CHAPTER 11: CONCLUSIONS AND RECOMMENDATIONS

11.1: Major Findings

The aim of this study has been to define the impact of Southeast Asian deforestation on climate and the large-scale atmospheric circulation. The impact of tropical deforestation in Southeast Asia, referred to as single-region deforestation, was simulated using the Unified Model, a general circulation model developed by the United Kingdom Meteorological Office. Using a 10-case ensemble approach, the model was run under 60-day integrations for the control and deforestation experiments to study the effects on the January and July atmosphere, representing the winter and summer monsoon, respectively. In the deforestation experiments, tropical moist forest throughout the Southeast Asia was replaced by scrub grassland. The results for January and July were compared to previous modelling conclusions based on deforestation throughout the tropics.

The methodology used in this study to model the impact of Southeast Asian deforestation has various advantages compared to previous studies. As reviewed in Chapter 4, the large-scale circulation changes simulated by earlier studies of deforestation over the Amazon Basin, Southeast Asia and tropical Africa cannot be attributed to land cover changes over any particular region. With the single region deforestation approach used in this study, the specific role of Southeast Asian rainforests in local climates and the larger-scale atmospheric circulation could be objectively assessed by controlling the effects from other sources. There are inherent uncertainties in any simulations using a GCM which may affect both the magnitude and the direction of the predicted consequences of tropical deforestation (or any other form of forcing). The use of a 10-case ensemble in deriving the modelled climate in this study has distinct advantages over single simulations in limiting one source of potential error associated with a restricted set of initial conditions and also reveals some insight into interannual variability.

On the other hand, limitations caused by the methodology used in this study, particularly related to the computer power constraints that have been deliberately explored, have hindered certain diagnostic analyses and limited interpretation of results on some issues. Given below is a list of key limitations (not in order of importance) that will be discussed further in the next section.

i. The short 60-day integrations used in this study could not capture seasonality, and the results cannot be strictly compared with the annually-averaged climatic changes predicted in previous studies. Moreover, a 60-day integration is not sufficient for all aspects of the model climate system to equilibriate. This limits in particular the ability to define remote effects.

ii. The use of an unrealistic deforestation scenario of scrub grassland and single region deforestation does not represent the actuality of either regional or global deforestation.

iii. The prescription of sea surface temperature from the monthly climatology constrains ocean-atmosphere interaction and, on a related point, important natural atmospheric and oceanic phenomena such as ENSO (El Niño-Southern Oscillation) have not been considered.

iv. The contribution of other, anthropogenic forcing mechanisms such as the changing greenhouse gas composition of atmosphere, has not been considered in this study but operates on a similar timescale to deforestation.

v. The model resolution used was not precise in representing local climate features and processes.

Despite these limitations, the results of the ensemble GCM sensitivity experiments reported in this thesis do shed light on the role of Southeast Asian deforestation in shaping local to regional climates as well as the dynamics of the large-scale atmospheric circulation. The use of a workstation as a computing platform has certainly not invalidated the exercise.

On assessing the effects on the January and July atmosphere, the major findings of this thesis are as follows.

i. In common with previous multi-region deforestation GCM results, the current ensemble simulations, simulating single region deforestation in Southeast Asian, show that the regional surface climate is appreciably modified by this land-cover change. It has been shown that the imposed land surface changes could effectively account for the change in the climatological variables and hydrological processes in the deforested region. Analysis of the spatial pattern of local- to regional-scale changes has shown that, overall, ground surface temperature, precipitation and cloudiness increase over and around the deforested region with a decrease in evaporation and relative humidity. One important conclusion from the analysis of spatially averaged regional climatic change is that the effect of increased surface albedo is cancelled out by decreased evaporation over the land area, thus explaining the relatively small changes in surface temperature over the deforested region.

ii. Unlike the situation in Amazonia, the alteration in local water recycling and hydrological processes as a result of the changes in the surface vegetation is not the main factor controlling moisture availability in the context of Southeast Asia deforestation. Rather, changes in the advective flux of water vapour into the deforested region are more important. In fact, the advective flux of water vapour into and out of the deforested region acts as a dominant factor in determining the behaviour of the hydrological cycle. This controlling factor indirectly explains why cloud and precipitation increases occur over the deforested region, despite the decrease in evaporation. The changes in the hydrological processes are connected to the surface and atmospheric energy budgets. It has been shown that the increase in the radiative energy absorbed by the atmosphere leads to an increase in the net energy available for supporting the regional atmospheric circulation.

