year.

In May 2005, river levels, were the lowest in 34 years in Rio Branco, Acre, Brazil, signaling that the subsequent dry season would be unusual. Rainfall became virtually absent for several months, not only in eastern Acre but also in the neighboring Bolivian department of Pando and the Peruvian region of Madre de Dios. This enhanced dry season extended over much of western Amazonia with severe societal impact; by October 2005, regional governments had declared states of emergency in Pando, Acre, and Amazonas, an area covering more than a million square kilometers. Whereas previous droughts could be linked to El Niño events [*Williams et al.*, 2005; *Marengo*, 2004], J. A. Marengo et al. (The drought of Amazonia in 2005, manuscript in preparation, 2006) suggest that this drought was not related to El Niño but was instead associated with anomalously warm surface water in the tropical North Atlantic, similar to a previous drought in 1963–1964.

Multinational Satellite Imagery

A combination of NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) rapid response imagery, near-real-time, multisensor reporting of 'hot spot' (fire) detection by the Brazilian National Institute of Space Research (INPE), and imagery from the China-Brazil Earth Resources Satellite (CBERS-2) became crucial in determining the extent of this disaster and defining emergency actions and policies.

By mid-July, hot spot counts (fire pixels in satellite images) for Acre began to climb. In mid-August, counts from the Advanced Very High Resolution Radiometer (AVHRR) U.S. National Oceanic and Atmospheric Administration's (NOAA)-12 sensor had exceeded the number for all of 2004, and anecdotal reports of fires escaping control and invading forests became frequent. Smoke began to affect urban life in Rio Branco, the capital of Acre. At a meeting of Acre's State Fire Committee, satellite imagery from MODIS sensors combined with hot spot data and meteorological information convinced the committee to recommend the prohibition of fires. The governor of Acre proclaimed the prohibition, but hot spot counts continued to climb until the total for 2005 was more than twofold that of 2004.

In August, a team of the NASA-supported Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA-ECO) began providing daily e-mail alerts of hot spot distributions and MODIS images of smoke patterns (Figure 1). The daily observations showed that multiple satellite coverage is essential; NOAA satellites suffer from periodic off-nadir imaging conditions, and MODIS sensors occasionally had gaps in their coverage for the Acre region during days of peak burning. Meteorological data (http://www.cptec.inpe.br) became essential in forecasting high winds that propagated fires.

By mid-September, reports of fires spreading into forests multiplied, and the Acre state government declared a state of emergency on 21 September. Smoke reduced ground visibility on one day to less than 800 meters. The Acre government mounted a situation room, staffed by two civil defense coordinators, three state employees, and several researchers and students from the LBA-ECO team.

For nearly three weeks while the situation room was in operation, the LBA-ECO team provided daily briefings on the locations of fires. Overflights began in late September for verification of the hot spot data and monitoring of fires spreading into standing rain forests. Visual patterns confirmed previous studies [*Pantoja et al.*, 2005] that hot spot data for the Acre region underestimate fire occurrence and that ground fires in forests are hard to detect by satellite observations.

In early October, sporadic rains had begun, and on 11 October, the state of emergency in

