Choose satellites to monitor deforestation
Illegal logging threatens tropical forests and plans for managing carbon stocks. Build a space warning system, say Jim Lynch and colleagues.

Governments are making headway on agreements to stop the destruction of tropical forests and thus save carbon emissions. International climate change negotiations are developing incentives for implementing the United Nations REDD+ framework: Reducing Emissions from Deforestation and Forest Degradation, extended to include conservation, sustainable management of forests and the enhancement of forest carbon stocks. So far, there is no agreed way to monitor forests on the scale necessary.

The tropics cover half the Earth's land area. Tropical deforestation contributed 12% of total anthropogenic carbon dioxide emissions in recent years[1]. Surveys on the ground of millions of square kilometres across international borders are not feasible for practical and political reasons. Satellites provide the only realistic means of viewing vast areas regularly. But guidance needs to be formulated on which Earth observation systems should be used and how monitoring, reporting and verification should be achieved.

The Intergovernmental Panel on Climate Change (IPCC), under the UN Framework Convention on Climate Change (UNFCCC), is developing forest remote sensing plans for adoption by the 19th Conference of the Parties (COP-19) in Warsaw in November 2013. But current discussions are failing to agree on standard set of satellite methods, which can be employed by all parties.

Two things are currently missing. First is a strategy to monitor global forests on a daily basis, to allow authorities to act quickly to stop illegal logging. To be effective this will require a new set of internationally funded tropical orbiting satellites**.** Only the step-change from damage mapping to early warning will enable us to protect global forests. Second is a set of agreed methods to provide Monitoring, Reporting and Verification (MRV) of forest carbon stocks at least annually to make a commodity of forest carbon to allow an income stream to reward avoid deforestation and reforestation.

Real time monitoring

Implementing REDD+ requires many facets of the carbon cycle to be monitored. Tree cover and carbon emission**s** as a result of felling must be tracked. The state and health of the forests must be assessed from colour changes due to chlorophyll loss. Biomass, dead organic matter and soils must be included in a carbon budget of the forest ecosystem.

Changes in land-use need to be recognized, as different types of forest vary in their capacity to store carbon. Indonesia's conversion of tropical forest to palm oil plantation, for example, reduces the land's value from a REDD+ perspective.

Illegal logging is a major issue as 1.2 billion people, a fifth of the world's population, depend on forests for their livelihood. International agencies estimate that governments lose between US$ 30-100 bn per year through this route. This results in timber prices being depressed by 16%; the money lost could be spent on the development of the countries. Reducing deforestation is one of the Princeton 15 Stabilization wedges to help control climate change[2]. If REDD+ will be successful and current deforestation rates are halved by 2050, avoided greenhouse gas emissions will amount to 50 Pg carbon[3,4].

Existing and planned optical and radar satellites are capable of monitoring all these characteristics, and could be made available to independent monitors. But international bodies and national governments have been slow to formulate guidelines for obtaining and applying remote sensing data. Without the right technologies being in place and globally accepted standards, billions of dollars could be wasted on projects that do not deliver.

The EU, for example, does not specify how forestry information should be collected by countries signed up to its Forest Law, Enforcement, Governance and Trade programme under Voluntary Party Agreements initiated in 2005 with supplementary regulation in 2008, which means a proliferation of different methods which cannot be directly compared. Moreover at the moment REDD+ credits will not be accepted within the European Emission Trading Scheme.

Some steps are being taken to fill this recommended methods gap. A group of scientists in the GOFC-GOLD (www.fao.org/gtos/gofc-gold/) programme have published a REDD Sourcebook on the use of satellite imagery for REDD, describing methods for monitoring and reporting anthropogenic greenhouse gas emissions and removals associated with deforestation, gains and losses of carbon stocks in forests remaining forests, and forestation. The Group on Earth Observation's Global Forest Observations Initiative (GFOI) is developing guidance to inform countries how to acquire, process and analyze satellite data**,** consistent with the good practice guidance for emissions inventories by the Intergovernmental Panel on Climate Change (IPCC).

