CARBON EMISSIONS

# Improved Monitoring of Rainforests Helps Pierce Haze of Deforestation

**Deforestation produces a significant amount of greenhouse gas emissions through burning, clearing, and decay. But exactly how much?**

Twenty-five years ago, the best way for Brazilian scientists to gauge the rate of deforestation in the Amazon was to superimpose dots on satellite photos of the world's largest rainforest that helped them measure the size of the affected area. INPE, the government agency responsible for remote deforestation monitoring, didn't release regional maps and refused to explain its analytical methods. The result was data that few experts found credible.

Today, Brazil's monitoring system is the envy of the world. INPE has its own remote-sensing satellite, a joint effort with China launched in 1999, that allows it to publish yearly totals of deforested land that scientists regard as reliable. Using data from NASA's 7-year-old Terra satellite, INPE also provides automated weekly clear-cutting alerts that other tropical nations would love to emulate. And image-analysis algorithms have eliminated the need for measurement dots. "They've really turned things around," says forestry scientist David Skole of Michigan State University in East Lansing.

Generating good data on deforestation is more than an academic exercise. The process of cutting down forests and clearing the land—by burning the wood, churning soil for agriculture or grazing, and allowing the remaining biomass to decay—produces as much as 25% of the world's yearly emissions of greenhouse gases. That makes keeping tabs on deforestation a crucial issue for government officials negotiating future climate agreements—including a meeting next month in Bonn, Germany, and one next year in Bali to extend the 1997 Kyoto agreement after its 2012 expiration.

## Peering Through the Clouds

**Not so hazy.** An image of the Amazonian rainforest by Landsat 5 (left) includes clouds that obscure deforested areas visible on a radar image by ALOS (right). The two satellites are among a number of key sensors (below) that help researchers monitor deforestation in the tropics.

| NATION | SATELLITE | SENSORS | RESOLUTION | FEATURES |
|---|---|---|---|---|
| **U.S.** | Landsat 5 | Optical | 30 m | This aging workhorse offers images every 16 days to any nation with satellite receiving station. |
| **U.S.** | Landsat 7 | Optical | 30 m | Some researchers have managed to use it effectively despite a crippled sensor. |
| **India** | IRS-2 | Optical | 6–56 m | Experimental craft shows promise, although images are hard to acquire. |
| **Japan** | ALOS | Radar | 50 m | Researchers hope cloud-penetrating radar could be key to deforestation studies. |
| **China/ Brazil** | CBERS-2 | Optical | 20 m | Experimental; Brazil uses on-demand images to bolster their coverage. |
| **U.S.** | Terra | Optical | 250–1000 m | Data easily available, almost daily. |
| **France** | SPOT | Optical | 20 m | Indonesia, Thailand use alongside Landsat data. |

Despite solid improvements by scientists in monitoring deforestation, the uncertainties are still substantial. The gap between remote-sensing data and field measurements on the amount of deforested land is between 5% and 10%, say researchers. And the error bars on estimates of the amount of $CO_2$ released by clear-cutting those tracts, they note, are 25% to 50%. Those errors, related to gaps in fundamental understanding of forest carbon, will make it harder for developing nations to verify the extent to which they have managed to reduce deforestation and, thus, reduce their output of greenhouse gases. In turn, the uncertainty undermines efforts to convince skeptical lawmakers in industrialized countries that efforts to diminish deforestation should be a part of future climate-change agreements.

"We need to get these error bars down," says climate negotiations veteran Annie Petsonk of Environmental Defense (ED), a New York City–based nonprofit. More precise satellite data for calculating carbon flux could also shed light on the role of trees in the global carbon cycle, a key ingredient in understanding whether global warming will accelerate.

### Margins of error

When negotiators in 2001 agreed on what the Kyoto treaty would cover, they omitted deforestation. One reason was fear that clear-cutting halted in one country trying to achieve its Kyoto goals would move to another country under less pressure to curb the practice. But uncertainty about the science didn't help. At the time, INPE was releasing only totals, not maps, and few nations had experience turning visual data from Landsat 5 and other satellites (see chart, left) into integrated totals. "You'd have [negotiators] saying that it's impossible to measure deforestation," says ecologist Paulo Mountinho of the Amazon Institute of Environmental Research at Para State, Brazil. "There was all this data but not enough know-how," adds regional ecologist Greg Asner of the Carnegie Institution of Washington in Stanford, California.

In the last 5 years, a growing cadre of researchers in rainforest nations has begun tapping satellite data to monitor their forests; the list includes India, Thailand, and Indonesia. In addition to Brazil's weekly alert system, experts across the Americas are making increased use of NASA's medium-resolution Terra, which can scan any point on Earth roughly each day, at a decent resolution.

Policymakers are taking notice of that increased capacity. A side presentation on detecting logging that Asner offered at the international climate meeting in Montreal in

CREDITS (LEFT TO RIGHT): JAXA

December 2005 drew hundreds of negotiators. There, Papua New Guinea and Costa Rica proposed including credit, after 2012, for efforts to curb deforestation. The idea has gathered momentum, and environmentalists are hoping that next month's meeting in Bonn, convened by a United Nations technical body, will lay the groundwork to measure and credit action against deforestation by developing countries. "The science has really driven the policy," says ED's Stephen Schwartzman.

The Bonn delegates will confront a number of technical challenges. The first is how to reduce primary errors in detecting forest losses from space. Brazil's yearly survey, dubbed PRODES, is based on the situation each August, before fall clear-cutting season, and uses software that searches images for bare ground. But Landsat passes over any one forest area only twice in a month, and clouds can obscure areas during one or both passes. Any gaps are filled with data from July or September, massaged with algorithms. "You're providing the best of your knowledge," says mathematician Thelma Krug of INPE, which reported that 18,793 $km^2$ of Amazon forest, with a 4% margin of error, were destroyed in 2005. That figure includes only clear-cutting, because the satellites' 20- to 30-meter resolution cannot detect less dramatic disturbances.

