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Original Article

Diurnally-micrometeorological responses to different vegetation cover in a highly-deforested tropical area in Nan, Northern Thailand, during the early Asian summer monsoon

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Abstract

This work aims to investigate diurnal-micrometeorological patterns for different vegetation covers; a hill evergreen forest, an integrated cropland, and a monoculture cropland in Nan, Northern Thailand. Biogeophysical effects of deforestation and cropland expansion on the local meteorological patterns are discussed. Results obtained from the analysis of satellite imagery suggest significant forest conversions from year 2001 to 2011/12. Field observations were taken during the early Asian summer monsoon season. The results indicate that the forest exhibited the highest day-night temperature difference, in which latent heat flux and surface roughness, in connection with wind speed, play important roles. Different cultivation practices (monoculture vs. integrated) clearly affected daytime sensible heat flux, resulting in colder nights at the monoculture cropland. Based on the findings in this study, an overall warming trend, especially at night, and higher short-term rainfall are likely to be associated with deforestation and cropland expansions.

Keywords: tropical climate, deforestation, cropland expansion, land cover, meteorology

1. Introduction

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, shows robust evidence that anthropogenic land use changes have increased land surface albedo, which is reflective properties of the Earth's surface (Kirtman *et al.*, 2013). However, land use change's impact on climate is uncertain and difficult to evaluate, resulting in inconsistent conclusions on the climate's response to land use changes among previous studies (Myhre *et al.*, 2013). Land use/cover changes cause two major types of climate feedbacks: biogeophysical and biogeochemical. The biogeophysical feedbacks affect heat and water fluxes, together with wind direction and wind magnitude on the Earth's surface. These biogeophysical factors include surface albedo, latent heat flux (absorbed energy during evapotranspiration), sensible heat flux (exchange energy between interfaces of land and the contacting air due to temperature difference), stomatal conductance (the rate of water vapor exiting through the stomata of a leaf) and surface roughness. The biogeochemical feedbacks affect climate by altering chemical compositions including aerosols and greenhouse gases in the atmosphere (Feddema *et al.*, 2005; Gaillard *et al.*, 2010). Betts *et al.* (2007) suggest significant changes of anthropogenic surface albedo due to deforestation since year 1750. The changes are responsible for cooler winters and springs in the temperate region (Betts *et al.*, 2007). Reforestation in temperate regions can cause further warming (Betts *et al.*, 2007; Gibbard *et al.*, 2005); whereas in tropical regions, it can effectively alleviate warming effects (Betts *et al.*, 2007).

Roles of vegetation cover changes in regional climate are dependent on the duration of the growing season, changes in albedo, roughness length, root depth, stomatal conduc-

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tance and cloud formation (Pitman *et al.*, 2009). Presently, tropical deforestation is a matter of great concern. Chase *et al.* (2000) examined effects of current tropical deforestation and found that it could increase regional surface temperature (+ 0.44 K compared with the natural state) and sensible heat flux (+ 6.57 W m^{-2}) and also enhance the magnitude, frequency and duration of warm Southern Oscillation episodes (Chase *et al.*, 2000). This condition is pronounced in Southeast Asia and the western Pacific and leads to decreased easterlies over the tropical Pacific (Chase *et al.*, 2000). Cropland extension could also affect local tropical climates, such as in India, where groundwater irrigation is used intensively (Pielke *et al.*, 2011).

Previous conclusions on climate responses to land cover changes have often been derived from global land–climate model simulations, which may provide high uncertainties among the models due to their diverse vegetation model assumptions (Pitman *et al.*, 2009). This work aims to investigate effects of vegetation covers, namely, a forest, integrated and monoculture croplands, on the micrometeorological conditions through analyses of satellite retrievals and field measurements. Effects of tropical deforestation and cropland expansions on local meteorological patterns are also discussed in this report. The results could assist meteorologists and climatologists to assess effects of land cover changes, including deforestation and cropland expansions, on the tropical climate.

2. Methodology

2.1 Site description

Located in the Southeast Asia, Thailand is influenced by a tropical climate system, having winter from December to February, local summer from March to mid-May and rainy (Asian summer monsoon) from mid-May to September. The studied period, from April 23rd to May 14th, 2014, is during the typical onset of the Asian summer monsoon, which is triggered by thermal gradient between the warming land over Eurasia, centered on the Tibetan Plateau, and the Indian Ocean (Li & Yanai, 1996). This thermal gradient results in the southwest monsoon, bringing moist air from the Ocean towards most part of Thailand.

