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Dry-season radiation balance of land covers replacing forest in northern Thailand

T.W. Giambelluca[a,*], J. Fox[b], S. Yarnasarn[c], P. Onibutr[c], M.A. Nullet[a]

[a]Geography Department, University of Hawaii at Manoa, Honolulu, Hawaii 96822, USA
[b]Program on Environment, East-West Center, Honolulu, Hawaii 96822, USA
[c]Geography Department, Chiang Mai University, Chiang Mai, Thailand

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Abstract

The results of numerous general circulation model (GCM) experiments of climatic effects of extensive tropical deforestation include significant reductions in regional precipitation. However, the simulated precipitation decrease is highly dependent on the large albedo shift associated with the assumed conversion of forest into grassland. Land cover change surveys of the Amazon and Thailand suggest that secondary vegetation at various growth stages, rather than grassland, is the dominant feature of deforested land. In this paper, we present field measurements, taken during the dry season, of radiative characteristics of various deforested land surfaces in montane northern Thailand, including secondary vegetation. Dry-season albedo at nine sites in the village of Pang Khum, Chiang Mai Province, ranged from 0.085 for irrigated bare soil to 0.171 for 3-year secondary vegetation. As a result of increased albedo and higher daytime surface temperature at exposed dry soil sites, net radiation is reduced substantially. Regional mean dry-season albedo is estimated to have increased from 0.13 to 0.144 by 1980 for all of northern Thailand, and from 0.13 to 0.14 by 1983 for the southern portion of Sam Mun watershed, the 10 000 ha area immediately surrounding the study site. Continuing significant upward trends in regional albedo at both spatial scales are suggested by the estimates. However, our measurements suggest a maximum deforestation-induced albedo increase of about 0.04, half that used to simulate the effects of deforestation in most GCM experiments. It is likely, therefore, that simulated reductions in precipitation in the region due to deforestation will not be seen in model runs using more realistic scenarios of post-deforestation land cover characteristics.

Keywords: Albedo; Tropical deforestation; Land cover change; Land-atmosphere interaction

1. Introduction

Clearing of forest for timber and to open land for agriculture is occurring at rapid rates throughout the tropics. Estimates of the annual rate of tropical deforestation vary, with a typical value being 1.8% of the remaining biome estimated for 1989 by Myers (1991). The areas of greatest concern in this regard are the Amazon Basin and Southeast Asia. Rapid tropical deforestation is viewed as a global problem because of concerns about extinction of forest plant species due to direct impacts, extinction of animal species due to habitat loss, contribution to global warming due to the transfer of carbon from biosphere to atmosphere, and regional climatic and hydrological change due to

*Corresponding author. Fax: +1-808-956-3512; e-mail: thomas@hawaii.edu

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shifts in land surface characteristics (Turner et al., 1993). The importance of potential climatic change associated with deforestation is elevated by the possibility of feedbacks that such change may have on biological systems.

Forest clearing changes land surface characteristics, including albedo (the fraction of shortwave radiation reflected by the surface), aerodynamic roughness (affecting the turbulent transfer of water vapor, sensible heat, and momentum vertically in the atmosphere), and soil hydrologic characteristics. The most important of these may be albedo because of its influence on the radiative balance and ultimately on the energy available at the surface for evaporation, heating the ground and atmosphere, and photosynthesis. Concern about possible climatic change resulting from land cover change has been studied intensively since Charney (1975) proposed a theory to account for expansion of desert in Africa due to anthropogenic vegetation loss and consequent albedo increase. Climatic effects of land surface change have subsequently been investigated in a series of numerical deforestation experiments using general circulation models (GCMs) (Henderson-Sellers and Gornitz, 1984; Nobre et al., 1991; Henderson-Sellers et al., 1993, 1996). These experiments have demonstrated the potential for extreme changes in land surface characteristics, i.e., the conversion of closed canopy tropical rainforest to impoverished grassland, to bring about significant changes in regional climate, including substantial decreases in precipitation. Simulated changes have been found to be greatest during the dry season (Nobre et al., 1991). However, parameter settings used in GCM deforestation experiments can produce unrealistic simulations of land surface processes over common replacement land covers, especially secondary vegetation (Giambelluca et al., 1996). Misrepresentation of the deforested surface has significant consequences for the outcome of GCM experiments. Dirmeyer and Shukla (1994), for example, have shown that the precipitation decrease predicted in most experiments is highly dependent on the large upward shift in albedo used to depict the effects of deforestation in the simulations.

