Deforestation impact assessment: the problems involved

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ABSTRACT  Deforestation may result in rapid positive environmental feedbacks because of the large energies inherent in the climate system, e.g. soils are eroded and fertility declines. The relative importance of the radiative and hydrospheric feedbacks and their respective relaxation times are extremely difficult to assess. The responses of general circulation climate models seem to be very sensitive to the land surface parameterization employed. Here we investigate some of the difficulties encountered by climate modellers undertaking climatic impact assessments of the removal of forest vegetation in tropical regions. This study considers the different results of climate models with varying degrees of sophistication. Improvements in hydrological and land surface parameterizations in climate models are necessary in order to obtain a more coherent picture of possible environmental impact.

INTRODUCTION

Land clearance during the development of a country results in the
removal of original vegetation and intensification and modification of agricultural practices in the reclaimed areas. Both these effects can have significant influence upon the local climate and ecology and may feed back to cause regional and global climatic perturbation. Tropical rainforests are biologically diverse, multi-layered, predominantly evergreen forests, with little to no seasonality, heavy rainfall (≥ 200-300 mm month⁻¹) and relatively constant temperatures (around 25°C) (see e.g. Fig.1). The dark, dense, moist vegetation gives these forests a lower surface albedo than almost any other natural or manmade area. Additionally, rainforests are hydrologically very active. Fluxes of water vapour from the dense vegetation canopy are often higher than from even tropical oceans (≥ 1500 mm year⁻¹ cf. ≈ 1000 mm year⁻¹).

Deforestation is detrimental in the tropical environment, since most of the nutrients are concentrated in the above-ground biomass and therefore removal of the vegetation leads to rapid decrease in soil fertility (Baumgartner, 1979; Jordan, 1982). Deforestation adds CO₂ to the atmosphere, thereby enhancing the greenhouse effect, and also leads to an increase in the surface albedo. It has been suggested that the removal of tropical rainforests will substantially alter
climate (Bolin, 1977; Woodwell et al., 1978; Sagan et al., 1979; Hampicke, 1980; Potter et al., 1981; Shukla & Mintz, 1982). Such claims merit careful investigation, especially as different climate models give rise to different predictions. In this paper, the possible climatic impact of tropical deforestation is discussed.

Climate modelling techniques are not yet sufficiently well developed to permit definitive statements about the magnitude or even the direction of likely perturbations. However, it is possible to consider the nature of the impact of these environmental changes and through analysing model results to establish possible climatic effects. Results from simple one-dimensional radiative convective models, a two-dimensional statistical dynamical model and from three-dimensional general circulation models are discussed here. It is concluded that, in terms of the potential for influencing climate at local scales, deforestation is a highly significant land use change. However, it is likely that a complete understanding of the way in which climatic modification will occur must await more complete and appropriate land surface parameterization schemes in climate models.

SURFACE ALBEDO CHANGE AND CLIMATE

Anthropogenic perturbations have already affected local urban climates and are now implicated in global climatic change (Hansen et al., 1981). Land clearance results in a number of environmental alterations possibly of significance for the climate: (a) increased surface albedo; (b) perturbation of the carbon cycle causing variations in the atmospheric levels of CO₂; (c) local changes in the water balance; (d) addition of particulates to the troposphere, both directly from combustion and by increasing the wind-blown dust, and (e) perturbation of the hydrological and turbulence characteristics over areas where tall forest stands are replaced by low crops of cleared land.

Increases in the level of atmospheric CO₂ have been monitored for over half a century (e.g. Keeling et al., 1976) and have been implicated in climatic change (e.g. Hansen et al., 1981). However, the interactions between the biosphere and the atmosphere are so complex (e.g. Woodwell et al., 1978; Hampicke, 1980) that there is, as yet, not enough information to permit climatic predictions based directly upon the effects of deforestation on the carbon cycle. Here we consider the climatic effects resulting from the two other primary changes caused by deforestation: surface albedo increase and modification of the surface hydrology.