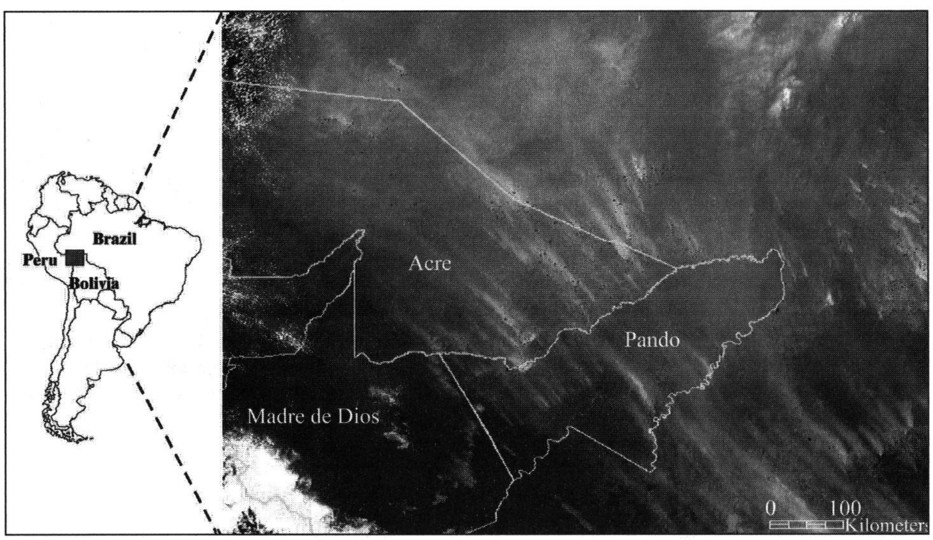

Fig. 1. MODIS rapid response image of part of Madre de Dios, Peru; Acre, Brazil; and Pando, Bolivia, or the MAP region, Aqua satellite, 17 September 2005. Strong southeast winds associated with a cold front created smoke plumes trending northwest from fires. Red points are detected hot spots. Original color image appears at the back of this volume.

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Acre was lifted as well as the prohibition against burning. Up to that time, however, the extent of fire-damaged rain forests had not been estimated.

The Brazilian government had decided in 2004 to provide free Internet access to CBERS-2 imagery for Brazilian institutions, and this past May, this access was extended to all South American countries. Users can download images rapidly, typically within days of the satellite's overpass. In October, CBERS-2 images provided the first estimates of the extent of burning: More than 200,000 hectares of pastures and agricultural plots along with new deforestation sites had a well-defined spectral response of burning, and more than 80,000 hectares of standing rain forests had canopy foliage altered by the fires (Figure 2). Current estimates indicate that the area of standing rain forests affected by fires was greater than 250,000 hectares in Acre, greater than 100,000 hectares in Pando (Ricard Cots, personal communication, 2006), and greater than 10,000 hectares in Madre de Dios.

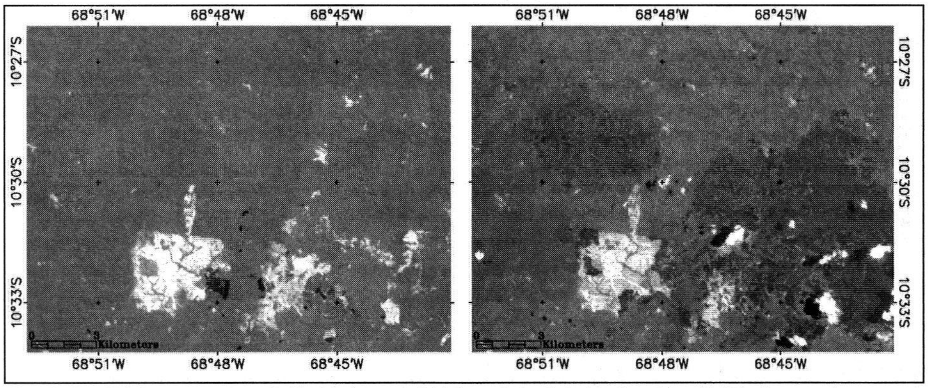

Fig. 2. CBERS-2 images on (left) 21 August 2005 and (right) 12 October 2005 of part of eastern Acre, Brazil. Green represents vegetation, light grey indicates deforested areas, and purple shows burnt areas. Dark purple is burned open areas (most noticeable in left image). The light purple patches (right image) show standing rain forests where the canopy was affected by fire. Original color image appears at the back of this volume.

Key Factors

A confluence of three factors led to the monitoring of this event and dissemination of the results. First, information was easily available. INPE had instituted a long-term project in hot spot monitoring, and its Web page (http://www.cptec.inpe.br/queimadas) provided easy access to near-real-time data from a variety of satellites. Daily MODIS imagery available in georeferenced files (http://rapidfire.sci.gsfc.nasa.gov/subsets) allowed the superposing of political boundaries and the distribution of the imagery to a wide audience. Free Internet access to the CBERS-2 imagery (http://www.cbers.inpe.br) permitted analysis to begin within days of satellite overpass.

Second, an active research program meant that regional scientists were using this information. The Brazilian-led LBA program, with support from NASA and the European Union, has projects in the Acre region that involve accuracy assessment of hot spot data and aerosol monitoring (http://lba.cptec.inpe.br/mirror/lbaeco). During the monitoring, doubts as to satellite coverage and hot spot counts were raised and resolved by communication between scientists at INPE, in Acre, and those at NASA/University of Maryland who already had begun working together in previous years [*Morisette et al.*, 2005; *Schroeder et al.*, 2005].

Third, the impact of smoke and fires created a tremendous demand for information. The daily e-mail list expanded quickly as local political representatives, newspaper and television reporters, professionals, and leaders of organized civil society requested to be placed on the list. Internet access is nearly universal in this region and permitted those with little technical capability to keep abreast of the research results. In one case, the mayor of a small, rural municipality used a map sent from the University of Maryland in his presentation to the governor of Acre.

