Ecological Characteristics of Mt. Nan Tropical Montane Cloud Forest

Peerasak Sangarun

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
Program in Computational Science
Walailak University

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ชื่อวิทยานิพนธ์	ลักษณะนิเวศเฉพาะของป่าเมฆแห่งเขานัน
ผู้เขียน	พีระศักดิ์ แสงอรุณ
สาขาวิชา	วิทยาศาสตร์เชิงคำนวณ
ปีการศึกษา	2552

บทคัดย่อ

การศึกษานี้เป็นการศึกษาลักษณะนิเวศเฉพาะของป่าเมฆของอุทยานแห่งชาติเขานัน จังหวัดนครศรีธรรมราช โดยแบ่งออกเป็น 3 ส่วนคือ การศึกษาลักษณะทางกายภาพของพืช ลักษณะทางกายภาพของดิน และการศึกษาลักษณะของสภาพภูมิอากาศ การศึกษาลักษณะพืช ได้ทำการศึกษาขนาดของลำต้น ใบ และพืชอิงอาศัยของไม้วงศ์ก่อ *Lithocarpus bennettii* (Miq.) Rehd. ตามระดับความสูงของเขาสันเย็น และเขานมที่ระดับความสูง 1276 และ 1270 เมตรจากระดับน้ำทะเล ตามลำดับ การศึกษาลักษณะดินได้เก็บตัวอย่างดินทุก ๆ 200 เมตรตามเส้นทางคลองกลาย เขาสันเย็น และเส้นทางคลองกัน เขานม และได้นำตัวอย่างดินที่ได้มาวิเคราะห์หา ค่า pH ความชื้น และปริมาณสารอินทรีย์ในดิน การศึกษาลักษณะภูมิอากาศ ได้ติดตั้งเครื่องมือวัดอากาศอัตโนมัติ ไว้ที่ยอดเขาเดือนหก และยอดเขานม ที่ระดับความสูง 1053 และ 1270 เมตร ตามลำดับ โดยมีการบันทึกค่าทุก ๆ 30 นาที

ผลการศึกษาทางกายภาพลักษณะพืช พบว่าพื้นที่ของใบ มีขนาดเล็กลง ความหนาของใบจะหนามากขึ้น และจำนวนพืชอิงอาศัยจะมากขึ้น เมื่อความสูงจากระดับน้ำทะเลเพิ่มขึ้น ผลการศึกษาลักษณะดินพบว่า ปริมาณสารอินทรีย์และความชื้นในดินเพิ่มขึ้น ที่ระดับความสูงจากน้ำทะเลเพิ่มขึ้น ความเป็นกรดด่างของดิน พบว่ามีค่า อยู่ระหว่าง 3.6 – 4.3 นับว่าดินค่อนข้างมีสภาพเป็นกรด แต่ไม่มีความแตกต่างกันในแต่ละระดับความสูง

ผลการศึกษาลักษณะอากาศของเขานมตามระดับความสูงพบว่า อุณหภูมิจะลดลง แต่ความชื้นสัมพัทธ์ จะสูงขึ้นเมื่อระดับความสูงจากระดับน้ำทะเลเพิ่มขึ้น ผลการศึกษาการจำแนกกลุ่มของลักษณะเฉพาะของข้อมูลอากาศจากสถานีตรวจวัดสภาพอากาศอัตโนมัติ โดยใช้ความสัมพันธ์ของตัวแปรต่าง ๆ ประกอบด้วย อุณหภูมิ ความชื้นสัมพัทธ์ ปริมาณรังสีดวงอาทิตย์ ดัชนีความร้อน สามารถแบ่งได้เป็น 3 กลุ่มคือ กลุ่มป่าเมฆประกอบด้วยบริเวณป่าเมฆเขานม เขาเดือนหก เขาดาดฟ้า ดอยอินทนนท์ กลุ่มป่าฝนประกอบด้วย สถานีห้วยเลข ที่ทำการอุทยาน

แห่งชาติเขานัน และกลุ่มพื้นที่ชายฝั่งทะเลประกอบด้วยสถานีตรวจวัดอากาศอำเภอขนอม มหาวิทยาลัยวลัยลักษณ์ และสถานีตรวจวัดอากาศ อ.เมืองนครศรีธรรมราช