All types of climate models have been used to test the sensitivity of the predicted climate to alterations in the land vegetation. Much more attention has been devoted to the effects of overgrazing in semiarid regions than to tropical deforestation (Charney et al., 1977). It is possible that results from the former type of sensitivity experiment may contribute to understanding of climate model sensitivity to all vegetation changes. We therefore review both types of experiments.

Sagan et al. (1979) used results from the one-dimensional radiative convective model of Manabe & Wetherald (1967) to estimate a 2 K temperature decrease caused by a planetary albedo change of 0.01.
They further suggest that anthropogenic changes over the last 25 years have led to a global temperature decrease of around 0.2 K. However, the rates of vegetation change and the albedo values they proposed have been questioned by Henderson-Sellers & Gornitz (1983). Their calculated planetary albedo increase is between 0.000 32 and 0.000 63 giving rise to a much smaller temperature decrease of the order of between 0.07 and 0.13 K. Such a temperature alteration is probably too small to be detected above the interannual and longer period variability (Hansen et al., 1981). The climatic modification proposed by Sagan et al. (1979) seems to be somewhat uncertain especially since their model did not include cloud-climate feedback effects.

Hansen et al. (1981) used their one-dimensional radiative convective climate model to calculate a temperature decrease of 1.3 K for a surface albedo change of +0.05. Using a linear interpolation of this result to estimate surface temperature change, the anthropogenic surface albedo changes given in Henderson-Sellers & Gornitz (1983) result in a temperature decrease of between 0.02 and 0.03 K. These temperature changes, which are forced, almost entirely, by the alterations in tropical forest areas, are very small. Henderson-Sellers & Gornitz (1983) therefore conclude that within the error ranges of global one-dimensional radiative convective climate models, the climatic impact of surface albedo change due to deforestation over the last 30 years is close to zero.

Two and three-dimensional climate models have also been used to study the possible impacts of vegetation changes. The nature of local feedback effects which could amplify the climatic impact of tropical deforestation are complex. Initially the increased albedo is likely to be offset by the reduced ability to lose energy through evapotranspiration and surface temperatures may increase. The stripping of vegetation from grassland areas, however, leads to a net cooling and hence an overall descent of air over the modified region, (Charney, 1975). Initially convection may increase and therefore, if there is sufficient water vapour available (say, transported from an upwind source area), cloud formation and possibly precipitation will increase. Hydrologists have not yet been able to make detailed studies of the local vs. regional movement of water vapour, and therefore estimating the environmental impact of forest removal and agricultural irrigation is difficult. Modelling studies by Lettau et al. (1979) suggest that a considerable proportion of the precipitation over the Amazonian forest results from regional evaporation rather than from advected moisture. Convective activity may be enhanced by providing an effective heat source at the surface. Water consumption for bare soils and young partial vegetation cover is found to be between 400 and 500 mm per year, whereas mature forests consume from 700 to 900 mm per year (Baumgartner, 1979). The decrease in evapotranspiration must lead to increased local runoff if precipitation rates remain constant. The interactions between the perturbed energy and water cycles as a result of deforestation are likely to be very complex. Negative and positive feedback effects may exist and predominate at different times and heights in the atmosphere. The interaction between surface albedo changes and local hydrological modifications may be critical for the final climatic state.
Charney et al. (1977) considered a simplified situation for their sensitivity studies of the effects of vegetation removal in semiarid regions. They attempted to estimate the effects of albedo-hydrology interactions by considering two extreme cases: zero evaporation and excessive evaporation. In the case of high evapotranspiration an albedo increase from 0.14 to 0.35 resulted in a large reduction in rainfall over all the semiarid and two of the three monsoonal regions investigated. In the case of negligible evapotranspiration, however, the same albedo increase resulted in a significant decrease in rainfall over only one of the semiarid regions considered.