Northern Thailand is located on a mountainous terrain with abundant forests. Nan province, in the Northern Thailand, was chosen for this study due to its experiencing high land cover conversions from forests to grass/croplands from 2001 to 2012 as obtained from MODIS (Moderate Resolution Imaging Spectroradiometer) land cover analysis. The three sites in Nan, shown in Figure 1, exhibiting different land use/covers, were selected for field observations including a monoculture cropland in Pieng Saovillage (19.387°N, 101.184°E, 1,340 m above mean sea level, MSL), an integrated cropland in Sajuk-Sakieng village (19.352°N, 101.179°E, 1,098 m above MSL) and a hill evergreen forest in Thai–Laos forest buffer zone (19.376°N, 101.191°E, 1,373 m above MSL). All three sites have mountainous ridges in the North to the Northeast and downhill plains in the South to the West. The croplands are under a rainfed system. The MODIS satellite imagery show significant land conversion in the monoculture cropland site, while no significant change was found in the other two sites (Figure 1). Crops in the monoculture cropland were composed mainly of rice and corn. The observation began at the onset of the rainy season, when most of the cereal croplands were still barren and weed-free, until young shoots had grown 7 to 15 cm. At that time, the integrated croplands consisted of tea trees, mulberry trees and various weeds whereas rice paddies and vegetable fields were full of weeds. In the hill evergreen forest, dominant plant species were *Pinus kesiya*, *Schima wallichii*, *Dalbergia velutina*, *Lithocarpus thomsonii*, *Quercus brandisiana* and *Cycas pectinata*.

2.2 Land cover data

The global land cover product used in this study was retrieved from Moderate Resolution Imaging Spectro radiometer (MODIS) onboard the Terra and Aqua satellites. The land cover product (short name of MCD12Q1) provides yearly land cover type with 500-m spatial resolution.. In this study, the product was acquired online for years 2001 to 2012 from the Land Processes Distributed Active Archive Center (LP DAAC) website (https://lpdaac.usgs.gov/data_access) through MODIS Reprojection Tool Web Interface (MRT Web).

2.3 Field meteorological measurements

The field measurements were simultaneously conducted at the three sites in Nan for 22 days from April 23rd to May 14th, 2014 to collect hourly meteorological data and surface soil temperature.

The meteorological data was collected at 1.8 to 2 m above the ground using mobile weather stations (Weatherwise MODEL WS-1090-solar). The data include hourly air temperature, relative humidity, wind speed and wind direction. A running test among the three mobile stations was conducted at Mahasarakham University and the result showed precisions of ±0.03°C for air temperature, ±3.15% for relative humidity, ±0.17 m s^{-1} for wind speed and 76% agreement within ±45° difference for wind direction. Since two self-empty rainfall buckets mounted in the stations clogged during the measurement, the amount of rainfall was subsequently evaluated from water levels in a 100-ml plastic cylinder secured with a metal pole at ~1.5 m above the ground. This measurement provided total daily rainfall subtracted by evaporation, referred to here as daily usable water (including transpiration, runoff and infiltration). All sensors and measuring devices were installed in open spaces directly exposed to the sun without any major obstacles within 5-m radius.

