ECCM technical note:

Carbon sinks in the Amazon – the evidence

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SUMMARY

There is a growing body of research about carbon cycling in tropical forests, particularly in the Amazon. Various studies focussing on the Amazon indicate that forests in this region are accumulating carbon due to the increased level of CO_2 in the atmosphere, so-called 'CO_2 fertilisation'. According to these studies the average uptake of carbon by forests in the Amazon region is approximately 1tC/ha/yr (ranging between 0.3 and 5.9 tC/ha/yr).

This figure is a composite of several studies and there is considerable year-to-year variation in carbon flux due to variation in annual rainfall; some studies suggest that forests can act as a net source of carbon in drought years, other data indicate that although carbon uptake is reduced in drought years forests continue to act as a 'carbon sink'. The future of the Amazon carbon sink will therefore depend on the extent to which forests continue to respond to climate change itself through CO_2 fertilisation and changes in rainfall in Amazonia.

CARBON UPTAKE BY FORESTS

Carbon dioxide is absorbed from the atmosphere by growing trees and other vegetation through the process of photosynthesis. Using the energy of sunlight, plants produce carbohydrates from CO_2 and water. However, as well as absorbing CO_2 through photosynthesis, CO_2 is also emitted by forests through plant respiration and through the processes of death and decay. The net balance of CO_2 uptake and release will determine whether an ecosystem is acting as a sink or source of carbon.

Carbon sequestration, where carbon from the atmosphere is absorbed by growing vegetation and stored in wood, other biomass and soil organic matter, is highest in young forests and will tend to reduce as forests reach maturity.

Carbon fertilisation

Intact, mature forests were once thought to be in a state of equilibrium in terms of CO_2 flux, with CO_2 uptake by photosynthesis being balanced by CO_2 releases through respiration. However, there is strong evidence to suggest that intact forests are actually responding to the increased levels of CO_2 in the atmosphere caused by anthropogenic emissions of carbon dioxide, so-called 'CO_2 fertilisation'. The pre-industrial level of atmospheric CO_2 concentration, estimated as 280ppm[1], had risen to 366ppm by 1998 and it is currently rising by about 1.5ppm per year[2] (Keeling and Whorf 1999). Controlled experiments (Norby *et al.* 1999) have shown that this increase in CO_2 concentration does promote tree productivity leading to an increase in carbon uptake by mature trees.

The extent to which CO_2 fertilisation affects productivity of natural forests will depend on a number of factors including the availability of water and nutrients. However even a small increase in productivity (Norby *et al.*'s results suggest a 0.3% increase in productivity per year) could produce an observable increase in carbon uptake by forests. Malhi and Grace (2000) estimated that a 0.3% increase would translate to an annual uptake of 1tC/ha/yr in Amazon forests.

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[1] ppm = parts per million

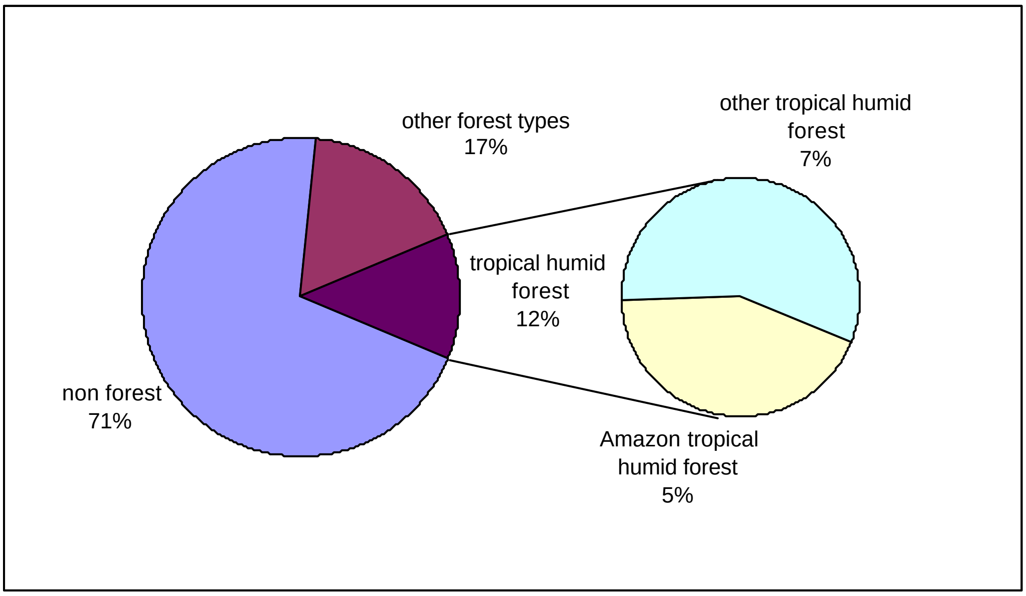
[2] equivalent to an annual increase of 3 billion tonnes of carbon.