Estimates of tropical deforestation rates vary for a number of reasons, including ambiguities surrounding deforested lands where cropping or grazing is later abandoned. Secondary vegetation in those areas will eventually resemble forest. While a fully mature climax forest may be easy to categorize, drawing the line is more difficult where secondary successional vegetation of a variety of ages forms the post-forest land cover mosaic. The rate at which primary forest is felled is an overestimate of the net rate of change of forested area if a substantial portion of deforested land is returning to forest. Turner et al. (1993) describe the complexity of land cover change in the Amazon, demonstrating how forest clearing is partly offset by regrowth. While land degradation due to extremely intensive land-use practices have been shown to prevent the recovery of forest vegetation for decades (Myers, 1994), Uhl et al. (1988) found that this applied to less than 10% of abandoned pasture land in an Amazon Basin study area. Two studies of land use in the Amazon (Moran et al., 1994; Watrin, 1994) showed that secondary successional vegetation was the dominant land cover in two deforested areas of Pará state. Hence, while primary forest continues to be cut at alarming rates in the Amazon, the effect on regional land surface characteristics such as albedo is offset by regrowth of forest in abandoned fields. In an earlier study (Giambelluca et al., 1997), radiative characteristics of secondary vegetation typically covering substantial portions of farmland under shifting cultivation in the eastern Amazon were shown to be much closer to those of forest than to the characteristics of pasture. The results of that study suggest that deforestation-induced regional mean albedo change in the eastern Amazon will level at a value substantially lower than that of pasture, the deforested land cover of choice in GCM deforestation experiments.

In Thailand, patterns of land cover change differ from those of tropical America. Currently forest covers as little as 17% of the original forested area, with remaining primary forest amounting to only 5% of its original extent (Myers, 1991). This contrasts strongly with that of the Amazon where only about 6% of the forest has been cleared thus far (Skole and Tucker, 1993). Unlike the situation in tropical America, expansion of cattle ranching is not a strong incentive for forest clearing in Southeast Asia and pasture has never been an important replacement land cover for forest in the region. Hirsch (1987) found that deforestation in Thailand was associated with the expansion of commercial agriculture in the wake of logging for timber export. Summarizing other qualitative and quantitative studies, Lambardini (1994) states that the main cause of deforestation in Thailand has been demand for agricultural land. Swidden cultivation, also called slash-and-burn or shifting cultivation, as practiced in northern Thailand (Kunstadter et al., 1978; Fox et al., 1995) involves cutting vegetation in the dry season, allowing it to dry, burning it late in the dry season, and planting a crop in the ashes early in the wet season. From an ecological perspective, swiddening can be viewed as a perturbation to a forested landscape that results in the formation of cleared patches, patches undergoing secondary succession, and mature forest. The extent or severity of the perturbation is a function of the rate of patch formation, the size and shape complexity of the patches, the length of fallow or successional period of each patch, and the size and shape complexity of the mature forest. A key component of swidden systems – unlike the conversion of a forested landscape into a permanent agricultural landscape – is the potential of recovery and the reliance on the forest to promote the recovery process. In this regard, mountainous northern Thailand is representative of the region at large including parts of Myanmar, southern China's Yunnan Province, Laos, eastern Cambodia, and northern Vietnam. With a history of swidden agriculture, the land surface of the region is dominated by secondary vegetation in the full spectrum of growth stages. The characteristics of secondary vegetation as well as those of bare soil and cropped fields are critically important regarding possible climatic change due to deforestation in Southeast Asia. While it is clear that the forests of this region are not being converted uniformly into grassland, important questions remain concerning the extent to which land cover change there affects land surface-atmosphere interaction.

In this paper, we present the results of field measurements, taken during the dry season, of radiative characteristics, including albedo, of a variety of deforested land surfaces in a rural area of mountainous northern Thailand. By relating these measurements to estimates of land cover change, we estimate rates of change of regional mean albedo.

2. Radiation balance

The radiation balance of an area of the earth's surface may be expressed in terms of the components of radiant energy flux as:

$$R_{\mathrm{net}} = K\downarrow - K\uparrow + L\downarrow - L\uparrow \qquad (1)$$

where R_{net} is net radiation, $K\downarrow$ is downward shortwave radiation, $K\uparrow$ is shortwave radiation reflected by the surface, $L\downarrow$ is downward longwave radiation, and $L\uparrow$ islongwave radiation emitted by the surface. All terms have units of W m^{-2}. R_{net} can be expressed with emphasis on surface conditions as:

$$R_{\mathrm{net}} = (1-\alpha)K\downarrow + \varepsilon(L\downarrow - \sigma(T_{\mathrm{s}})^4) \qquad (2)$$

where α is the surface albedo (ratio), ε is the emissivity (ratio), σ is the Stefan–Boltzmann constant (5.67×10^{-8} W m^{-2} K^{-4}), and T_{s} is the surface temperature (K). The surface albedo is defined as

$$\alpha = \frac{K\uparrow}{K\downarrow} \qquad (3)$$

The albedo of a vegetated surface may be only half or less the reflectivity of its principal components, leaf surfaces, because of the greater absorption afforded by multiple reflection of light penetrating the upper canopy. Because this effect generally increases with vegetation height, forests generally have the lowest, and grassland the highest albedo of any class of vegetation. Albedo usually exhibits diurnal and annual cycles associated with changes in sun angle and, especially in deciduous forests, seasonal changes in foliage. At high sun angles, light can penetrate to greater depths within a forest canopy, whereas winter foliage loss diminishes the light-trapping ability of the forest. For these reasons, albedo is typically lowest in summer. In a tropical location with a significant annual rainfall cycle, albedo is generally observed to be highest during the dry season(s) because of foliage changes (Pinker et al., 1980; Barradas and Adém, 1992). Because diffuse light more effectively penetrates the vegetative canopy and, therefore, is absorbed more effectively than parallel beam radiation, albedo is expected to be lower under cloudy conditions. When incident radiation has a high proportion of diffuse light, sun angle is less important.