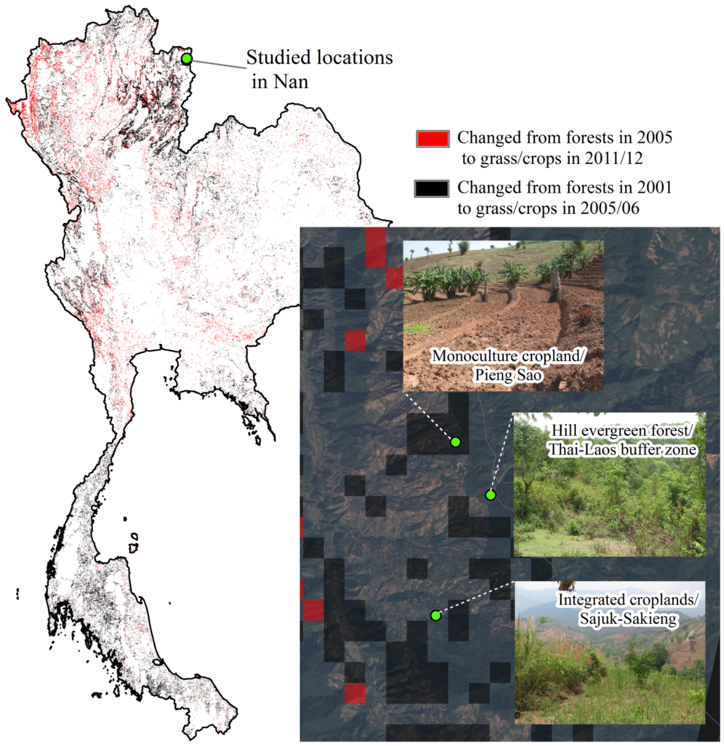

Figure 1. Three studied sites in Nan overlaid on the THAICHOTE satellite image from GISTDA, taken on January 3rd, 2014 and then again on forests-to-grass/crops conversion map derived from MODIS with transparent black color indicating the significant change from 2001 to 2005/06 and the red color indicating the change from 2005 to 2011/12

Surface soil temperatures at 2–3 cm depth and corresponding surface air temperatures were measured manually every 1 to 3 hours using soil thermometer in the daytime at different locations (5 to 7) distributed within 200 m around the weather stations. Difference between the surface air and the surface soil temperatures was used to infer sensible heat flux transfer in the studied sites.

3. Results and Discussion

3.1 Micrometeorological responses to hill evergreen forest and integrated cropland and effects of the vegetation conversion

Figure 2 shows temperature profiles for the three studied sites. The hill evergreen forest was experiencing the lowest average temperature of 22.7°C and the highest day–night temperature difference with average minimum temperature (T_{min}) of 15.2°C and maximum temperature (T_{max}) of 35.1°C. The highest average temperature (26.1°C) and the lowest temperature fluctuation (average T_{min} of 17.9°C and T_{max} of 32.9°C) were observed at the integrated cropland. Spatially enhanced evaporative cooling in the nighttime indicated from relatively higher relative humidity and lower surface air temperature was observed in the forest as compared with that in the croplands (Figure 2). The increases in evapotranspiration and latent heat exchange to the atmosphere observed in the forest primarily due to greater root depth, leaf area and canopy interception (Narisma & Pitman, 2003; Pitman *et al.*, 2009). Based on the observed micrometeorological conditions in different vegetation covers in Northern Thailand, deforestation and cropland expansions can result in warming trends, more typically in the nighttime.

In the daytime, the warm air found at the forest site was mainly associated with high surface roughness, which subsequently increases surface drag and reduces horizontal wind. The consistently calm wind speed (average 1.36 m s^{-1}) observed in the forest, as shown in Figure 2, promotes accumulation of long wave radiation and heat, both of which consequently warm the surface air. Stronger winds for the integrated croplands (average 2.47 m s^{-1}), were chiefly a result of its relatively lower surface roughness. Furthermore, in the daytime many observations show similar air humidity levels between the forest and the croplands and some observations show slightly drier air over the forest (Figure 2), suggesting reduction of latent heat release can be attributed to weakened winds.

As shown in Figure 3, daytime sensible heat flux in the forest often transfers from the atmosphere to soil (84% of total observations); whereas more observations for the integrated croplands exhibited positive flux (39%) from soil to the atmosphere. These different sensible heat fluxes resulted from lower soil moisture and stronger winds induced by