Recently Sud & Fennessey (1982) have performed a similar series of experiments which support the earlier conclusions of Charney (1975) and Charney et al. (1977). It is interesting to note that Sud & Fennessey (1982) also draw attention to disturbances in areas removed from the region of albedo perturbation. They suggest that such relationships should be more fully investigated. Carson & Sangster (1982) also tried to incorporate the effects of simultaneous changes in surface albedo and local surface hydrology. Their investigation consisted of three sets of experiments: (a) fixed soil moisture content permitting potential evaporation with global snow free land albedo of 0.1 and 0.3: designed to test the sensitivity of the model to surface albedo; (b) fixed global snow free land albedo 0.2 with interactive soil moisture initialized at 15 and 0 cm: designed to test the sensitivity of the model to soil moisture content; (c) albedo as a quadratic function of soil moisture content with interactive soil moisture initialized at 15 and 0 cm. Lower albedo resulted in lower pressure over most land areas resulting in increased atmospheric ascent and convective rainfall in the case of fixed soil moisture. Higher soil moisture with fixed albedo resulted initially in greater rainfall over the land. Initially dry and initially wet runs were shown to converge, although global differences of approximately 0.2 mm day\(^{-1}\) in precipitation persisted even after 260 days. Moisture-albedo coupling generally caused greater spatial contrasts in rainfall, evaporation and heat fluxes than occurred in decoupled simulations. Carson & Sangster (1982) concluded that regional scale anomalies may be strengthened if interaction between hydrology and albedo is incorporated into climate models.

Potter et al. (1975) also considered two extreme cases of "wet" and "dry" deforestation. They found that in the latter experiment, in which the albedo of rainforest areas was increased from 0.07 to 0.25 and runoff was increased whilst evaporation was decreased, the resulting climatic response was smaller than in the "wet" deforestation in which only the albedo change was made. They suggested that the increased effect in the case of "wet" deforestation is the result of increased cloudiness in this experimental simulation. They calculated that the globally averaged surface temperature decreased by 0.2 and 0.3 K respectively in the "dry" and "wet" deforestation experiments. Despite these interesting results Potter et al. (1981) do not consider the additional impact of hydrological changes in a later paper on a similar theme.

The impact of forest removal on the climate has also been studied using the GISS GCM (Hansen et al., 1983). In this study Henderson-
Sellers & Gornitz (1983) maximized the impact of tropical deforestation by concentrating all the likely alterations of the surface vegetation into one locality: a large-scale deforestation of the Brazilian Amazon region. The magnitude of the modification is equivalent to 35-50 years of deforestation at the current global rate concentrated in the Brazilian Amazon. This is therefore the locational antithesis of the global estimates of, for example, Sagan et al. (1979). Detailed climatological data for this region are extremely difficult to obtain. There were only 515 climatological stations in the whole of Brazil in 1976 (Schwerdtfeger, 1976) of which only four were radiosonde stations. The studies of Molion (1975) and Lettau et al. (1979) were based on hydrological data from as few as 28 stations in the Amazon basin. Validation of all climate models is therefore difficult. Here the climatology of two observation stations, Alegrete and Belém, are compared with model-derived rainfall and temperature statistics from the GISS GCM (Fig. 2). The regimes of these two locations, prior to the deforestation experiment, are reasonably well simulated despite the coarseness of this model's horizontal resolution: 8° latitude by 10° longitude.