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Abstract

This study was investigated the ecological characteristics of tropical montane cloud forest at Mt. Nan National Park, Nakhon Si Thammarat Province along two elevational transects: (1) Klongkai - Mt. Sanyen and (2) Klongkun - Mt. Nom trails. We divided our studies into three parts: (1) vegetation characteristics, (2) soil characteristics and (3) atmospheric characteristics. For vegetation characteristics, we studied the percentage of epiphyte cover, leaf size and tree size of *Lithocarpus bennettii* (Miq.) Rehd We estimated the percentage of epiphyte cover and used the simple linear regression to find the association between tree height, bush size and elevation. We also collected the soil samples every 200 m interval at along two elevational trails and measured soil pH, soil moisture, and the percent organic content in the laboratory. We installed the automatic weather stations at Duan Hok and Mt. Nom cloud forest at the elevation of 1053 and 1270 m a.s.l., respectively. In addition we installed weather stations at seven study sites at Dadfa, Doi Intanon, Huilek, Mt. Nan headquarters, Khanom, Walailak University and Muang Nakhon Si Thammarat stations. We collected the atmospheric data every 30 min interval and compared the atmospheric data by using descriptive statistics, linear and non linear regression and classified habitat types by fitting atmospheric data distribution.

The results of the vegetation characteristics at Mt. Nom showed that as the elevation increased, leaf area decreased, leaf thickness increased and the percentage of epiphyte cover increased. For tree size, as the elevation increased, bush height and tree height decreased. The results of soil characteristics showed that as the elevation increased, the percentage of organic content and the percentage of soil moisture increased. Soil pH at Mt. Nom was highly acidity (pH 3.6-4.3). There were no association between soil pH and elevation.

The climatic characteristics at Mt. Nom showed that as the elevation increased, temperature decreased but the percentage of relative humidity increased. In this study, we collected atmospheric data from weather stations at nine study sites which can be grouped into three categories: (1) four cloud forest sites (Duan Hok, Dadfa, Mt. Nom, and Doi Intanon stations), (2) two tropical forests (Huilek and Mt. Nan headquarters stations) and (3) three coastal sites (Walailak University, Khanom and Muang Nakhon Si Thammarat stations).

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Peerasak Sangarun

Disclaimer

I certify that the material contained in this dissertation is my own work and does not contain significant portions of unreferenced or unacknowledged material. I also warrant that the above statement applied to the implementation of the project and all associated documentation.

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Peerasak

Signature

21/05/2010

Date

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List of Abbreviations

CF	Cloud Forest
DBH	Diameter at Breast Height
DCF	Dadfa Cloud Forest
DO	Dissolved Oxygen
LAI	Leaf Area Index
LMRF	Lower Montane Rainforest
LRF	Lowland Rainforest
NCF	Mt. Nom Cloud Forest
NHQ	Mt. Nan Headquarters
NPP	Net Primary Production
TMCFs	Tropical Montane Cloud Forests
TMF	Tropical Montane Forest
UMRF	Upper Montane Rainforest
D6	Duan Hok cloud forest

Chapter I

Introduction

Significance of Research

Tropical montane cloud forests (TMCFs) are an exceptional biome found in tropical areas where local climatic conditions cause cloud and mist to be regularly in contact with the evergreen montane forest vegetation. These forests support ecosystems of distinctive floristic and structural form and contain a disproportionately large number of the world's endemic and threatened species. One of their most obvious features is an abundance of mosses, ferns, orchids and other epiphytic plants on every tree and rock surface (Bubb et al., 2004).

The research stems in large part from my own study, interest and experience of environmental science that I have involved for a period of time. The characteristics of cloud forests were much cooler than tropical rainforests. It hosts various and large number of plants and animal species. It has a high number of epiphytes (plants that grow on other plants). It plays an important role in capturing, storing and filtering water to feed human community in lower area. Moreover, this study may lead me and others to recognised the advantages and important of cloud forests in Thailand and around the world before their gradually disappearing along with the global change.

Cloud forest characteristics

In general, cloud forests are defined as forests that are frequently covered in cloud or mist; thus receiving additional humidity, other than rainfall, through the capture and/or condensation of water droplets (i.e. horizontal precipitation), which influences the hydrological regime, radiation balance, and several other climatic, edaphic, and ecological parameters (Stadtmüller, 1987). TMCFs are covered in clouds and fog and are abundant with mosses, lichens and epiphytes. The hydrology of these ecosystems is poorly understood due to the extreme wetness, complex topography, and remoteness. TMCFs are also susceptible to several types of disturbance (Wård, 2007).