3. Albedo of tropical land surfaces: previous research

Investigators have measured radiative exchange of tropical forested areas at several locations. Albedo of tropical forest has been studied intensively in the Amazon (Shuttleworth et al., 1984; Bastable et al., 1993; Culf et al., 1995). Results there have ranged between 0.1225 (Shuttleworth et al., 1984) and 0.134 (Culf et al., 1995). Measurements taken elsewhere are in general agreement with Amazonian values, with 0.12 found in Nigeria (Oguntoyinbo, 1970) and 0.13 in Thailand (Pinker, 1982). Albedo of deforested tropical surfaces is more variable, dependent on the replacement land cover. Most albedo measurements in deforested tropical areas have focused on pasture land. Bastable et al. (1993), Fisch et al. (1994), and Culf et al. (1995) obtained albedo for Amazonian pasture ranging from 0.163 to 0.190. Oguntoyinbo (1970) found albedo ranged from 0.15 to 0.21 for non-forested locations in Nigeria. Pinker (1982) measured a mean albedo of 0.150 for tall grass in a forest clearing in Thailand. In an earlier field study, the albedo of secondary vegetation in a small farm in the eastern Amazon Basin was found to decline with age from greater than 0.17 to near the forest value within about 10 years (Giambelluca et al., 1997).

4. Study area

Radiative measurements were taken near Pang Khum, a village located at an altitude of 1250 m in the mountainous region north of the city of Chiang Mai in northern Thailand (Fig. 1). Pang Khum is located within the 1865 km^2 Sam Mun Highland Development Project, a Thai Government–United Nations program dealing with drug control and forest management (Sam Mun Highland Development Project, 1994). The village was originally settled 200 years ago by the ethnic hilltribe group know as the Karen and, for the past 20 years, also a group of Lisu tribes people (Fox et al., 1994). The villagers of both the groups practice a dual production system with swidden agriculture on the slopes surrounding the settlement and paddy rice grown on terraced fields in the valley bottoms (Kunstadter et al., 1978; Poffenberger and McGean, 1993). Swidden crops, which were chiefly for subsistence in the past, now include vegetables, fruit, barely, and cut flowers for sale outside the village. Opium production in the watershed has been reduced since the area was targeted by the Narcotics Control Board of Thailand and the United Nations Fund for Drug Control. The opium poppy, once prevalent in Pang Khum, is now grown only in a few small plots. Natural vegetation in the region has been described as lower montane (Hansen, 1992) or hill evergreen (Poffenberger and McGean, 1993) forest. In a study of vegetation in an area with similar terrain about 70 km ENE of Pang Khum, Hansen (1992) declared that no undisturbed primary forest remains. This is probably also true of the Pang Khum area, although stands of mature old growth and exploited primary forest are in evidence. The population of the village as well as the surrounding region is growing rapidly (Sam Mun Highland Development Project, 1994). The increased land pressure has reduced fallow periods and expanded the area of cultivation at the expense of old growth forest. Competition among upland and midland hilltribe groups and the use of unsustainable land-use practices resulted in rapid deforestation and accelerated soil

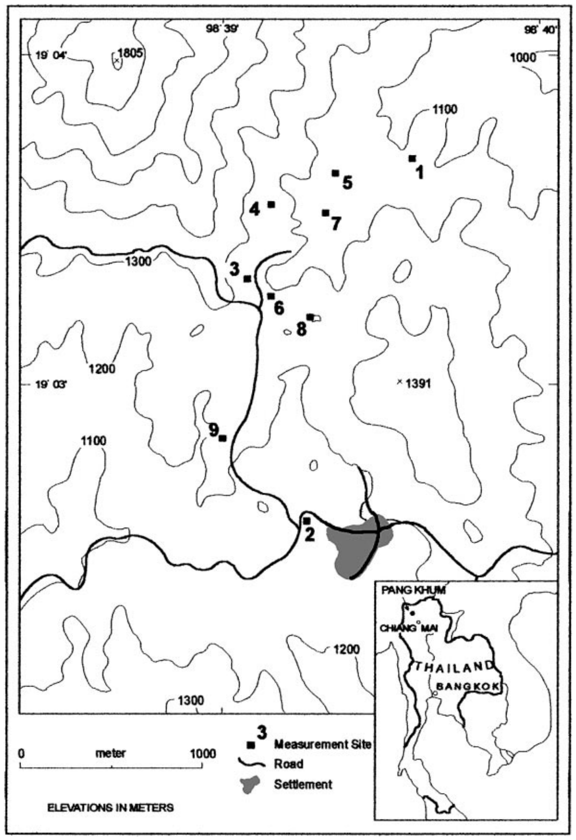

Fig. 1. Map of Pang Khum study area showing measurement sites.

erosion in the region (Poffenberger and McGean, 1993).The Sam Mun Highland Development Project (1994) report impressive increases in forested area between 1984 and 1991 for the project area as a whole. For the southern part of the Sam Mun project area, where Pang Khum is located, analysis of aerial photography and satellite imagery by Fox et al. (1995) show forest cover stabilizing at approximately 50% of the total area since the mid-1970s. While the total amount of closed canopy forest has remained relatively constant since then, vegetative cover at any given location has remained dynamic.