EVIDENCE FOR CARBON FLUXES IN THE AMAZON

Amazon region (general description, areas, forest types etc.)

The Amazon region contains the largest expanse of tropical forest in the world, accounting for 17% of the world's forest area (FAO 2001, Phillips *et al*. 1998). The total area of lowland, humid Amazon forest in 1990 was 710 million ha (Phillips *et al.* 1998) 500 million ha of which was closed forest (Houghton 1997). Due to the large area of forest in this region even a very small rate of carbon uptake per hectare could lead to a very significant global carbon sink.

Global forest cover (FAO, 2001, Phillips *et al*. 1998)



Carbon flux studies from Amazon forests

There are a number of studies that have attempted to estimate carbon flux in intact Amazon forests. There are various methods available for measuring carbon fluxes and these have different strengths and weaknesses; some provide very accurate measurements but operate at small temporal and spatial scales, others provide longer-term estimates for larger areas of forest but rely on critical assumptions for the accuracy of the estimates (see also annex 1):

Forest inventory

Forest inventory provides a means of directly measuring changes in forest biomass. Forest inventories have been carried out routinely for a number years in the Amazon. Inventory data allows estimates of changes in carbon stocks over a number of years. However, the accuracy of estimates is dependent on the standardised data collection techniques. Also, most inventories only consider timber stocks so it is necessary to estimate carbon in other pools (roots, branches, leaves and soil) using biomass coefficients. Phillips *et al.* (1998) used data from these inventories to calculate changes in forest carbon stock and concluded that Amazon forests were accumulating 0.62 (± 0.37) tC/ha/yr. Phillips' team found that in El Niño years carbon uptake was reduced but that forests were still acting as a net carbon sink.

Eddy covariance

Eddy covariance involves the measurement of changes in CO_2 concentrations above the forest canopy. Eddy-covariance allows direct measurement of changes in all ecosystem carbon stocks. However, eddy covariance studies are limited in temporal and spatial scales and there are suggestions that carbon uptake may be overestimated due to various limitations in the method. Three studies have been carried out in Amazon forests to date (Grace *et al*. 1995, Fan *et al*. 1990 and Malhi *et al*. 1998). These studies concluded that Amazon forests were accumulating 1.0, 2.2 and 5.9 tC/ha/yr respectively.