The typical features and characteristics of TMCFs (Hamilton et al., 1995) are:

1. Capacity to capture or strip water from clouds, which may result in an increased catchment water yield compared to other vegetation types.
2. High proportion of biomass in the form of epiphytes.
3. Fewer woody climbers than in lower altitude tropical forests.
4. High local biodiversity in terms of shrubs, herbs and epiphytes, with a high proportion of endemic species.
5. They typically occur in the following soil types:
    - (i) Wet, frequently water logged soils that typically have high organic matter contents (Histosols)
    - (ii) Shallow soils with weakly developed horizons (Leptosols)
    - (iii) Drought sensitive soils with low water holding capacity (Regosols)

In the past, attempts to study TMCFs have been complicated by the lack of agreed definition of TMCFs, and a corresponding abundance of names for them. As many as 35 distinct definitions have been identified (Stadtmüller, 1987). Finally, a rather simple system for classifying TMCFs (Bruijnzeel and Hamilton, 2000), based purely on elevation and abundance of mosses, was proposed

1. Lower montane tropical cloud forest (affected by low clouds, 25-50% moss cover on stems)
2. Upper montane tropical cloud forest (affected by low clouds, 70-80% moss cover on stems)
3. Subalpine cloud forest (elfin forest, affected by low clouds, >80% moss cover on stems)

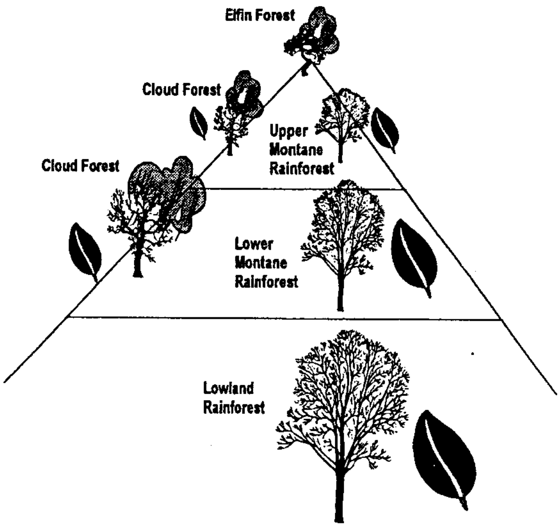

Figure 1 Ecotone zonation on tropical mountains.
Source: (Foster, 2001)

Typical gradation of mountain ecosystem types is shown in figure 1. From the lowland rainforest through the lower montane rainforest up to the upper montane rainforest, tree stature and leaf size decrease. In the presence of frequent cloudiness, the cloud forest can occur in either the lower montane rainforest or upper montane rainforest. Within the cloud forest, tree height and leaf size are even smaller than in standard forests at the same altitude. Accompanying the decrease in size in the cloud forest, trees become twisted and gnarled and leaves become thick and hard. On exposed ridges and peaks these effects can be even more magnified and the crown of trees often assumes an umbrella-like shape. The characteristics of cloud forest are the importance of epiphytic bryophytes and fog deposition in nutrient cycling of this subtropical montane forest ecosystem (Foster, 2001).

The canopy height in TMCFs varies from 2 m, on the most exposed peaks in the elfin forests, to 35 m in sheltered areas. Excluding the lowest elfin forests, they are generally complex, two-layered canopy systems with abundant mosses, lichens and epiphytes (Frahm, 1990; Veneklaas and Van Ek, 1990), with epiphyte abundance increasing with elevation (Stadtmüller, 1987). One such example is Mt. Kinabalu, Sabah, in Malaysia, where the canopy consists of two layers, one at *ca.* 30 m and one at *ca.* 15 m on lower altitudes, with increasing altitude the tree height decreases (Kitayama, 1995).

The potential global area of cloud forest is about 380,000 km^2, which is approximately 0.26 percent of the Earth's land surface. TMCFs account 2.5 percent of all tropical forests in the world today. In the Americas and Africa, Cloud forest is an even rarer forest habitat, forming 1.2 percent and 1.4 percent, respectively, of the tropical forests of these regions. Cloud forests are also a scarce habitat amongst all forest types in tropical mountain regions, occupying 8.4 percent, 10.5 percent and 14.6 percent of tropical mountain forest in the Americas, Africa and Asia, respectively (Table 1). Cloud forest is not distributed equally across the tropical regions. Of the global area of potential cloud forest 25.3 percent occurs in the Americas, 15.0 percent in Africa and 59.7 percent in Asia (Table 2). One of the most noteworthy results of this analysis is the very large extent of potential cloud forest in Asia, principally in Indonesia and Papua New Guinea (Bubb et al., 2004).

Table 1 Potential cloud forest as a percentage of all tropical forest and tropical mountain forest.

