FORESTS & WEATHER SYSTEMS

The role of forests in influencing local climate is well documented. Studies from many parts of the world show that forests affect cloud formation, rainfall and temperature. In recent years, the evidence has been growing that forests also have an impact on global climate processes, and that tropical forests in particular play a crucial role. Studies of the hydrological cycle, energy budget and atmospheric circulation indicate that tropical deforestation could have large-scale climatic effects (Shem & Dickinson, 2006).

Much of this evidence comes from research in Amazonia, where the majority of work in this field has been undertaken. In contrast, there remains a lack of understanding of the climate of Central Africa, reflecting both the absence of long-term data and the limited research facilities for this region (Todd & Washington, 2004). This gap is beginning to be filled, and the existing research indicates that the forests of Central Africa play an important role not only in the local climate, but also that of Africa and other parts of the world.

HOW FORESTS AFFECT CLIMATE

Forests influence weather systems through the exchange of water and heat with the atmosphere. Forests tend to absorb solar energy (i.e. they have a low albedo or reflectivity). They also have a high leaf area index, and due to both these features, the rate of evapotranspiration is very high, comparable to the evaporation rate from the oceans. In addition, the surface of forests is aerodynamically rough, increasing air turbulence. In contrast, deforested areas tend to have a higher albedo, reflecting more solar energy. They also have lower surface roughness and leaf area index, and the moisture storage capacity of the ground is less (Mahé et al., 2005; Maynard & Royer, 2004). Consequently, changes in land-cover alter the cycling of energy and moisture within the atmosphere, affecting local air temperatures, humidity, as well as atmospheric circulation patterns.

The role of forests on climate have been studied using several approaches, including global climate modelling, regional climate modelling, theoretical approaches and also field observations and historical records (Berbet & Costa, 2003). Much of the research is based on modelling, and it should be noted that, because of the limitations of technology and computer power, relatively simple scenarios have had to be used, particularly in earlier studies (Nasi, 2005). For example, many models assume complete deforestation, whereas in reality, the process of deforestation may be a gradual one, forests undergoing gradual degradation and fragmentation and often being replaced by mosaics of vegetation. Furthermore, sea-surface temperatures (SST) and the effect of the El Niño-Southern Oscillation (ENSO) are often not included, both of which have a major impact on global and African climates (Hulme et al., 2001). However, even these relatively simple models are important in giving an indication of the processes at work and possible outcomes of land-use change. Furthermore, the models are becoming more sophisticated, for example, taking into consideration the evolution of vegetation types, and allowing for incorporation of various feedbacks between global warming and vegetation.

THE EVIDENCE

There is a large body of evidence to indicate that deforestation has a significant impact on local rainfall and temperature. In Amazonia, where much of this work has been undertaken, modelling experiments indicate that deforestation would result in an increase in local surface air temperatures, with figures of up to 5°c being suggested if there was complete deforestation (Dickinson & Henderson-Sellers, 1998, cited in Snyder et al., 2004b). Most research suggests that there would be a reduction in local evapotranspiration and rainfall (Costa & Foley, 2000; Mahé et al., 2005; Voldoire & Royer, 2004), although some studies indicate that if there is only small-scale or sporadic deforestation, then local rainfall could be increased (Berbet & Costa, 2003; Snyder et al., 2004b).

A number of studies have modelled the impact of complete deforestation in tropical Africa, and these all predict that this would result in a decline in rainfall and increase in surface temperatures within the affected region (Avissar & Werth, 2005; Maynard & Royer, 2004). Semazzi & Song (2001) suggest that during the dry season, when the effect would be severest, rainfall could decline by up to 3mm per day. Snyder et al. (2004b) reported similar findings, calculating that seasonal rainfall would decline by up to 3.2 mm per day, equivalent to a reduction of 47%.

Models of the impact of deforestation within Central Africa also suggest that there would be a decline in local rainfall (Shem & Dickinson, 2006). Baidya Roy et al. (2005) modelled the effects of complete deforestation in Gabon and Congo-Brazzaville, suggesting that this would result in a substantial reduction in rainfall during the wet season, of over 10% in some regions. Furthermore, they concluded that extensive logging could result in a shift in vegetation distribution because of the resulting decline in rainfall.