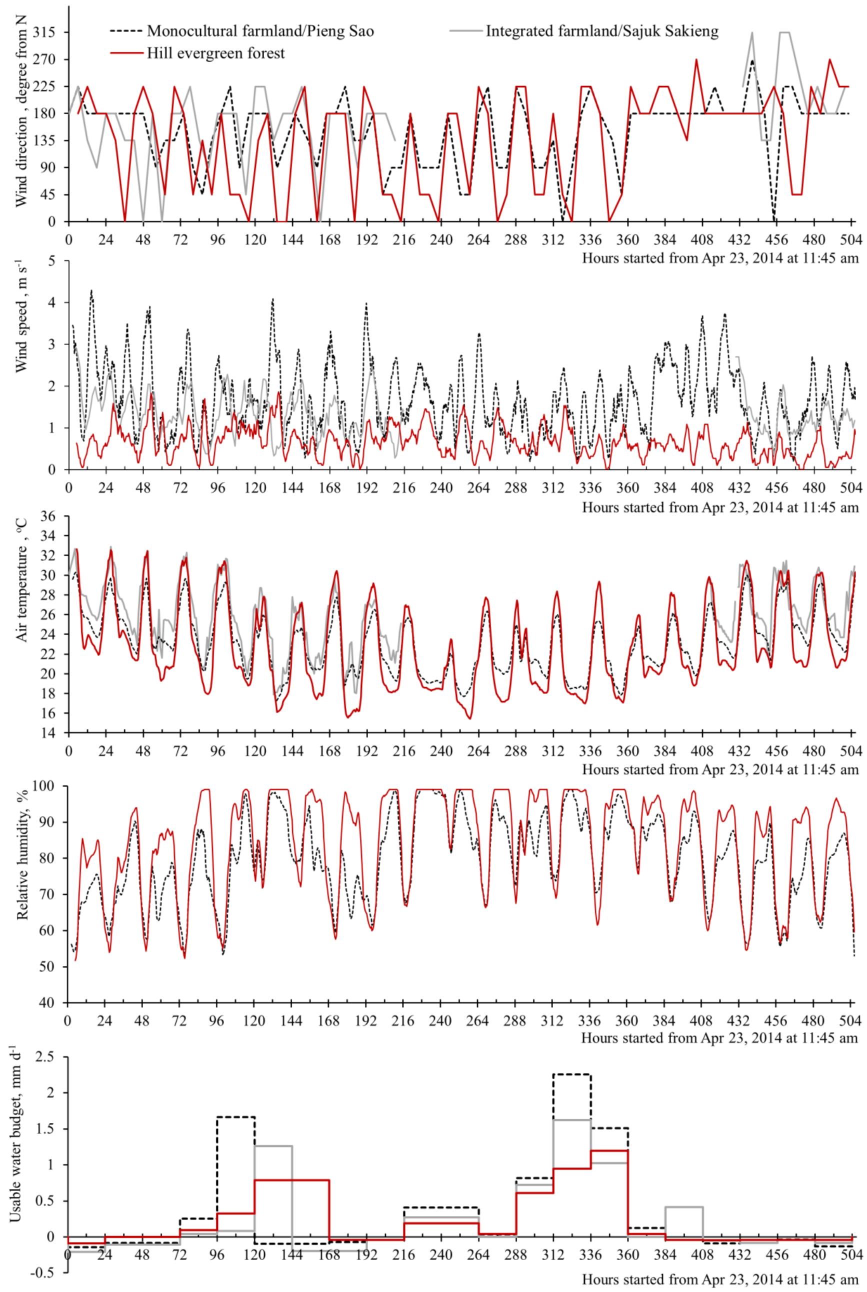

Figure 2.Time-series 6-hour moving average wind direction, wind speed, air temperature and relative humidity and daily usable water budget (rainfall – evaporation) at the three studied sites from Apr 23rd to May 14th, 2014. Note: there are missing data for Sajuk-Sakieng site in certain periods.

reduced surface roughness in the croplands (McAlpine *et al.*, 2007). High soil moisture content promotes a greater amount of heat stored in the soil; whereas dry soil releases the absorbed energy more rapidly. Since observing spatially warmer air over the forest in the daytime, this effect of sensible heat was not useful in describing surface air temperature observed in this study. We can then conclude the dominant role of the latent heat over the sensible heat, which has been typically observed in Indonesian and Amazonian forests as well (Feddema *et al.*, 2005; Malhi *et al.*, 2008).

Daily usable water (rainfall minus evaporation) in the forest was lower than those measured at the croplands. This rainfall pattern should be influenced by spatially-thermal differences between dense forests and deforested/croplands driving local air mass circulation. Vegetation conversions are found to highly affect cloud development and rainfall patterns in many forests, such as those in the Amazon (Negri *et al.*, 2004) and the central USA (Adegoke, *et al.*, 2007). The forest, nevertheless, was infrequently experiencing negative usable water values (Figure 2), indicating it is less vulnerable