Region	All Tropical Forest(km^2)	CF as %all Tropical Forest	TMF (km^2)	CF as %all TMF
Americas	7,762,359	1.2	1,150,588	8.4
Africa	4,167,546	1.4	544,664	10.5
Asia	3,443,330	6.6	1,562,023	14.6
Global total	15,373,235	2.5	3,257,275	11.7

Source: (Bubb et al., 2004)

Table 2 Area of potential cloud forest by continental region.

Region	Potential Cloud Forest Area (km^2)	% of Global Cloud Forest
Americas	96,394	25.3
Africa	57,190	15.0
Asia	227,582	59.7
Global total	381.166	100.0

Source: (Bubb et al., 2004)

TMCFs normally found at altitudes between 1500 m a.s.l. and 3300 m a.s.l., occupying an altitudinal belt of approximately 800 to 1000 m at each site (Stadtmüller, 1987). The lowermost occurrence of low-statured cloud forest (300–600 m a.s.l.) is reported from specific locations like small islands, were the cloud base may be very low and the coastal slopes are exposed to both, high rainfall and persistent wind-driven clouds (Bruijnzeel, 2001). On small tropical islands, such as Puerto Rico, TMCFs can be found at lower altitudes. On average, rainfall in tropical montane cloud forest ecosystems ranges from 500 to 10,000 mm/yr (Wård, 2007).

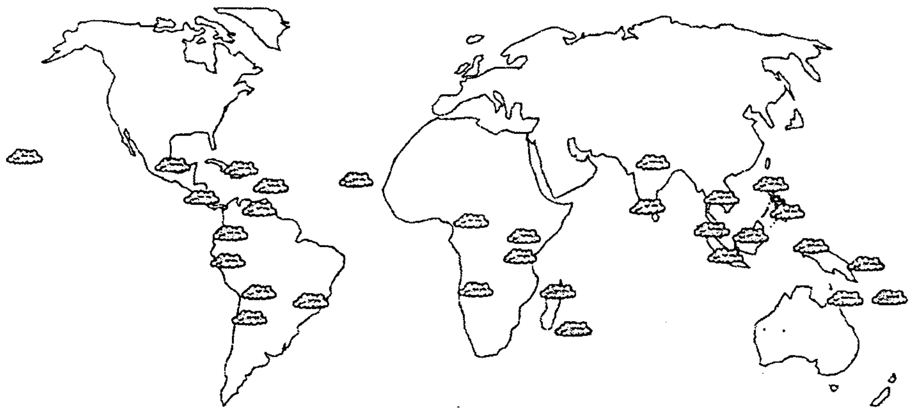

Figure 2 Generalised occurrence of tropical montane cloud forests.
Source: (Bruijnzeel and Hamilton, 2000)

An overview of the worldwide distribution of cloud forest is given in Figure 2. The frequent bathing in clouds leaves its traces.

Table 3 Listing of some of the principle attributes of the cloud forest.

	Characteristics
Climatic	Frequent cloud presence Usually high relative humidity Low irradiance
Vegetation	Abundance of epiphytes Stunted trees Small, thick and hard leaves High endemism
Low Productivity	Low NPP Low LAI (although locally it can be very high)
Slow Nutrient Uptake	Sap flow depressed Low transpiration Low photosynthesis rates (though capacity not reduce)
Soil and Litter Difference	High organic content in soil High concentration of polyphenols in litter Soils wet
Positive Water Balance	Additional moisture input from cloud stripping Stream flow/incident rainfall very high Low evapotranspiration and evaporation

Source: (Foster, 2001)

Climatic Characteristics

Many studies have been done on cloud forest climatic characteristics throughout the world. Most of the studies were focusing on only two main climatic factors: temperature, and relative humidity.

The study of the climatic characteristics in a subtropical mountainous cloud forest at the Yuanyang Lake long-term ecological research site (YYL-LTER) in Chilan Mountain, at an elevation of 1650 to 2420 m a.s.l. in northeastern Taiwan showed weather data collected from January 1994 to December 2004. The average annual temperature was 12.7 °C over the period from 1994 to 2004, with the highest annual temperature of 13.2 °C in both 1998 and 2000 and the lowest one of 11.9 °C in 1997 (Lai et al., 2006). The cloud forests in eastern Mexico were reported the annual temperature between 13.4–22.2 °C and the mean temperature was 16.6 °C. The mean temperature at the tropical Montane Cloud Forest Ecosystem in Costa Rica was 17.7 °C with a maximum of 23.3 °C and a minimum of 13.0 °C (Schmid, 2004). The average annual temperatures in the western part of the Talamanca Mountain Range in Costa Rica (2300-2800 m a.s.l.) ranged from c.a.12 °C at 2800 m to c.a. 14.5 °C at 2300 m elevation (Oosterhoorn and Kappelle, 2000).