Changes in rainfall may be due to the impact of deforestation on mesoscale circulations within the atmosphere, as these strongly influence the transport of heat and moisture, and thus, cloud formation. Evidence for this has been found from observations of cloud patterns over deforested areas (Baidya Roy & Avissar, 2002; Chagnon et al., 2004; Lawton et al., 2001). Forest fragmentation may also influence rainfall patterns, because of its impact on convective flows and the hydrological cycle (Marland et al., 2003). In fact, edge effects may exacerbate changes in hydrology, for example, with drying of the soil. Therefore, fragmentation can have a greater impact than would perhaps be assumed from considering only the area of deforestation. For example, research in Amazonia found that a decline in forest cover of 17% had had a significant impact on regional rainfall regimes (Baidya Roy & Walsh, 2005).

In Central Africa it is thought that deforestation would have a particularly strong effect on local rainfall. This is because a large part of the rainfall in this region comes from the recycling of moisture by the forest, whereas in other monsoon regions most rainfall comes from water vapour accumulated from the oceans (Cadet & Nnoli, 1987; Monteny, 1987). One report estimates that as much as 75-95% of rainfall is recycled within the Congo Basin, while in Amazonia, this figure was put at 50% (Job, 1994, citing Brinkman, 1983). In particular, Cadet & Nnoli (1987) suggest that a significant source of rainfall in Central Africa is evapotranspiration of moisture in the coastal areas of the Gulf of Guinea.

The same is thought to be true in West Africa. Here, one estimate suggests that the tropical rainforests of the southern Ivory Coast inject water into the atmosphere equivalent to 55-75% of the annual precipitation in the region (Brou Yao, 1997 cited in Mahé et al., 2005). Indeed, deforestation in West Africa is thought to have been a major factor accounting for the decline in rainfall in the region in the last few decades, because of its impact on the monsoon circulation, as considered further below (Zheng & Eltahir, 1998).

REGIONAL AND GLOBAL EFFECTS

There is growing evidence that deforestation in tropical areas impacts on weather systems both regionally and globally. The tropics are thought to have a major influence on global weather systems because of their important role in the exchange of water and energy

[6] Teleconnections are linkages between changes in atmospheric circulation occurring in widely separated parts of the globe.
[7] The Hadley circulation dominates the tropical atmosphere, and is intimately related to the trade winds, tropical rainbelts, subtropical deserts and the jet streams. Within this circulation air rises near the equator, flows towards the pole some 10-15 km above the earth's suface, (cont. next page)

with the atmosphere and on atmospheric circulation patterns. Therefore, the impact of deforestation in this region is thought to be especially strong.

There remains considerable uncertainty as to the scale of such impacts. However, if the worst case scenarios prove true, then land-cover change in tropical regions could have devastating consequences for water resources, agriculture and other activities in various parts of the world (Avissar & Werth, 2005: 144-5).

Tropical land-use change is thought to affect the global climate through teleconnections[6]. This influence may be especially strong for tropical forests because the tropical forest regions are where the major deep convection systems are located (Shem & Dickinson, 2006; Todd & Washington, 2004). Through these systems, large amounts of moisture are transferred into the atmosphere from the transpiration and evaporation of water from the forest canopy and soil. This moisture is transported to higher levels in the atmosphere, and is redistributed to other tropical regions as well as to regions outside the tropics through the Hadley and Walker circulations[7] and forcing of the Rossby wave[8].

The Congo Basin is the third largest region of deep convection. As such, it is not only responsible for the majority of rainfall in tropical Africa (Mahé et al., 2005), but is also a major driving force of large-scale atmospheric circulation (Chase et al., 2000; Snyder et al., 2004a). Therefore, deforestation in this region could disturb global circulation patterns through changing the distribution and intensity of the convection system (Feddema et al., 2005; Marland et al., 2003; Maynard & Royer, 2004; Pielke et al., 2002; Snyder et al., 2004a).

A further reason why changes in land-cover in the tropics could have a significant impact on the climate is that horizontal temperature gradients are weak in this zone. This means that the atmosphere is sensitive to any changes in the distribution and intensity of heat sources and sinks. Therefore, any changes of surface condition in the tropics (such as those resulting from deforestation) will have a strong influence on vertical advection, with repercussions on circulation systems such as those of Hadley and Walker (Mahé et al., 2005).