The monitoring described above was possible only because of long-term funding and the joint efforts of hundreds of scientists and engineers in several countries who developed readily accessible satellite products, user-friendly online systems, and the knowledge necessary for analysis. Similar long-term investments of time and human resources are essential to help societies devise responses to increased vulnerability to climate variability.

Legacy for the Future

Droughts of similar magnitude have occurred within the last hundred years in western Amazonia, some of which were associated with El Niño events, as in 1926, 1983, and 1998, while the droughts of 1964 and 2005 had no direct association with El Niño. The 2005 drought in the MAP region interacted with a relatively high human population density, active fire propagation, and extensive areas of fire-prone pastures to produce a disaster never previously experienced by modern societies in this part of Amazonia. The associated fires and smoke produced direct economic losses of over US$50 million and affected the health of tens of thousands of persons in eastern Acre alone. An enduring legacy of this disaster is the more than 300,000 hectares of damaged rain forests that have become more susceptible to repeated burning, as the increased tree mortality in these forests has produced more dead, dry material and has reduced leaf area, allowing greater penetration of hot sunlight to the forest floor.

During early May 2006, water levels of the Acre River had dipped below those of the same dates in 2005, with similar patterns being reported for the Madre de Dios River at Puerto Maldonado, Peru. These ominous indicators have raised concern that anomalous drought conditions could occur again this year. In preparation for such a scenario, the Environmental Institute of Acre has established a permanent situation room that will incorporate the use of multiple satellite sensors to monitor the extent of fire and drought conditions.

The results of several climate models suggest that El Niño–like conditions are likely to become more frequent in the future, shortening the recurrence interval of droughts in southwestern Amazonia. Not to devise adequate societal responses to this possible change may mean that the fires of the MAP region in 2005 will become the harbingers of larger disasters in this portion of Amazonia.

Acknowledgments

We are privileged to have worked with the Civil Defense of Acre and are indebted to those who risked their lives in combating the fires in the region. The work reported here was funded by the NASA LBA-ECO (LC-02) program, the U.S. Agency for International Development, the Moore Foundation, the Conservation, Food and Health Foundation, and the National Research Council of Brazil (PIBIC). Max Holmes kindly reviewed the text.

References

Marengo, J. A. (2004), Interdecadal variability and trends of rainfall across the Amazon basin, *Theor. Appl. Climatol.*, *78*, 79–96.

Morisette, J. T., L. Giglio, I. Csiszar, A. Setzer, W. Schroeder, D. Morton, and C. O. Justice (2005), Validation of MODIS active fire detection products derived from two algorithms, *Earth Interact.*, *9*(9), EI141, doi:10.1175/EI141.1.

Pantoja, N. V., D. Sehorst, K. S. Rocha, F. M. C. Lopes, L. S. Saraiva, S. S. Vasconcelos, and F. Brown (2005), Observations of fires in eastern Acre: Support for validation of hot spots derived from satellite data (in Portuguese), paper presented at the XII Brazilian Symposium of Remote Sensing, Goiânia, Brazil, 16–21 April.

Schroeder, W., J. T. Morisette, I. Csiszar, L. Giglio, D. Morton, and C. O. Justice (2005), Characterizing vegetation fire dynamics in Brazil through multisatellite data: Common trends and practical issues, *Earth Interact.*, *9*(13), EI120, doi:10.1175/EI120.1.

Williams, E., A. Dall'Antonia, V. Dall'Antonia, J. M. Almeida, F. Suarez, B. Liebmann, and A. C. M Malhado (2005), The drought of the century in the Amazon Basin: An analysis of the regional variation of rainfall in South America in 1926, *Acta Amazonica*, *35*, 231–238.

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Exploring Earth's Composition and Energetics With Geoneutrinos

PAGES 253, 260

The production of heat by radioactive decay plays a major role in the evolution of the Earth. Present constraints of the amount of heat production come from conflicting assessments of global surface heat flow, which can be directly measured. A high value of 44 ± 1 terawatts accounts for significant heat flow through the ocean floor by both conduction and hydrothermal convection [*Stein*, 1995]. A low value of 31 ± 1 terawatts assumes only a minor hydrothermal effect [*Hofmeister and Criss*, 2005]. This heat flux is thought to result from heat production and cooling of the planet.