The climate of the region is monsoonal, with a well defined annual rainfall cycle. The rainy season extends from mid-May through October or early November, during which approximately 90% of annual rainfall occurs. Mean annual rainfall in the region is about 1000–1200 mm (Alford, 1992). However, spatial variability is probably high due to orographic influences. For example, Doi Mon Ang Get (1300 m elev.), a station close to Pang Khum, receives approximately 3000 mm annually (unpublished data). Mid-November through late February is the cool season with mean air temperatures of around 17°C. During the hot season, March to mid-May, air temperature averages about 25°C, reaching daytime highs above 30°C.

5. Measurements

Meteorological measurements were taken in Pang Khum using a single set of sensors, which was moved from site to site to produce a sequence of observations for different covers. Sensors were mounted on an aluminum extension ladder, which served as a telescopic mast with a 3–15 m height range. Downward looking radiation sensors were mounted on booms of 1–1.5 m in length. Sensor were positioned approximately 2 m above the estimated mean radiative surface height at each site. Sensors, therefore, responded primarily to an approximately 50 m^2 area of the vegetation or soil surface beneath the sensor at each site. Field instruments and data recording equipment are listed in Table 1. Sensor data were adjusted on the basis of several in-field intercomparison runs. In particular, the output of the two Eppley radiometers was recorded with both sensors positioned facing upward and used to derive a best-fit adjustment of the 8–48 to the PSP. Measurement sites (Fig. 1) are described in Table 2. Observations were taken primarily during the driest part of the year but continued into the first several weeks of the rainy season, which begins in May.

Sites were selected to afford a broad sample of land cover types representative of deforested areas in the region, including active and fallow swidden sites, fallow rice paddy, and areas covered with secondary vegetation of a range of growth stages. Sensors were mounted near the center of each selected land cover patch over a relatively homogeneous and representative sample area. Table 3 lists representative species at each site as identified by taxonomy expert J.F. Maxwell (Biology Department, Chiang Mai University) who conducted a field survey of each study site except Sites 5 and 6.

Measurements at most sites were taken during the driest part of the year. Very little rain fell until the last two weeks of the study, during the second measurement period at Site 9. Because observations over different land covers were not made simultaneously, day-to-day variations in cloud cover, precipitable water, and atmospheric turbidity affected the measure-

Table 1
Sensors and data recorders

Instrument	Company	Location	Model
Shortwave radiation			
Downward	Eppley Laboratory	Newport, RI	8–48
Reflected	Eppley Laboratory	Newport, RI	PSP
Net all-wave radiation	REBS	Seattle, WA	Q*6
Canopy temperature	Everest Interscience	Fullerton, CA	4000ALCS
Air temperature	Vaisala	Helsinki, Finland	HMD30UYB
Rainfall rate	Campbell Sceintific	Logan, UT	TE525
Data loggers	Licor	Lincoln, NE	LI-1000

Table 2
Characteristics of measurement sites at Pang Khum, Chiang Mai Province, Northern Thailand

Site[a]	Land cover	Elevation (m)	Slope (°)	Aspect (°)	Height (m)[b]	Measurement Start	Period End
1	Irrigated exposed soil	1120	9	270	0.0	24 March	30 March
2	Fallow rice paddy	1120	0	–	0.0	26 April	11 May
3	Harvested barley	1240	17	65	0.3	13 March	21 March
4	Harvested corn	1245	10	87	0.2	17 January	23 January
5	Irrigated stringbean	1145	8	56	1.6	9 January	16 January
6	Secondary vegetation (2 year)	1220	18	35	1.9	07 March	13 March
7	Secondary vegetation (3 year)	1170	3	75	1.7	30 March	08 April
8	Secondary vegetation (8 year)	1290	21	300	3.2	24 January	02 March
9	Secondary vegetation (25 year)	1240	14	310	5.6	09 April (and) 11 May	21 April 24 May

[a] Refer to site numbers shown in Fig. 1.
[b] Mean vegetation height.

ments over each land cover differently. Direct comparisons among sites of measurements such as reflected shortwave radiation and net radiation are less meaningful because of day-to-day differences in solar radiation. However, when examining relatively time-invariant surface properties, such as albedo or net radiation as a fraction of incident solar radiation, comparison among sites is possible.