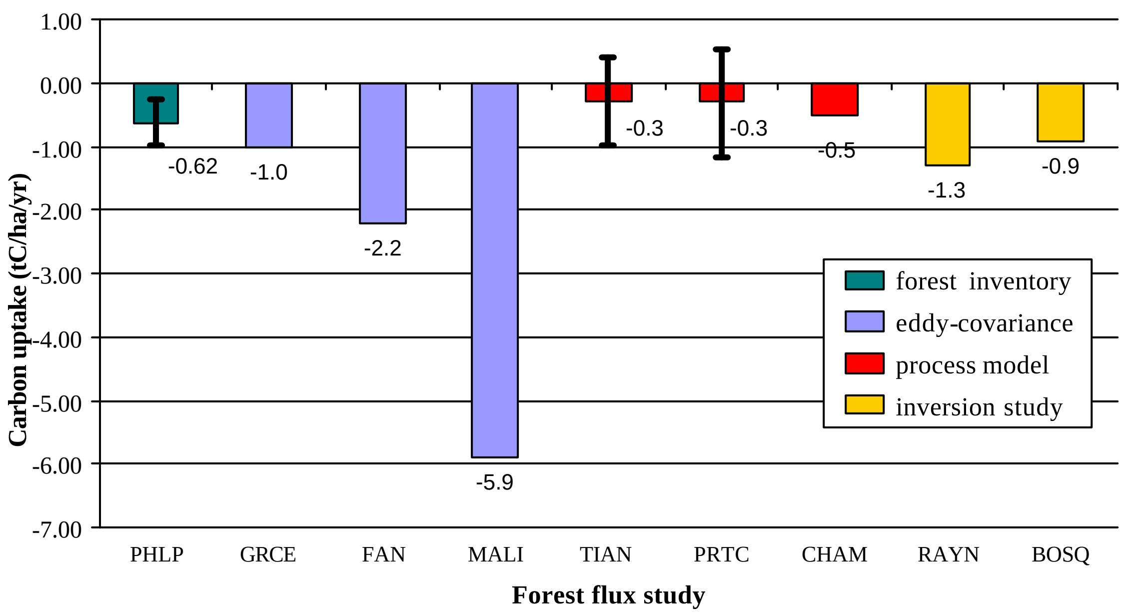
Carbon models

Computer-based models of the processes that underlie ecosystem functions have been developed by researchers. These models simulate how the processes of photosynthesis and respiration through which carbon is exchanged with the atmosphere respond to changes in temperature, rainfall and other external influences. Tian *et al.* (1998) and Prentice and Lloyd (1998) both estimated that average uptake by Amazon forests was 0.3tC/ha/yr. Chambers *et al.* (2001) estimated that uptake was 0.5 tC/ha/yr. It is important to note that Tian *et al.* and Prentice and Lloyd both found considerable year-to-year variation and that in dry El Niño years forests acted as a net source of carbon of 0.3 and 0.6 tC/ha/yr respectively.

Inversion techniques

Inversion studies estimate carbon fluxes at global and regional levels using measurements of changes in atmospheric CO_2 concentration together with atmospheric transfer models. Although inversion studies estimate total net carbon fluxes for a region (i.e. carbon uptake by intact forests and carbon emissions by deforestation), carbon uptake by intact forest can be calculated by deducting estimated emissions from land use change. The two most relevant studies Rayner *et al.* (1999) and Bosquet *et al.* (2000) both imply a carbon uptake of around 1tC/ha/yr. These refer to the entire tropical South America region rather than the Amazon Basin alone.

Comparison of results from different carbon flux studies (negative sign denotes carbon uptake, positive sign denotes carbon emission)



Uncertainties associated with carbon uptake estimates

All available studies indicate that on average Amazon forests are accumulating carbon. If we take the mean of all available estimates this would suggest that carbon uptake is currently around 1tC/ha/yr. However, several of the studies show considerable year-to-year variation, this is particularly important in the modelling studies by Tian *et al.* 1998 and Prentice and Lloyd 1998 who conclude that in some years Amazon forests act as a net source of carbon to the atmosphere. These variations are primarily due to changes in rainfall and temperature associated with the El Niño weather phenomenon which causes drought in some area of the Amazon.

The future rate of carbon uptake by Amazon forests will therefore depend on the extent to which forests continue to respond to CO_2 fertilisation. Some studies (e.g. Cox *et al.* 2000) suggest that climate change will cause significant drying in the Amazon[3], creating a carbon source as forests decline although there is also evidence to suggest that CO_2 fertilisation today will continue to result in carbon uptake for many years to come (Chambers *et al.* 2001).

[3] Cox et al 2000 suggest that drying in the Amazon will cause a reduction in forest carbon stocks after 2050.

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Annex

Comparison of flux measurement techniques

Method	Scale	Advantages	Disadvantages
Forest inventory (measurement of changes in biomass in vegetation/soil)	Sample plots (1 to 10's ha)	Long term data sets (10's of years)	Reliant on generic biomass coefficients. Assumes standardised inventory techniques.
Eddy covariance (direct measurement of CO_2 fluxes above forest canopy)	Forest stands (10-100's ha)	Allows direct measurement of changes in all carbon stocks in an ecosystem.	Short term datasets (1 year or less). May overestimate carbon uptake.
Process based models (simulation of changes in carbon stocks in vegetation/soil)	Ecosystems		Based on numerous ecological and climatic assumptions
Inversion studies (atmospheric geochemistry carbon cycle models)	Regional/global		No data available specific to Amazon region

Carbon uptake by intact Amazonian forest

Study type	Net flux from forest (tC/ha/yr)	Notes	Reference
Forest inventory	0.62 (± 0.37)	Duration: 1975 to 1996. Location: 97 sample plots across Amazon region	Phillips et al. (1998)
Eddy-covariance	1.0	Duration: 44 days in 1993 (results extrapolated to 1 year). Location: Jaru, Rondonia	Grace et al. (1995)
Eddy-covariance	2.2	Duration: ~ 1 month in 1987. Location: Ducke, near Manaus,	Fan et al. (1990)
Eddy-covariance	5.9	Duration: the year of 1995/96 Location: Cuieiras, near Manaus,	Malhi et al. (1998)
Process model	0.3 (max inter-annual variation -1to 0.3)	Duration: 15 years Location: whole Brazilian Amazon.	Tian et al. (1998); Tian et al. (2000)
Process model	0.3 (max inter-annual variation -1.1 to 0.6)	Duration: 15 years Location: whole Brazilian Amazon.	Prentice and Lloyd (1998)
Stochastic-model	0.5		Chambers et al (2001)