iii. Analysis of the impacts over Southeast Asia and the neighbouring region has clearly shown that the effect of deforestation extends beyond the deforested region, by changing the regional atmospheric circulation. The atmosphere over the region becomes more energetic following deforestation, and this is clearly seen in the increased strength of the monsoon circulations. The changes in the Walker and Hadley circulations seem to be responsible for disturbances in the near-surface climate within the deforested region and in areas distant from the site of deforestation. The Walker circulation is affected not only over the deforested region but also over the tropical oceans, the west Pacific Ocean and Indian Ocean in particular. Meanwhile, changes in the Hadley circulation induce disturbances in the meridional moisture transports between the tropical region and the mid- and high latitudes. Both the changes in the Walker circulation and in the Hadley circulation provide some explanation for the wider changes in the general circulation simulated over the extratropical regions. Significant changes in the velocity potential fields and divergent flows, both at low and upper levels, have provided clear signals regarding these circulation changes. By changing the regional atmospheric circulation, Southeast Asian deforestation affects the winter and summer monsoon circulations. The increase in precipitation and cloudiness over the study area, as simulated by the ensemble, is related to the strengthening of the monsoon circulations over the region in both seasons.

iv. A series of mechanisms has been proposed regarding how large-scale deforestation in Southeast Asia modifies the atmospheric circulation of the region. According to this model experiment, the change in the thermally direct converging circulation in the boundary layer resulting from the positive changes in surface temperature induced by deforestation is the primary agent in communicating the impact of Southeast Asian deforestation. This is responsible for reinforcing the large-scale, convergent monsoon circulation in this region. The increase in convergence over the deforested region implies an increase in ascent. By mass continuity, the increase in ascent above the deforested region will cause changes beyond the area of disturbance. Because of feedbacks from the cloud and moisture radiative forcing, remote changes in the shortwave and longwave radiative budget outside the deforested region and beyond the study area are observed following deforestation. This radiative energy perturbation re-regulates the larger-scale atmospheric circulation. Direct changes in the hydrological processes induced by deforestation are not, in this region, significant compared to changes in the surface radiative energy budget. The changes in the surface radiative budget are then closely related to the atmospheric radiative energy budget, which is very important in sustaining the favourable dynamic structure of the larger-scale atmospheric circulation. It is found that there are no appreciable local changes in the entropy of the boundary layer occur, resulting from changes in surface temperature and humidity over the deforested region. Rather, the change in the gradient of the boundary layer entropy over a wider region plays a role in maintaining the strengthened summer and winter monsoon circulations.

Notable differences occur between the results of this experiment, based on single region deforestation, and previous simulations based on multi-region deforestation. For example, surface temperature and precipitation as well as cloudiness increase over the region in both months, corresponding to the intensification of the two monsoons. Again, different from the previous multi-region deforestation results which emphasise local effects on the water balance, this study shows that the induced regional circulation change exerts the greatest effect on moisture availability over the deforested region. Although in both cases, the monsoonal flow is perturbed, the nature of the disruption differs in the two cases. While the previous studies indicated weakening of both the winter and summer monsoons, the current results show the opposite. These differences are physically plausible. In general terms, then, the impact of Southeast Asian deforestation differs from that in other tropical regions, particularly the Amazon, in two important respects. First, induced changes in local hydrological processes are not as important as elsewhere because of the dominant convergent flow and the nearby oceanic moisture sources. Second, a related point, the effect of deforestation occurs through the medium of the large-scale monsoon circulation of the region which acts to export the effects over a wider area.

11.2: Recommendations for Future Study

The changes in regional atmospheric circulation following deforestation in Southeast Asia are significant enough to suggest an important role of the vegetation in this region in influencing the overall general circulation of the atmosphere. Deforestation enhances regional atmospheric circulations, implying that the undisturbed forest is responsible for regulating and limiting the atmospheric flow. The same circulations, however, are responsible for maintaining the environmental conditions (precipitation, temperature and humidity) that sustain vegetation and rain forests. As such, a complex relation exists between vegetation and climate which warrants further investigation in the future. It is impossible to come to firm conclusions about the impact that Southeast Asia deforestation has on global-scale climate until such causal mechanisms are fully identified. The following suggestions for further research, corresponding to the limitations in this study mentioned in the last section, may clarify points that remain uncertain in this analysis and throw light on further causal mechanisms.

i. Undertake full one-year ensemble simulations: The nature of the current experimental design, specifically the use of a workstation to run the model and producing an ensemble from 60-day simulations, meant that it was only possible to derive changes for

January and July, taken to represent the winter and summer monsoon seasons, respectively. The seasonality of the atmospheric phenomena is not included in the simulation and, therefore, neither is any effect of seasonally-specific processes and evaluation of seasonal variations is not possible. Full one-year simulations should be undertaken.