In the surroundings of Xalapa, Veracruz, Mexico, between 1120 and 1590 m elevation in the upper region of the La Antigua River Basin, the mean annual temperatures ranged from 17 °C at higher elevations to 20 °C at lower elevations, and total annual precipitation ranged from 1500 to 1900 mm (Soto and Gómez, 1990).

The study of three different localities in the Anaga cloud forest: Pijaral, La Ensillada and Monte Aguirre that situated on the island of Tenerife showed that all of them were located at altitudes between 750 and 850 m, where the mean annual temperature was 13.7 °C and the mean annual relative humidity was nearly 90% (Eguchi et al., 1999).

At Yuanyang Lake, the relative humidity was usually higher than 90%. The annual precipitation varied between 2109 mm and 4,727 mm, with an average of 3,396 mm and average annual solar radiation at the YYL site was 2475 MJ m^{-2} (Lai et al., 2006).

Vegetation characteristics

The trees height decreases when elevation increases (Figure 3). With increasing elevation the vegetation on wet (tropical) mountains changes markedly upon reaching the cloud belt. Trees become smaller and much mossy.

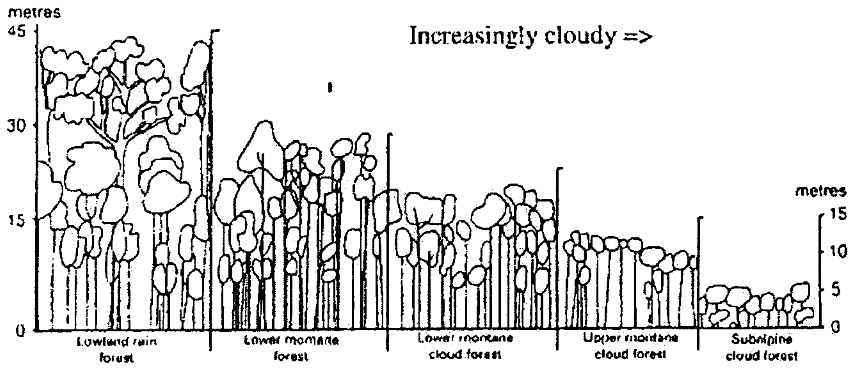

Figure 3 With increasing elevation trees become smaller and much mossy. Source: (Bruijnzeel and Hamilton, 2000).

Most of forest community at Mt. Nan National Park is evergreen forest but at the elevation from 1000 m the plant community in which differs from the lower area. At the cloud forest with the height up to 15 m and the stunted trunk. From the survey study, the prominent species of plants were cited; *Fagaceae* in the top canopy, *Theaceae*, *Myrtaceae* and *Lauraceae* in the secondary canopy and *Rubiaceae* in the lower canopy. Up on these trees, lichen, moss, fern and orchids appear. Outline of forest community at Mt. Nan National Park was showed in Figure 4.

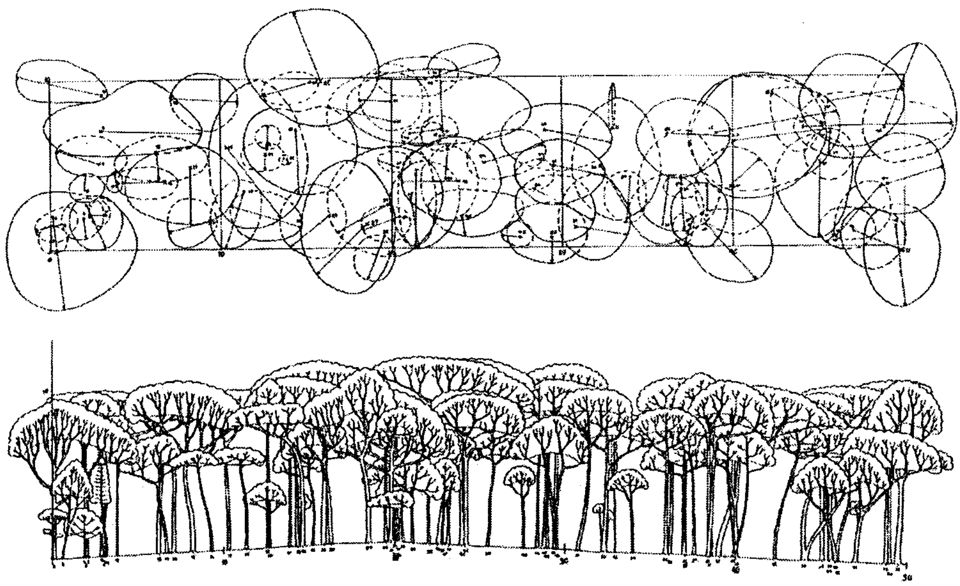

Figure 4 Forest structure of Sanyen cloud forest at Mt. Nan.
Source: (Panumas Jantarasuwan)