Concurrent incident and reflected shortwave radiation measurements were taken over multiple diurnal cycles at each site to capture the sun angle effect on albedo. Eppley Model 8–48 and PSP measurements, sampled every 5 s and averaged and recorded each hour were used to estimate the mean diurnal pattern of K↓ and K↑ over each cover in the form of hourly means. To examine the diurnal pattern mean hourly albedo was calculated (Fig. 2). The sums of the hourly means of $K\downarrow$ and $K\uparrow$, respectively comprise the site means of incident and reflected shortwave radiation. Albedo site means, computed as the ratio of site means of $K\downarrow$ and $K\uparrow$, are given in Table 4. Also shown are albedo values computed for sunny and cloudy periods. Sky condition was determined on the basis of the ratio of $K\downarrow$ to estimated clear day radiation (K_{cd}). The SPECTRAL2 model (Bird and Riordan, 1986) was used to estimate K_{cd}. The cloudy condition was defined arbitrarily as periods during which $K\downarrow/K_{cd}$ was less than 0.5. Table 5 gives net to solar radiation

Table 3
Vegetation taxonomy at radiation measurement sites, Pang Khum Thailand (plant identification by J.F. Maxwell, Biology Department, Chiang Mai University)

Site[a]	Representative species
1	No live vegetation.
2	*Fimbristylis aestivalis* (Retz.) Vahl. var. *aestivalis* (Cyperaceae) *Digitaria seigera* Roth ex Roem. and Schult. var. *setigera* (Gramineae)
3	No live vegetation.
4	Low ground cover (taxonomy not surveyed)
5	Stringbean (taxonomy not surveyed)
6	*Ageratina adenophorum* (Spreng.) R. King and H. Robinson (Compositae) *Coffea arabica* L. var. arabica (Rubiaceae)
7	*Imperata cylindrica* (L.) P. Beauv. var. *major* (Nees) C.E. Hubb. ex Hubb. and Vaugh. (Gramineae) *Thysanolaena latifolia* (Roxb. ex Horn.) Honda (Gramineae)
8	*Lithocarpus elegans* (Bl.) Hatus. ex Soep. (Fagaceae) *Gluta tavoyana* Wall. ex Hk. f. (Anacardiaceae)
9	*Lithocarpus elegans* (Bl.) Hatus. ex Soep. (Fagaceae) *Gluta tavoyana* Wall. ex Hk. f. (Anacardiaceae)

[a] Refer to site numbers shown in Fig. 1.

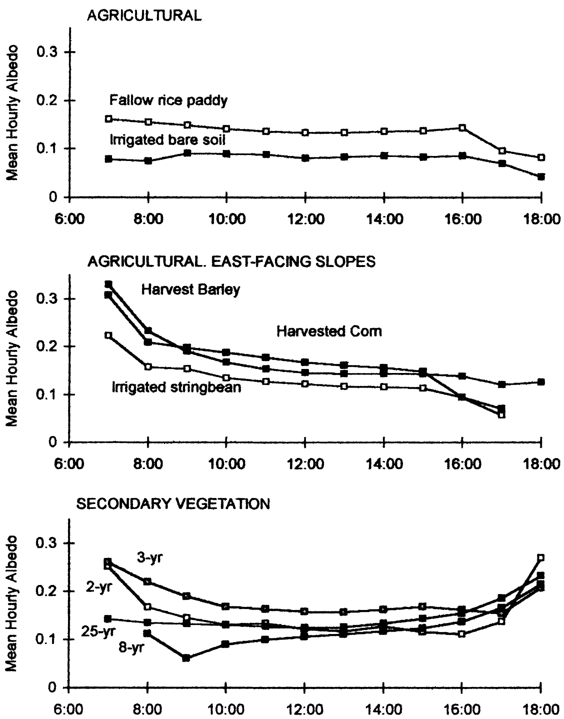

Fig. 2. Diurnal cycle of albedo for Pang Khum sites.

ratios for Pang Khum sites. Table 6 gives mid-day surface temperature and air temperature differences (T_s–T_a).

6. Radiative characteristics of deforested sites

With the exception of the irrigated bare soil site, albedo was higher during the early morning than at mid-day (Fig. 2). Secondary vegetation sites all exhibited late afternoon increases in accordance with expected sun angle-related effects. Agricultural sites, however, were characterized by albedo decreases in the late afternoon, especially those on east-facing slopes. Several other investigations have found similar diurnal albedo asymmetry for various land covers, including those of Pinker (1982) over forest in Thailand and Giambelluca et al. (1997) over deforested surfaces in the eastern Amazon Basin. In the case of agricultural surfaces at Pang Khum, topography is likely to have contributed to the asymmetrical pattern for the east-facing agricultural sites. Exaggerated early morning reflection and reduced afternoon values are consistent with the pattern of illumination result-

Table 4
Summary of albedo measurements at Pang Khum, Thailand

Site[a]	Land cover	Albedo		
		All	Clear	Cloudy
	Agriculture			
1	Irrigated exposed soil	0.085	0.086	0.062
2	Fallow rice paddy	0.141	0.142	0.130
3	Harvested barley	0.163	0.165	0.162
4	Harvested corn	0.167	0.166	0.187
5	Irrigated stringbean	0.125	0.125	0.161
	Mean	0.136	0.137	0.140
	Initial secondary successional vegetation			
6	Secondary vegetation (2 year)	0.134	0.131	0.133
7	Secondary vegetation (3year)	0.171	0.169	0.197
	Mean	0.153	0.150	0.165
	Intermediate secondary successional vegetation			
8	Secondary vegetation (8 year)	0.115	0.115	0.131
	Advanced secondary successional vegetation			
9	Secondary vegetation (25 year)	0.135	0.135	0.130

[a] Refer to site numbers shown in Fig. 1.