The relative size of these contributions and their origin allow a range of models. Models are often compared via the ratio of radioactive heat generation to heat flow, called the Urey ratio. Estimates of the Urey ratio, based on chemical models of the early Earth, range from 0.4 to 0.8 [*Kellogg et al.*, 1999; *Korenaga*, 2003], reflecting the cooling of the planet and indicating the time for heat conduction to the surface. Different models have significantly different implications for Earth's composition, formation, and evolution. Thus, resolving the question of how much heat is produced by radioactive decay within the Earth will refine the models that help describe the Earth.

A new technology has emerged that provides the first direct constraints on poorly known concentrations of radioactive elements in the Earth and the heat they generate. This involves measuring the flux of geoneutrinos, which are produced within the Earth along with heat by the decay of radioactive isotopes of uranium, thorium, and potassium. Neutrinos come from nuclear beta decay in the Earth, but they also can be produced by similar processes in the Sun and nuclear reactors.

The Earth is glowing with neutrinos. Millions of these uncharged elementary particles flow out of every fingernail-sized area of Earth's surface every second. However, because they interact with other particles only via the weak force, almost all neutrinos pass unaffected through the Earth, making them difficult to detect.

Nevertheless, detecting neutrinos is crucial for understanding the planet's geological history. The concentrations of radioactive elements, which reflect the process by which Earth accreted 4.6 billion years ago, are one of the most important controls on the planet's subsequent thermal, chemical, and mechanical evolution. As a result, they are crucial to understanding processes such as mantle convection, plate tectonics, and the core's dynamics and magnetic field.

By S. Dye and S. Stein

Neutrino Detection

Detecting geoneutrinos employs essentially the same technology used five decades ago to discover neutrinos from a nuclear reactor: a large vat of clear liquid viewed by inward-looking photomultiplier tubes. Mineral oil, a relatively inexpensive, clear liquid containing a significant fraction of hydrogen and whose free proton nucleus is a good neutrino target, is usually used within the vat. Scintillating material, which emits visible light proportional to the energy of ionizing particles created in a neutrino interaction, is dissolved in the oil. The scintillation light is collected by photomultipliers and used to identify neutrino interactions by reconstructing their energy and position.

The challenge of detecting geoneutrinos comes from their tiny probability of interacting. Unless neutrino flux is extremely high, as it is close to a nuclear reactor, only an enormous detector can observe a reasonable interaction rate. The KamLAND detector, located in a kilometer-deep zinc mine on the Japanese island of Honshu and which was built for measuring reactor neutrinos, weighs 1000 tons and records about one geoneutrino per month.

This small detection rate makes reduction of background noise, which is due primarily to cosmic rays and radioactivity in and around the detector itself, a primary experimental concern. The Earth attenuates cosmic rays, so geoneutrino detectors operate best in tunnels, mines, or the deep ocean. Deeper is better, with an overburden equivalent to several kilometers of water usually considered a minimum. Size, radio-purity of materials, and shielding make detecting geoneutrinos a major project.

Although geoneutrinos and reactor neutrinos both are produced in the decay of neutron-rich nuclei, they can be distinguished by their energy spectra. In this form of beta decay, a radioactive isotope emits an electron and an antineutrino when one of its neutrons spontaneously changes to a proton (Figure 1). Geoneutrinos and reactor neutrinos are thus antineutrinos, the antiparticles

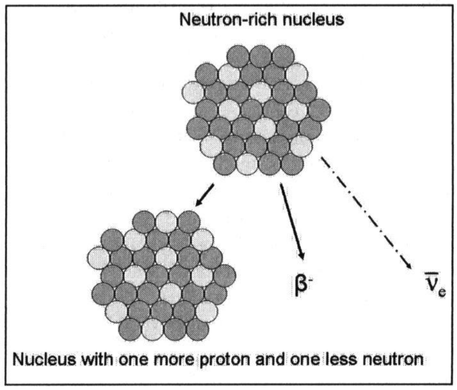

Fig. 1. The beta-decay radioactive process in which a neutron decays into a proton, emitting an electron (beta-minus particle) and an antineutrino, and releasing heat.