Soil characteristics

High acidity (pH 2-4) at TMCFs was reported in many studies (Hardon, 1936; Barshad and Rojas-Cruz, 1950; Askew, 1964; Burnham, 1974; Schawe et al., 2007). However, other researchers found pH values over 5 (Edwards and Grubb, 1982; Bracho and Sosa, 1987; Vance and Nadkarni, 1992; Bruijnzeel and Proctor, 1995). The soil samples taken from the top soil (0-10 cm) at TMCFs elevation 1500 – 3000 m a.s.l. have pH values of 4-6 (Schawe et al., 2007).

Cloud water deposition often increases with elevation, and it is widely accepted that this cloud water increases acid loading to TMCFs ecosystems. Cloud water deposition can be four times more acidic than bulk precipitation (Sigmon et al., 1989). Since cloud cover tends to increase with elevation, we expect a positive relationship between forest acidification and elevation (Foster et al., 1989; Hendershot et al., 1992).

Climate change affecting cloud forest

As average temperature increases, optimum habitat for many species will move to higher elevations or higher latitudes. Where there is no higher ground or where changes are taking place too quickly for ecosystems and species to adjust, local losses or global extinctions will occur. Observations suggest that tropical montane cloud forests are highly at risk due to fewer, higher clouds and warmer temperatures, with serious impacts already underway (Still et al., 1999). Amphibians may also be especially susceptible (Lips, 1998). Many amphibious species already appear to be declining, and serious losses have been recorded for example in Australia and Central America.

If cloud forest species are unable to migrate fast enough to keep up with the rate at which climate change is shifting from climatic optimums, then these systems will not survive. In general, the migration rates of montane species are estimated to be significantly slower than those of lowland species (Foster, 2001). Slow growth and maturation rates exacerbate migration difficulties. In addition to reaching a new site, forest species must also complete their life cycle before the climate envelope has passed (Foster). The slow growth rates of many cloud forest species imply that they may be ill equipped to compete with new and nonnative species. Climate change is likely to increase competitive threats by (1) encouraging invasion from lower altitude species into cloud forest habitat, (2) increasing disturbance-induced canopy openings that allow for the establishment of fast-growing pioneer species, and (3) forcing cloud forest migration into new regions where they may not have the competitive advantage (Foster).

TMCFs are defined by their regular immersion in clouds, possible only along mountain peaks and narrow bands of altitude where orographic clouds tend to form. Consequently, these systems exist as highly isolated and fragmented strips, which some ecologists have compared to island archipelagoes. Such conditions encourage speciation as well as high levels of endemism, as is reflected in the biodiversity of these forest communities. Unfortunately, the same characteristics that uniquely define these systems also render them extremely sensitive to the potential impacts of global climate change. Evidence suggests that climate changes could potentially threaten the future viability of tropical cloud forests in a number of ways including ecotone altitude shifts, changes in cloud formation, and increases in severe disturbance events. Recent disappearances of several cloud forest anuran and anoline species implie that such impacts may already be influencing cloud forest communities (Foster, 2001).

The isolation and unique vegetative structure of tropical cloud forests encourage high levels of speciation and endemism. The ranges of many of these species are incredibly limited, some even endemic to particular mountain peaks. On a global scale, nearly 10% of all range-restricted birds are either confined to or found primarily in cloud forests. Of the 327 threatened bird species of the Americas, 38 are cloud forest species (Bubb et al., 2004).

More disturbance events would cause wind damage to trees, as well as increased soil erosion. Soil erosion is then likely to cause a number of problems such as nutrient leaching and drought. These same regions have also decreased in soil moisture and relative humidity. Extended dry seasons will increase water stress for the forest systems, damage vegetation, and eventually cause increases in drought and fire. Worsening the matter, cloud forests are known to be especially vulnerable to disturbance due to their slow growth and inability to colonise disturbed regions (Foster, 2001). Consequentially, the likelihood of cloud forest survival/recovery appears grim, especially when considered in conjunction with other potential impacts of climate change.

Epiphytes are essential to the viability of tropical cloud forest ecosystems. Arboreal flora controls a number of systemic cycles and serves as nesting and breeding area for many of the unique cloud forest fauna. The high density of epiphytes greatly influences the light cycle, and is responsible for both decreased UV radiation in the understory and increased leaf area index (Foster, 2001).