Table 5
Ratios of net radiation to incident solar radiation for sites in Pang Khum, Thailand

Site[a]	Land cover	$R_{net}/K\downarrow$
	Agriculture	
1	Irrigated exposed soil	0.644
2	Fallow rice paddy	0.631
3	Harvested barley	0.482
4	Harvested corn	0.441
5	Irrigated stringbean	0.543
	Mean	0.548
	Initial secondary successional vegetation	
6	Secondary vegetation (2 year)	
7	Secondary vegetation (3year)	
	Mean	0.518
	Intermediate secondary successional vegetation	
8	Secondary vegetation (8 year)	0.568
	Advanced secondary successional vegetation	
9	Secondary vegetation (25 year)	0.644

[a] Refer to site numbers shown in Fig. 1.

ing from aspect. Although the study site itself is horizontal, the fallow rice paddy site is located in a narrow valley bottom where adjacent topography influenced incident radiation at low sun angles. The bare soil site is not subject to the effects of canopy light penetration and exhibits a relatively flat diurnal pattern, with slightly lower reflection at low sun angles. Differences among diurnal patterns at secondary vegetation sites are likely to be related to differences in early-morning versus late afternoon shading due to small-scale effects of canopy geometry in the area beneath the sensor at each site.

Table 6
Mid-day surface temperature-air temperature differences for sites in Pang Khum, Thailand

Site[a]	Land cover	Mid-day $T_s - T_a$ (K)
	Agriculture	
1	Irrigated exposed soil	9.5
2	Fallow rice paddy	6.5
3	Harvested barley	20.4
4	Harvested corn	11.0
5	Irrigated stringbean	7.2
	Mean	10.9
	Initial secondary successional vegetation	
6	Secondary vegetation (2 year)	2.8
7	Secondary vegetation (3year)	5.0
	Mean	3.9
	Intermediate secondary successional vegetation	
8	Secondary vegetation (8 year)	1.8
	Advanced secondary successional vegetation	
9	Secondary vegetation (25 year)	2.4

[a] Refer to site numbers shown in Fig. 1.

The albedo site means at Pang Khum (Table 4) reveal (1) shortwave reflection from advanced (25-year) secondary vegetation is very similar to that measured primary tropical forest; (2) albedo of intermediate (8-year) secondary vegetation is lower than that of advanced secondary vegetation or primary forest; and (3) albedo of initial secondary vegetation and agricultural sites spans a range of values below and above that of forest. The finding for 25-year secondary vegetation is significant as it indicates that shortwave reflection of deforested land recovers relatively quickly to the pre-disturbance value. The 8-year secondary vegetation had a surprisingly low albedo, lower than most measurements of primary forest in the tropics. Measurements at the site were probably affected by the fire or fires that had recently affected the site, darkening soil and the lower branches and trunks of the trees. The low value obtained there may not be representative of intermediate secondary vegetation in general, but attests to the residual impacts of burning on radiative characteristics. Bastable et al. (1993) found a similar reduction of albedo in an Amazonian pasture which they attributed to the effects of repeated burning on the darkness of the underlying soil.

The relative amount of sunlight reflected is expected to be greater during clear sky periods when the fraction of diffuse light is relatively low. Our observations, however, do not show this conclusively (Table 4). The statistics here are affected somewhat by the diurnal cloud cover pattern. Clear conditions were more frequent during mid-day, when the sun angle effect tends to reduce albedo. A longer period of observation at each site is necessary to sort out the effects of cloud cover from those of sun angle.

The result that advanced secondary vegetation and primary forest are similar in terms of shortwave reflection suggests the radiative balance of the two land covers may be similar. The ratio of net radiation to incident solar radiation, R_{net}, is expected to decrease as albedo increases. Net to solar ratios are high for tropical forest; for example 0.583 for forest in Thailand (based on data of Pinker et al., 1980) and 0.706 for Amazonian forest (based on data of Shuttleworth et al., 1984). From our measurements (Table 5), $R_{net}/K\downarrow$ for intermediate and advanced secondary vegetation lies within the range of primary forest values. The ratio generally increases with age of secondary vegetation. Among agricultural sites, those with moist soil (the fallow rice paddy and the two irrigated sites) have high values, while those with dry soil (the two harvested swidden fields) have very low values. This result is expected because of the higher surface temperature, and hence greater longwave emission from dry surfaces. The difference between surface temperature and air temperature ($T_s - T_a$) at midday is generally low, on the order of 1°C, for actively transpiring forests (Bastable et al., 1993). Table 6 shows that, for deforested land covers in Pang Khum, $T_s - T_a$ is quite high for agricultural sites, especially those with a dry soil surface. Surface temperatures are lower for intermediate and advanced secondary vegetation than for early secondary and agricultural sites due to more effective turbulent energy exchange of higher, more deeply-rooted vegetation (Giambelluca, 1996).