Circulation of the monsoons could also be affected, since these are partly driven by the contrast between the land and oceans. Dense forests have high heat flows, because of their low albedo and high surface humidity. Deforestation lessens the contrast between the land and oceans, and so could disrupt the monsoons (Mahé et al., 2005; Zheng & Eltahir, 1998).

As a result of these processes, it has been hypothesised that continued deforestation in Central Africa could significantly affect the regional moisture balance, leading to irreversible regional climatic changes and also affecting global rainfall patterns. For example, research has indicated that Central Africa is a major source of moisture for West Africa (Cadet & Nnoli. 1987), with one study estimating that 17% of the latter region's rainfall comes from evapotranspiration in Central Africa (Gong & Eltahir, 1996).

Modelling of the changes induced by tropical deforestation either within Central Africa or the tropics as a whole gives some indication of the possible impact on the global climate, although there is some variation in the researchers' findings. Chase et al. (2000) investigated the possible role that existing vegetation change has played on the climate, by comparing model scenarios of current observed vegetation, with that of a simulated 'natural' land cover. Their findings suggest that deforestation in the tropics has increased temperatures globally and in many higher latitude regions, in particular over North America, southern Asia and central Europe, changes that could be

(from previous page) before descending in the subtropics, and flowing back towards the equator (the trade winds) near the surface. The Walker circulation lies over the Pacific Ocean - air rises over the Western Pacific and descends over the Eastern Pacific. It is an important element of the El Nino Southern Oscillation (ENSO).

[8] Rossby waves are large-scale motions in the atmosphere.

explained by the impact of land-cover change on large-scale atmospheric circulations. Based on models of future tropical deforestation, Avissar & Werth (2005) found that this would significantly reduce rainfall throughout the equatorial region. Voldoire & Royer (2004) predict that complete tropical deforestation would result in a decline in global rainfall. In addition, while there would be little effect on the mean global temperature, their research suggests that there would be an increase in the day-to-day variability with more extreme minimum and maximum temperatures. They also found that there would be greater variability between years, with extreme conditions becoming more frequent. Such changes in the variability of the climate could be more significant than changes in mean climate, since they would have a greater impact on agriculture and ecologically, while an increased occurrence of extreme weather could have potentially devastating consequences for people. For example, the daily maximum and minimum temperature are an important determinant of species distribution and the viability of different agricultural systems (Voldoire & Royer, 2004).

Semazzi & Song (2001) used a model based on the total clearing of African tropical rainforests, and predicted a decline in rainfall over Eastern and Western Africa, but an increase in other regions, including over southern DRC and southern Africa. They also estimated that there would be an increase in surface temperature of up to 2.5° C and of ground temperature of 5° C in deforested areas. In another such study, Avissar & Werth (2005) predicted that although deforestation in Central Africa would not affect the total amount of global rainfall, its distribution would be affected. Thus, they estimated that there could be reductions in rainfall of 5-15% in north America, and up to 25% over Ukraine and Russia, while there would be increases of up to 30% in the Arabian Peninsula and East Africa.

RELATIVE IMPORTANCE OF GREENHOUSE GAS EFFECTS AND LAND-USE CHANGE

Palaeoclimatic evidence and modelling of the climate both indicate that land-cover has a major role in climate. However, there remains uncertainty as to its relative importance compared with the impact of increases in the concentration of atmospheric greenhouse gases. Recent studies do suggest that at a global scale the latter may be more important than land cover change (Mahé et al., 2005). However, that is not to say that the impact of deforestation can be ignored, since its impact at the local and regional level may be significant, and it is changes at this scale that are of most concern to people, for example, through its impact on agriculture.

Additional modelling is needed at this scale to predict likely scenarios. For example, it has been suggested that in Africa, the effects of deforestation and global warming could be counteractive in relation to their effect on rainfall. Thus, deforestation is likely to reduce rainfall while global warming is predicted to increase this. However, these two factors are both likely to enhance temperatures, and so the effect of each will be exacerbated (Maynard & Royer, 2004). These researchers conclude that more detailed modelling is required to determine the interaction of these phenomena and thus, the direction and magnitude of any such changes.