Studies indicate that changes in precipitation, temperature, cloud immersion, and frequency of disturbance events pose significant threats to tropical montane cloud forests. Their characteristic narrow ranges, slow growth, maturation, and migration rates, inability to compete in disturbed areas, and strict climatic requirements amplify such threats and suggest that impacts may be felt sooner rather than later. Recent population crashes of some of the forests' more sensitive species provide forbidding evidence of the impending consequences. It is a great tragedy that these unique systems, which house extraordinary biotic treasures and supply millions of people with clean water, may be amongst the first victims of climate change.

Objectives of the research

To study cloud forest characteristics of Mt. Nan National Park, Nakhon Si Thammarat: climatic, vegetation and soil characteristics.

To compare the climatic characteristics of cloud forest with tropical montane rain forest and coastal sites in Nakhon Si Thammarat Province.

Methodology

Study Area

Mt. Nan is situated at Noppitam sub-district, Thasala district, and Sichon district in Nakhon Si Thammarat province. The geographical characteristics of Mt. Nan is a high mountainous range in North-South direction which is a part of Nakhon Si Thammarat mountain range. The forest at Mt. Nan is tropical mountain forest which is an important watershed source of Nakhon Si Thammarat. The area of the Mt. Nan National Park is 253,750 Rai or 406 km^2 (Figure 5).

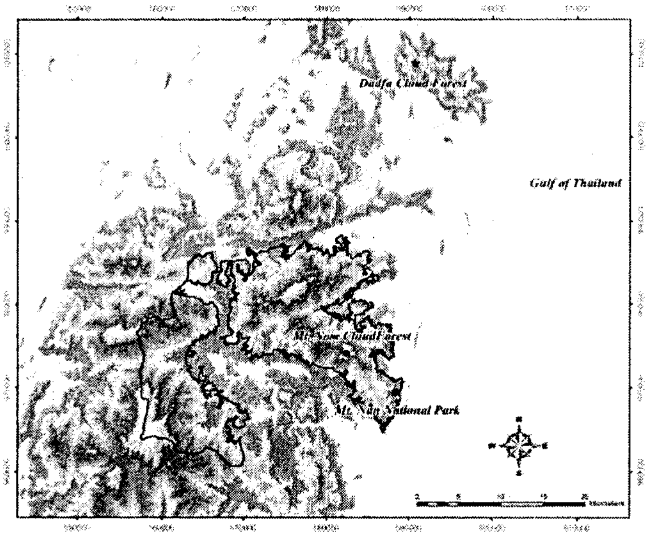

Figure 5 Mt. Nan National Park boundary.

There are many important mountains in Mt. Nan, Mt. Yai, Mt. Nan Yai, Mt. Nan Mea, Mt. Lek, Mt. Chong Lom, Mt. Dai, and etc. The highest peak is Mt. Yai which is 1,438 m a.s.l. and it is a part of Nakhon Si Thammarat mountain range. As 90 percent of the area in Mt. Nan is primary tropical evergreen forest, it is also a watershed source, a forest of famous plants, a home for various species of living being and wild lives, and natural minerals such as tin, barite, wulfenite, and etc. The climatic characteristics of Mt. Nan is high moisture of a tropical evergreen forest and with a high precipitation, the weather is cool all year round.

Many valuable economical plants are found in Mt. Nan area; Dipterocarpus, *Intsia palembanica* Mig., *Hopea pierrei* Hance, *Hopea odorata* Roxb., *Parashorea* *stellata* Kurg.; Phyllanthus, *Michelia champaca* Linn., and so on. Furthermore, in the area of Ban Tapnamtao, Ban Naprachao, Ban Huaiprik, and Ban Huaihang, there is *Elaleriospermum tapos* Bl. in large area. This type of tree with edible fruit is rarely found growing in a large area as it is in Mt. Nan. The wild animals seen in this area are goat-antelope, *Tapirus indicus*, cervidae, wild pig, mouse-deer, virerridae, civet and so on included with more than 150 types of birds; big types as the great hornbill and local Nakhon Si Thammarat range's bird as a green-tailed sunbird.

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Chapter II

Cloud Forest Characteristics of Mt. Nan, Thailand

Publications

Sangarun, P., Srisang, W., Jaroensutasinee, K. and Jaroensutasinee, M. (2007). Cloud Forest Characteristics of Khao Nan, Thailand. *International Journal of Mathematical, Physical and Engineering Sciences*, 1, 232-237.