The Committee on Earth Observation Satellites (CEOS) began in November 2011 to implement a strategy to assure satellite data supply to GFOI-participating countries. This strategy is limited, however, as it currently only foresees one optical image survey per year. This is a problem to the large variations in forest carbon stocks with seasons. In addition cloud cover is a major obstacle for optical satellites and thus much of the world will be missed; to achieve good annual coverage optical measurements need to be taken every week or two weeks to ensure the best complete annual coverage. In summary the GFOI and CEOS lack ambition and the understanding of the full potential of satellite surveys.

What is missing from these efforts is a strategy to monitor global forests for deforestation in a near-real-time mode. We must go beyond just mapping damage to offering early warnings so that Governments can take direct and immediate action to catch illegal loggers.

Satellites offer the cheapest way to scan large areas, with cost ranging from £200 down to £50 per km^2 depending on spatial resolution. Optical sensors in different spectral domains are sensitive to vegetation greenness, fractional tree cover, forest type and vegetation density**.** They can cover millions of km^2 in a single image while resolving around 20 metres on the ground, or 1 km over a smaller area**.** Current satellites include NASA's Terra and Aqua, the Chinese/Brazilian CBERS series, the Disaster Monitoring Constellation (DMC) and SPOT.

Radar systems penetrate cloud, which is common in the topics. Microwave backscatter from leaves is picked up by Synthetic Aperture Radar (SAR) satellites such as TerraSAR-X. Although historically expensive, within the next year a new generation of cheap radar mini-satellites, such the UK's NovaSAR-S range, the

European Sentinel-1 mission and the Japanese ALOS-2, will complement optical systems affordably.

However, no current or planned radar satellites will monitor deforestation within a sufficiently repeated time window of at least four times a day that would allow effective intervention from authorities in cases of illegal logging.

Image analysis and information distribution after on-board data acquisition is also slow taking months as there is currently no urgency for the data. Thus deforestation is only mapped a long time, may be years, after it happened.

Increased effort is needed on the ground to calibrate the optical and radar satellite data by tracing it to known 'ground truth' characteristics, which can be supplemented by laser imaging (LIDAR). Airborne LIDAR is expensive and can only sensibly be used for small plots, and the ICESAT satellite carrying LIDAR was decommissioned in 2010 and the new version will not be launched until 2016.

Way Forward

First, governments and the IPCC need to accept that satellites are the only efficient and realistic way to provide monitoring for REDD+ [5,6]. This must be enshrined in international law through the UNFCCC process and documented in detail. Second, governments must commit to securing and maintaining systems of Earth observing satellites to carry out the monitoring.

Two networks will be needed: a constellation of 5 tropical-orbiting radar satellites to provide daily scanning of tropical forests at 5-20 m resolution irrespective of weather for an early warning system of deforestation; and optical satellites to measure reflectance on a weekly or monthly basis, to allow more detailed annual monitoring of forest carbon stocks.

The former would need a new set of low-cost radar satellites to be built and launched. Conventional SAR satellites have been very expensive (typically £250-500M each in orbit). However recent developments in modern satellite techniques by SSTL and ASTRIUM in the UK have produced an affordable S-band mini-satellite, ideally suited to forest monitoring, that reduces the cost to enable the whole constellation of 5 satellites to be built and launched for under £200M**.** In addition a dedicated ground crew would be required to ensure that the data was processed immediately to ensure it could be used as an early warning system. The latter could be achieved with existing and future satellites at a range of resolutions, including NASA's MODIS, DMC, SPOT or Landsat, as available. But major efforts would be required by participating countries to provide regular ground data to calibrated the satellite data and reduce the uncertainties in their carbon estimates.

Policy-makers must back the right satellites to monitor and save the world's forests.

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