The vegetation alteration (forest to grass/crop) caused a number of immediate effects. The surface albedo increased as a result of the vegetation replacement. This effect is particularly noticeable in the near infrared spectral region where grass/crop cover is known to exhibit high albedoes (values range from 0.1 at 0.5 μm to 0.35 at 1.0 μm). The roughness length is also significantly affected by the

![Graph of Monthly precipitation vs. temperature plots for the two stations, Alegrete (29°46'S, 55°47'W) and Belém (1°28'S, 48°27'W) cf. precipitation vs. temperature plots for two grid elements of the GISS GCM.](image-url)
vegetation change due to the small scale of topography in this region. An anticipated climatic response to the perturbation would be a lowering of surface temperatures together with a reduction in turbulent fluxes from the surface to the atmosphere, similar to the results of Potter et al. (1975, 1981). However, the field capacities, which are related to the vegetation in the GCM are also perturbed by the simulated deforestation. These and subsequent hydrological changes are found to feedback in such a way that the final surface temperature change is close to zero. Figure 3 shows that despite the increase of surface albedo from 0.11 to 0.17, the temperature does not decrease. This is because the reduction in evaporation caused by a combination of less available water and reduced ability

![Graph showing temperature, rainfall, albedo, evaporation, cloud cover, and ground water layer changes over 10 years for standard and deforested conditions.](image)

**FIG. 3** 12 month running means for the last five years of the control and deforestation runs of the GISS GCM (after Henderson-Sellers & Gornitz, 1983).
to transpire has offset the radiative cooling by an evaporative (or latent heat) warming.

The effects of deforestation in the Amazon have been assessed here by comparison with a control (standard) climatic simulation: five years from 10 and 20 year runs respectively are illustrated in Fig.3. The results of deforestation were to alter significantly all the climate parameters considered, except the surface temperature. Figure 3 underlines the departure of the hydrology from the control run: rainfall has decreased by between 0.5-0.7 mm day$^{-1}$ and evaporation and total cloud cover are both reduced. The effects of reduced rainfall and increased runoff are shown in the significantly lowered values of water available in the upper ground layer. These results contradict the assumption that the surface albedo is the most important parameter. The overall albedo-plus-hydrology effect is to produce a negligible temperature change.

It should be noted that the surface is not the only area in which the hydrosphere seems to oppose the input alterations. The decreased cloud also opposes the increase in the surface albedo, leading to a smaller overall albedo increase than would have been expected from a model which did not incorporate both atmospheric and hydrological feedback effects, e.g. the model used by Sagan et al. (1979).

The local results of the GISS GCM deforestation experiment can be summarized as follows from Fig.3: no change in the surface temperature; precipitation decreased by around 0.6 mm day$^{-1}$; evapotranspiration decreased by 0.4-0.5 mm day$^{-1}$; planetary albedo increased by between 0.010 and 0.015 as a combined result of the increased surface albedo and the decrease in cloud cover. These results contrast with those shown in Table 1. During the course of the simulation, the excursions of the regional climate were carefully monitored (Henderson-Sellers & Gornitz, 1983). At the termination of the simulation there was found to be only a very small region of significant departure from the control Walker cell circulation pattern in July although in January there is a significant decrease in the vertical velocity above the deforested region. This is consistent with the reduction in the surface evapotranspiration and the reduction in the moist convective heating aloft. This latter effect became statistically significant at two levels in the atmosphere in January only. The resultant decrease in the vertical velocity over the deforested area is similar to that predicted by Charney (1975) as a result of desertification. In the case of deforestation, however, there is no strengthening feedback and decreased upward motion never becomes descent. Henderson-Sellers & Gornitz (1983) do not find any effects that penetrate beyond the area local to the perturbation.

The effects upon the simulated climate of albedo changes associated with tropical deforestation have also been considered using the UK Meteorological Office 11-layer GCM (UKMO). In this case the control run was initialized with a geographically specified albedo based on the land type data set of Hummel & Reck (1979). In the perturbation experiment equatorial rainforest was replaced by grazing and marginal farm land, thus introducing a local increase of 0.07 in surface albedo. Three areas of significant sensitivity were recognized: Amazonia, southern Africa and northern Australia. The response in Australia seems to be due to changes in large-scale circulation patterns and is dominated by changes in the surface moisture regime. Preliminary
TABLE 1 Characteristics and main results of a two-dimensional (zonal) atmospheric model (Potter et al., 1975) in comparison with the study of Lettau et al. (1979) concerning responses to albedo increase in the tropical rainforest zone (from Lettau et al., 1979)