ii. Use a realistic deforestation scenarios: As in other previous GCM studies of the impact of multi-region deforestation, this single region deforestation experiment again assumed a large perturbation of the land surface properties in order to gain a significant model response. Future studies should adopt parameter settings representative of diverse range of forest replacement in Southeast Asia and, representing realistic deforestation scenarios, instead of using a crude grassland scenario. In particular, characteristics of a variety of land surfaces from field studies in Southeast Asian deforested areas should be considered in the prescription of post-forest albedo, roughness length, soil hydrologic properties and other important land surface parameters. Hence, field measurements should be undertaken to provide a realistic portrayal of Southeast Asian deforestation. Finally, interactions between the effects of deforestation of the three major tropical rainforests were deliberately ignored in this study, resulting in an unrealistic global deforestation scenario. Future study, therefore, should also run ensemble simulations with multi-region deforestation with realistic land surface parameters as well as comparative single region studies for Africa and the Amazon.

iii. Use updated sea surface temperature from observations or couple with a mixed layer ocean: This study used prescribed sea surface temperatures derived from a monthly climatology, partly to reduce computational time but also isolate the deforestation response by holding certain factors constant. The surface temperatures over the majority of grid-points in the study area were, therefore, constrained by returning them to the monthly climatological values every five days in the model integration. This constrained interaction between the ocean and atmosphere. With the ensemble approach, future studies could use updated sea surface temperatures derived from observations to provide more realistic surface temperature changes throughout the study area. Furthermore, if the computer resource is not a constraint, future study with an ensemble approach may make use of a coupled mixed layer ocean to give a better representation of the ocean-atmosphere interactions. This is important given the role of the ocean moisture source.

iv. Undertake simulations under El Niño and La Niña conditions: In this study, initial data were selected for ten consecutive years for the ensemble without considering the importance of natural phenomena such as El Niño and La Niña. Future study should effectively separate simulations between the two said phenomena to gain a better understanding of the effect of Southeast Asian deforestation under different conditions. This recommendation should be considered together with recommendation (iii) above as ocean-atmosphere interaction is obviously critical in these simulations.

v. Undertake simulations under global-warming condition: In this study, the GCM was run with initial data representative of present-day conditions derived solely from observational data. Future study should consider using data representative of a global warming future (say, for the year 2050) when regional deforestation is likely to be more extreme than at present.

vi. Use a limited area model nested within the global GCM: Currently, efforts to increase the resolution and physical parameterizations of a global GCM are limited by computing resources. Running a GCM at a mesoscale resolution of about 50 km in the horizontal will increase the need for computer resources by at least two orders of magnitude over current GCM simulations (Ji and Vernekar, 1997). This increment is calculated without considering the additional resources needed for the required increase in the sophistication of the parameterization of physical and dynamic processes and the increased vertical resolution. An alternative way to simulate regional weather and climate variability is to use a high-resolution limited area regional model (LAM) nested, for example, in a GCM (Dickinson *et al.*, 1989; Liu *et al.*, 1994). A LAM is formulated in a similar fashion to the corresponding GCM but simulates only a limited area of the GCM's global grid. In this approach, the GCM provides large-scale atmospheric information through lateral boundary conditions for the region, while the LAM provides an improved description of the effects of sub-GCM grid-scale forcing (Giorgi, 1990). In studies of perturbations close to present-day conditions, e.g.

seasonal climate prediction, observational (analysis or reanalysis) data may also provide the large-scale input rather than a GCM.

11.3: Implications for Policy

In the past, future climate change scenarios have been linked primarily to the increase in atmospheric concentrations of the so-called greenhouse gases such as carbon dioxide and methane. As we have seen from the results of this study, deforestation in Southeast Asia alone can also influence climate, changing regional weather patterns and contributing significantly to global shifts in the atmospheric circulation. The possibility of global climate change cannot be ruled out. The loss of tropical forest cover must be considered a significant source of global environmental change in its own right, implying responsibilities that cross national borders for the governments of forested countries and for the international community.

With regard to policy, of great concern is the rate at which tropical deforestation is occurring. The processes resulting in the conversion of moist tropical forest are unavoidable to some extent: new agricultural land to feed growing numbers of people, development of cash crops and cattle ranching, both of which earn money for developing countries, and commercial logging which supplies the world market with wood of high commercial value. While this and previous modelling studies have demonstrated that the destruction of the world's great tropical rainforests could have substantial effects on the climate, from the regional to the global scale, we do not know just what proportion of forest must be left for the climate system in its present form to be self-maintaining. Whether or not the current proportion of remaining forest is close to the limit is the issue of most relevance at this point. It is up to the policy makers to determine the right balance between exploitation of the forest resource and protection of regional and global climate.