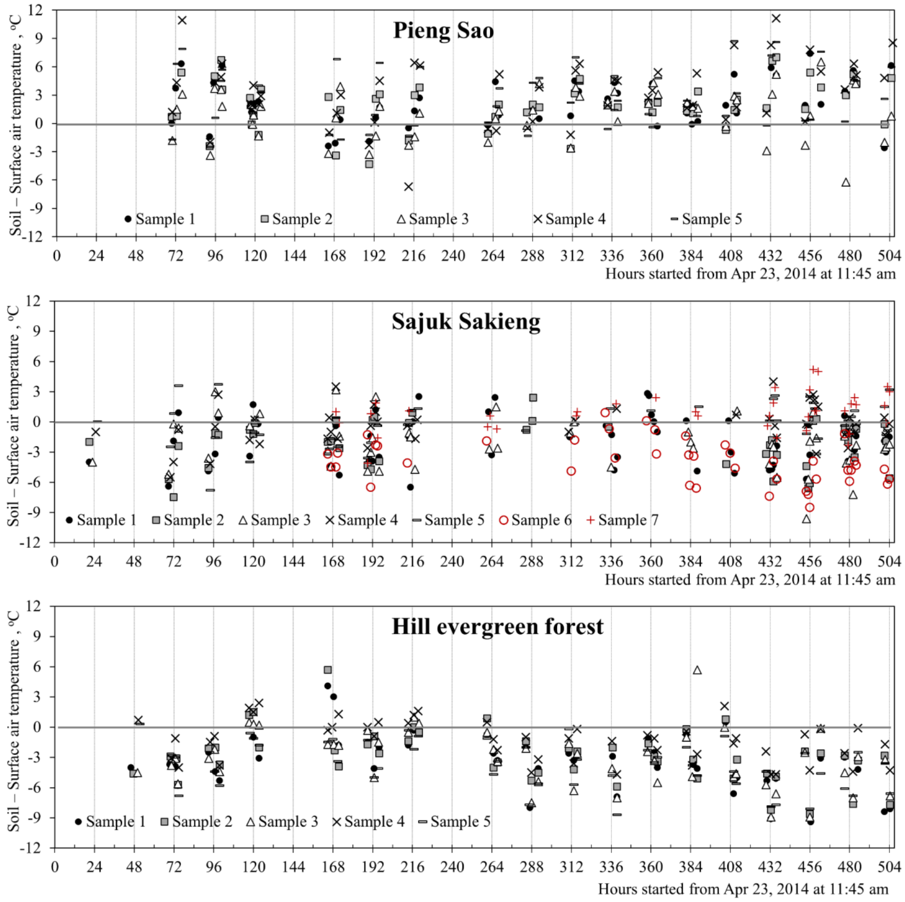

Figure 3. Temperature differences between surface soil and surface air in the daytimes at Pieng Sao (monoculture cropland), Sajuk-Sakieng (integrated cropland) and hill evergreen forest. Negative values indicate sensible flux from atmosphere to soil and the positive value is the flux from soil to the atmosphere.

to drought.

3.2 Micrometeorological responses to integrated and monoculture croplands

As shown in Figure 3, integrated and monoculture croplands evidently exhibited different sensible heat fluxes. As compared with the integrated cropland (39%), the monoculture cropland had more observations (79%) with positive sensible heat flux from soil to the atmosphere during the day. This strong positive sensible heat flux was mainly due to reduction of surface roughness (Findell *et al.*, 2007; McAlpine *et al.*, 2007). Since sensible heat over the monoculture cropland rapidly released during the day, it quickly cooled down in the late afternoon (Figure 2) and therefore low stored energy expected in the nighttime. This resulted in a colder night in the monoculture cropland (~19.1°C) when compared with that of the integrated cropland (~21.5°C).

4. Conclusions

Land cover changes, especially deforestation in Northern Thailand are of great concern. Impacts of the land use changes on the climate, including surface temperature, are uncertain and difficult to evaluate, resulting in limited agreement on a climate response to the land use changes outlined in previous studies. This work aims to investigate diurnally-micrometeorological conditions among different vegetation covers during the early Asian summer monsoon and discuss biogeophysical feedbacks from the vegetation changes. Time-series analysis of satellite imagery was used to evaluate areas with significant land cover changes. Field measurements were conducted in a remote area in Nan, Northern Thailand with significant forest-to-grass/cropland conversions.

Results obtained from the field measurements at a hill evergreen forest site, an integrated cropland and a monoculture cropland during the period of April 23rd to May 14th, 2014 show that the forest was experiencing the lowest average temperature and the highest day–night temperature difference. Latent heat flux, associated with root depth, leaf area, canopy interception, and evapotranspiration, plays a dominant role in the average low temperature, especially at night, in the forest. In the daytime when similar humidity profiles were observed among the sites, the warmest air found at the forest site was associated with its high surface roughness, resulting in higher surface drag, low winds and reduction of latent heat flux. Daily usable water (rainfall – evaporation) in the forest showed lower peak of the usable water than those observed at the croplands. This pattern could be influenced by a spatially-thermal difference driving local air mass circulation between the forest and the croplands. The forest, nevertheless, does not usually experience negative usable water budget, indicating less vulnerability to drought. As compared with the integrated cropland, the monoculture cropland had more observations with positive sensible heat flux from soil to the atmosphere in the daytime. Furthermore, different cultivation practices clearly affected sensible heat fluxes. These results imply an overall warming trend, especially at night, and higher short-term rainfall over deforested/croplands associated with deforestation and cropland expansions.

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