7. Regional mean albedo

The decline in forest cover and concurrent growth in alternative land covers in the northern Thailand region during the 100-year period ending in 1980 is shown in Fig. 3 (Richards and Flint, 1994). Land cover change since 1954 in the southern portion of the Sam Mun watershed, the 10 000 ha area immediately surrounding the study site, is shown in Fig. 4 (Fox et al., 1994). It is clear that rates of forest decline and growth of cultivated area were increasing non-linearly for the northern Thailand region as a whole (Fig. 3). While prior to 1970, grass/shrub complexes increased in extent, presumably in abandoned agricultural fields, since that time, growth of cultivation has reduced both forest and grassland. For the Sam Mun Watershed (Fig. 4), forest cover stabilized since the mid-1970s, although increases in cultivated land have continued.

Using the land cover analyses of Richards and Flint (1994) and Fox et al. (1994) (Figs. 3 and 4), we estimated trends in the regional mean albedo by assigning an albedo to each land cover category, and computing regional albedo as a weighted average. Albedo assignments are given in Table 7. In our field study, we did not make measurements of albedo for all categories of the two land cover analyses. We have, therefore, used the measurements of Pinker (1982) for

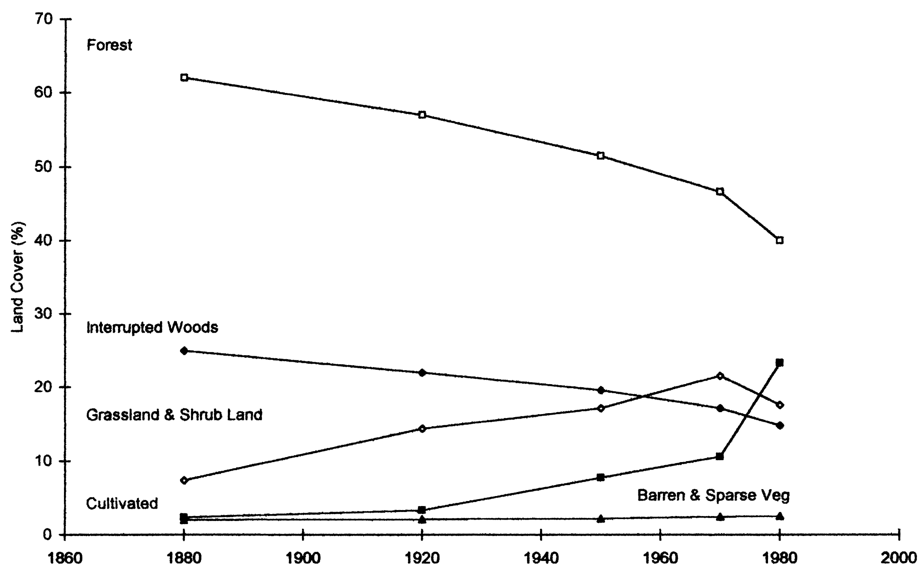

Fig. 3. Land cover change in the northern Thailand region (after Richards and Flint, 1994).

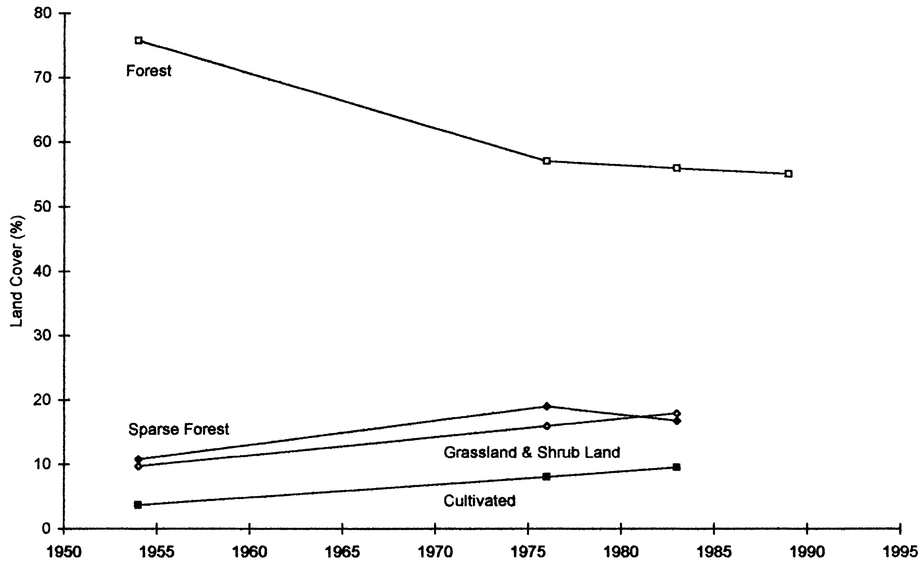

Fig. 4. Land cover change in Sam Mun Watershed (after Fox et al., 1994).

forest, and in other cases substituted measurements of what we judged to be the most similar land cover type for which we had data. Our measurements were made primarily during the dry season. Because significant changes in albedo accompany the annual cropping cycle, our analysis is confined to providing an estimate of dry season conditions. Assignments of albedo values to the various land cover categories (Table 7) are consistent with conditions during the dry season.