One important omission is selective logging for timber, says Asner. In 2005, his team determined the fraction of green reflectance from each Landsat pixel, aided by considerable fieldwork to calibrate how nonvisual light frequencies could inform that calculation. They concluded that Brazil was omitting a whopping 12,000 $km^2$ or more of so-called selectively logged forest areas per year (*Science*, 21 October 2005, p. 480). Asner fears that any system rewarding efforts to halt deforestation could miss a substantial source of emitted carbon if selective logging is not included. Others believe that logging has less of an impact: Skole says Asner could have mistaken thin forests or wetlands for logged forests because their infrared image can "mimic … a logged forest." He also notes that many logged areas grow back. INPE estimates that the per-hectare emissions from selective logging are 2% of those from clear-cutting.

Even if scientists improve their monitoring of activities on the ground, however, they have only crude methods of calculating how much carbon a particular area of rainforest will emit once cleared. Estimates of the Amazon's total organic stock of carbon—including living and dead trees—range from 60 billion to 120 billion tons. National estimates are equally uncertain: Brazil calculated that deforestation and loss of grassland had emitted roughly a billion tons of $CO_2$ into the atmosphere in 2004, plus or minus 30%. Several experts told *Science* that the margin of error is even larger.

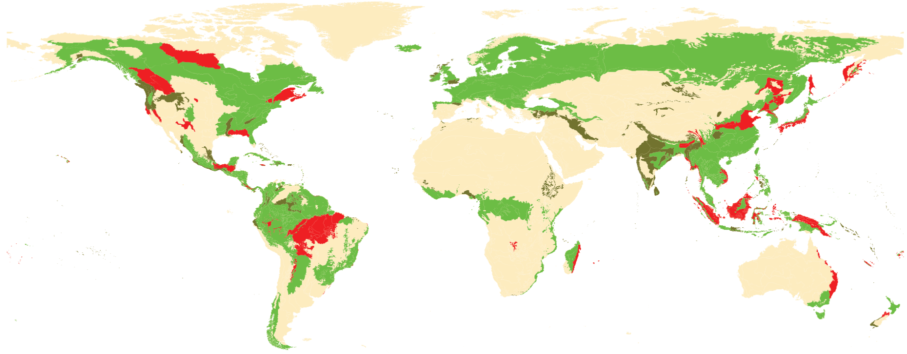
One problem is the heterogeneity of forests and the inability to identify denser, taller forest areas within larger regions. Historical sampling measurements in western Brazil only include trees at least 10 cm in diameter. "We need more science," says geographer Ruth DeFries of the University of Maryland, College Park. One low-tech step, says ecologist Richard Houghton of Woods Hole Research Center in Massachusetts, would be repeated sampling of trunks and better biomass equations that encompass the whole tree. "We don't have many studies that have looked below ground at the roots," he says. Even within a 1-hectare site, he says, the variability is maddening.

> "We need to **get these error bars down.**"
> —Annie Petsonk, Environmental Defense

Better eyes would also help. Japan's Advanced Land Observing Satellite (ALOS), launched last year, uses radar to see through the canopy and spot cleared sites that Landsat's cameras would miss. Initial results show decent contrast between forested and nonforested areas to a 50-meter resolution, says Woods Hole's Josef Kellndorfer. Upcoming ground studies in Brazil, Congo, and Uganda will aim to calibrate ALOS's ability to estimate biomass, aided by interferometry that could infer tree heights.

Radar would also be a boon to cloudy countries such as Gabon, whose rainforests have been largely hidden from satellites until now. And ALOS's youth is also welcome. Widely available and relied upon, Landsat 5 was built for a 3-year stint and is nearing a quarter-century of labor. It "could go any moment," worries DeFries. Christopher Justice of the University of Maryland, College Park, says that possibility highlights the need for "better international cooperation" to make sure data from other sources is just as easy to share.

## Global Deforestation, 1990–2000




**Going, going…** Tropical deforestation, in hot spots including Brazil, Madagascar, Indonesia, and West Africa, is a big driver of rising $CO_2$ levels.

SOURCE: THE NATURE CONSERVANCY AND HANSEN AND DEFRIES, 2004

### Ground truth

DeFries says that those who care about rainforests shouldn't let the quest for improved detection stand in the way of making good use of what is already clearly visible. She's cheered by a campaign that has protected tens of thousands of square kilometers of Brazilian rainforest since 2004. A general trend of falling beef and soy prices has helped by cutting demand for land, environmentalists say. So has daily data from Terra, analyzed by INPE, that Brazilian officials have used to probe roughly 100 instances of possibly illegal deforestation, says INPE's Dalton Valeriano.

The government could step up its enforcement activities, says geographer Carlos de Souza Jr. of independent watchdog Imazon in Brazil, if its mapping work were more solid. Using the same data that INPE collects, de Souza has calculated monthly totals that exceed or fall short of the government's number by thousands of square kilometers. He fingers data-sampling techniques, clouds, or different aggregating methods as possible culprits. And he worries that the government is learning about some illegal clear-cutting belatedly, from the yearly PRODES survey. "The most important thing is stopping deforestation as it is happening, not after," says de Souza.

An international incentive system could strengthen Brazilian resolve, says Daniel Nepstad of Woods Hole. "If this is happening without a carrot, imagine what would happen with a carrot," he says. **–ELI KINTISCH**





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