<table>
<thead>
<tr>
<th>Area coverage</th>
<th>Potter et al. (1975)</th>
<th>Lettau et al. (1979)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Entire globe (510 x 10^6 km^2)</td>
<td>Amazonia (6.3 x 10^5 km^2)</td>
</tr>
<tr>
<td>Independent variables</td>
<td>Height and geographic latitude</td>
<td>Distance from Atlantic coast</td>
</tr>
<tr>
<td>Horizontal resolution</td>
<td>10° latitude</td>
<td>5° longitude</td>
</tr>
<tr>
<td>Albedo modification</td>
<td>0.07 changed to 0.25</td>
<td>0.13 changed to 0.16</td>
</tr>
<tr>
<td>Area of albedo change</td>
<td>About 15 x 10^5 km^2 of land between 5°N and 5°S latitude</td>
<td>About 2 x 10^5 km^2 between 57°W and 68°W longitude</td>
</tr>
<tr>
<td>Atmospheric tropical circulation</td>
<td>Weakened Hadley cell as model output</td>
<td>Regional tradewinds assumed unchanged</td>
</tr>
<tr>
<td>Precipitation change</td>
<td>-230 mm year^-1 between 5°N and 5°S latitude</td>
<td>+75 mm year^-1 average for Amazonia</td>
</tr>
<tr>
<td>Precipitable water</td>
<td>-0.74 mm globally</td>
<td>+0.59 mm over Amazonia</td>
</tr>
<tr>
<td>Air temperature near the surface</td>
<td>-0.4°C between 5°N and 5°S latitude</td>
<td>+0.55°C in Amazonia</td>
</tr>
</tbody>
</table>

Analysis suggests that in each of these regions a cellular circulation appears to have been induced. In South America and Africa the descending limb occurs in the deforested region and an ascending limb in the area to the south. Only in Amazonia is the area of maximum response coincident with the deforested region. Here the increase in albedo resulted in reduced fluxes of energy to the lower atmosphere and suppressed convective activity. There was a corresponding decrease in soil moisture. Decreased absorbed energy and flux of latent heat resulted in only a very small decrease in the surface temperature.

The results from these two recent GCM experiments (GISS and UKMO) contrast with earlier, simpler climatic simulations. For example, Table 1 lists the predicted climatic alterations resulting from a deforestation experiment calculated by Potter et al. (1975) and Lettau et al. (1979). These two simulations differ from one another, predicting surface temperature and precipitation changes of −0.4 and +0.55 K and −230 and +75 mm year^-1 respectively. Additionally, these results also differ from those from the GCM simulations (e.g. Shine & Henderson-Sellers, 1983). The latter suggest much smaller climatic perturbations which can be difficult to identify above the natural variability of the model. Parameterization and the nature of feedback effects implemented seem to influence the results produced in climate model simulations.
CONCLUSION

One of our major conclusions is that the effects of the hydrosphere, which have generally been neglected in simpler climate models and incompletely incorporated into more complex two and three dimensional models, must be adequately parameterized if realistic and useful simulations are to be produced (see also Manabe et al., 1981). Our results seem to suggest that the climatic effects of a surface albedo change are smaller in a very moist atmospheric environment than in arid regions (cf. Charney et al., 1977, and Sud & Fennessey, 1982). However, attention must be drawn to the considerable range in the types of climate models applied in analysis of the impact of deforestation. These models differ considerably in the methods employed and level of sophistication of the parameterization of land surface processes. The diversity in the climatic perturbations found reflect both this range in parameterization schemes and their ability to simulate time-lagged feedback effects.

These considerable differences underline the clear need to reconsider and improve the parameterization of land surface processes in climate models. Until such improvements are implemented it is unwise to draw conclusions about the possible impact upon climate of tropical deforestation.

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