Results (Fig. 5) show that mean dry-season albedo for the northern Thailand region is increasing non-linearly, having climbed from an assumed undisturbed value of 0.130 to 0.144 by 1980. For the southern Sam Mun watershed area, mean dry-season albedo is estimated to have increased by about 0.01, to a value of 0.140, by 1983, with a declining rate of change. In both the cases, the rate of increase for the most recent time interval is significant, an indication of the

Table 7
Assignment of albedo to land cover categories used in estimates of regional mean albedo

Category	Albedo	Source
Richards and Flint (1994) analysis		
Cultivated Area	0.165	Harvested corn and harvested barley sites
Forest/woodland	0.130	Pinker (1982)
Interrupted woods	0.135	25-year secondary vegetation site
Grass/shrub complexes	0.153	2-year and 3-year secondary vegetation sites
Barren/sparsely vegetated	0.167	Harvested barley site
Fox et al. (1994) analysis		
Dense forest	0.130	Pinker (1982)
Sparse forest	0.135	25-year secondary vegetation site
Grassland	0.171	3-year secondary vegetation site
Paddy fields	0.141	Fallow rice paddy site
Active swidden	0.165	Harvested corn and harvested barley sites
Abandoned swidden	0.171	3-year secondary vegetation site
Forest plantation	0.135	25-year secondary vegetation site
Tea garden	0.134	2-year secondary vegetation site

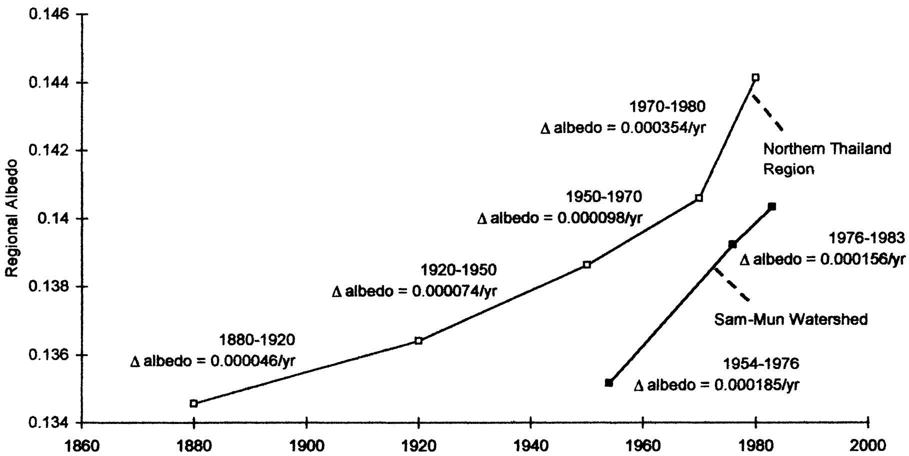

Fig. 5. Regional mean albedo for the northern Thailand region and for the Sam Mun Watershed.

severity of environmental degradation due to rapid land-use change. We emphasize that this estimate is valid only for the scenario of albedo-land cover associations given in Table 7, which pertains to dry-season conditions. Regional albedo is probably lower during the wet season because of wetter, and hence darker, soil and greater vegetative cover.

8. Summary and conclusions

In this paper, we have presented the results of field measurements of radiative characteristics over a variety of deforested land surfaces in northern Thailand. Measurements indicate that significant disruption of energy exchange is associated with forest removal. Dry-season albedo of recently or actively used land is generally 0.03–0.04 higher than that of primary forest. In addition, net radiation is substantially lower for actively used sites, due to higher albedo and higher daytime surface temperature. Mid-day surface temperatures were very high and net radiation low for surfaces characterized by exposed dry soil. Secondary vegetation 25 years after abandonment was found to be radiatively very similar to primary forest.

Estimates of regional mean albedo for northern Thailand and for the southern part of the Sam Mun watershed reveal that significant shifts in radiative exchange have occurred. At both spatial scales, mean dry-season albedo is seen to be increasing rapidly. These results differ from those obtained in a similar analysis of the eastern Amazonian village of Igarapé Açu, Brazil (Giambelluca, 1996), where mean albedo is higher, but the rate of albedo increase has declined. Deforestation in the Igarapé Açu area is much more advanced than in northern Thailand or Sam Mun in particular. In comparison with Igarapé Açu, a relatively large portion of Sam Mun watershed is still forest covered, cumulative albedo increase has, therefore, been smaller, but opportunities for continuing change remain.

With respect to possible impacts of changing land surface characteristics on regional climate, the measurements taken here suggest less extreme shifts in albedo due to deforestation. GCM deforestation experiments commonly use an albedo increase of 0.08 to simulate the effects of deforestation. Measurements taken in Pang Khum suggest a maximum shift of about 0.04 from an assumed primary forest value of 0.13. The mean value of deforested land is likely to be substantially less if it is comprised of a mixture of bare soil, cultivated land, and secondary vegetation of various ages. Hence, a realistic representation of deforested land surfaces in GCM experiments would probably result in significantly different climate changes than those predicted using the extreme scenario of impoverished grassland. In light of the results of Dirmeyer and Shukla (1994), simulations using realistic albedo increases, such as those suggested by our measurements, would probably not produce significant reduction in precipitation.

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