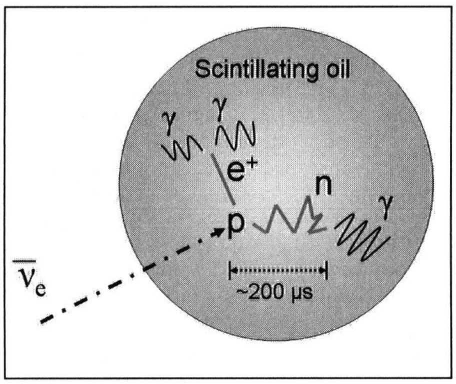

Fig. 2. Antineutrinos (ν_e bar) are detected by inverse beta decay, which causes a characteristic sequence of events.

of neutrinos. The energy available to the antineutrino, derived from the daughter nucleus being more tightly bound than the unstable parent, is shared in varying amounts with the electron. Sometimes the electron gets no energy, defining a cutoff to the antineutrino spectrum characteristic of the particular transformation. If the daughter nucleus itself is unstable, transformation continues until a stable daughter is produced. Because reactor neutrinos and geoneutrinos come from different radioactive isotopes, they have different energy spectra.

Antineutrino detection relies on inverse beta decay, the reverse of the reaction that produced the antineutrinos. Antineutrinos with enough energy initiate a distinct signature upon colliding with a proton. In the collision, the proton converts to a neutron while the antineutrino becomes a positron (Figure 2). Both products interact quickly in ordinary matter, producing ionizing particles. The positron annihilates with an atomic electron, and later the slowed neutron is captured by a nearby hydrogen nucleus, forming deuterium. The positron's ionization signal is proportional

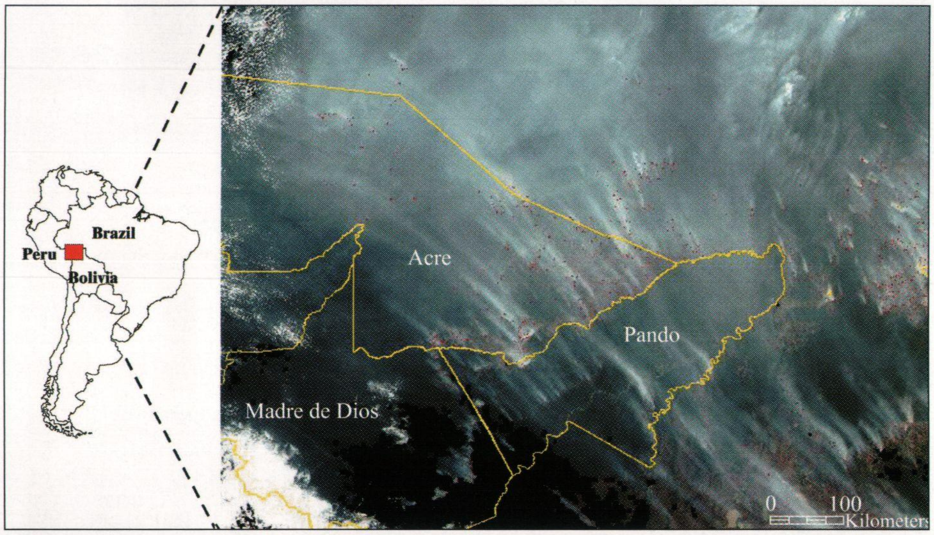

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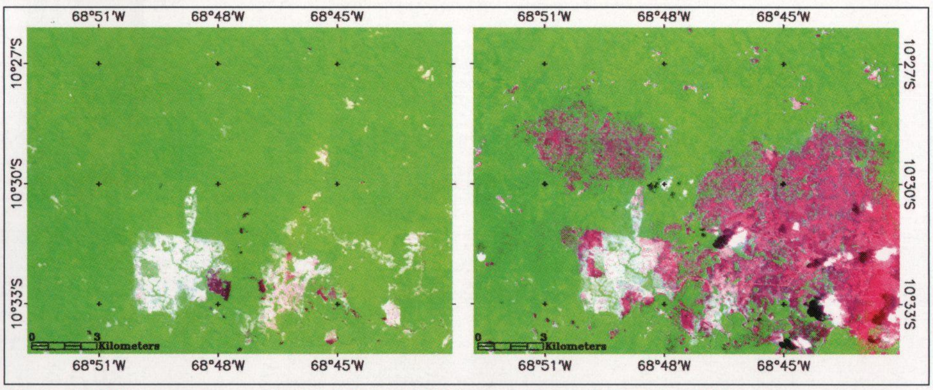
Fig. 2. (a) Changes in weight resulting from variations in density of underlying crustal rocks. (b) Measuring sequences of forest soil, clay, and tsunami sand layers retrieved by coring in tidal flats south of Astoria, Ore. Note stumps of trees killed by the 1700 Cascadia earthquake in background.

Page 257



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Page 259