Prathet, P., Sangarun, P., Srisang, W., Jaroensutasinee, M. and Jaroensutasinee, K. (2007). Vegetation characteristics of cloud forest at Khao Nan National Park, Nakhon Si Thammarat. 33rd Congress on Science and Technology of Thailand, Nakhon Si Thammarat, Thailand. 18th-20th October, B6_B0047 p. 125.

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Sangarun, P., Jaroensutasinee, K. and Jaroensutasinee, M. (2008). Ecological Characteristics of the Tropical Montane Cloud Forests of Khao Nan. Abstract: Research and Thesis 2008, 12th BRT Annual Conference. Suratthanee, Thailand. 10th-12th October p. 12.

Abstract

A better understanding of cloud forest characteristics in a tropical montane cloud forest at Mt. Nan, Nakhon Si Thammarat on climatic, vegetation, soil and hydrology were studied during 18-21 April 2007. The results showed that as air temperature at Sanyen cloud forest increased, the percent of relative humidity decreased. The amount of solar radiation at Sanyen cloud forest had a positive association with the amount of solar radiation at Parah forest. The amount of solar radiation at Sanyen cloud forest was very low with a range of 0-19 W/m^2. On the other hand, the amount of solar radiation at Parah forest was high with a range of 0-1000 W/m^2. There was no difference between leaf width, leaf length, leaf thickness and leaf area with increasing in elevations. As the elevations increased, bush height and tree height decreased. There was no association between bush width and bush ratio with elevation. As the elevations increased, the percent epiphyte cover and the percent soil moisture increased but water temperature, conductivity, and dissolved oxygen decreased. The percent soil moistures and organic contents were higher at elevations above 900 m than elevations below.

Keywords: Cloud forest, Climate, Vegetation, Soil, Hydrology

Introduction

Tropical montane cloud forest occurs in mountainous altitudinal band frequently enveloped by orographic clouds (Eguchi et al., 1999; Foster, 2001). This forest obtains more moisture from deposited fog water in addition to bulk precipitation (Frahm, 1990; Hamilton et al., 1995; González-Mancebo et al., 2004). The main climatic characteristics of cloud forests include frequent cloud presence, usually high relative humidity (RH) and low irradiance (González-Mancebo et al., 2004). At high altitude tropical mountains, the trees typically decrease in stature, and leaves become smaller, and harder. If the tropical mountain intersects the cloud cap, their effects are magnified. Twisted stunted trees are encountered and the leaves become even more akin to desert xeromorphic leaves. The dwarfed trees in the cloud cap are laden with a heavy mass of epiphytes whose roots suspend in air. Cloud forest soils are wet and frequently saturated, though rarely waterlogged. No cloud forest soil ever showed a water deficit, even during severe drought (González-Mancebo et al). There has been one observation of cloud forest dieback in response to a drought (Hamilton et al., 1995).

Little has been done on climatic factors, vegetation, soil, hydrology and their effects on tropical montane cloud forest in Thailand. The lack of understanding of the cloud forest characteristics makes it difficult to predict what the impacts of climate change will be on the cloud forest. This study was the first to investigate the climate, vegetation, soil and hydrology characteristics of tropical montane cloud forest at Mt. Nan, Nakhon Si Thammarat, Thailand.

Materials and Methods

Site Description

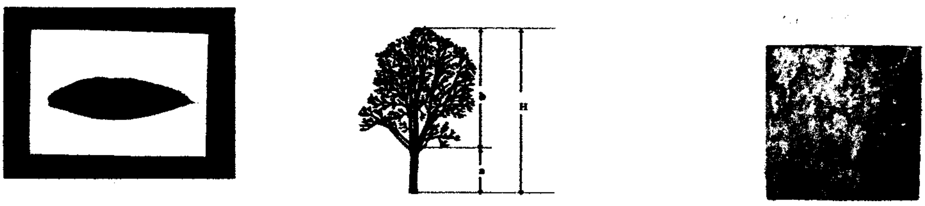
Mt. Nan is situated at Noppitam sub-district, Thasala district, and Sichon district in Nakhon Si Thammarat province. The geographical characteristic of Mt. Nan is a high mountainous range in North-South direction which is a part of Nakhon Si Thammarat mountain range. The forest at Khao Nan is tropical mountain forest which is an important watershed source of Nakhon Si Thammarat. The area of the Mt. Nan is 406 km^2. The highest peak is Khao Yai which is 1,438 m above sea level and it is a part of Nakhon Si Thammarat mountain range.

Many valuable economical plants are found in Mt. Nan, such as Dipterocarpus, *Intsia palembanica* Mig., *Hopea pierrei* Hance, *Hopea odorata* Roxb., *Parashorea stellata* Kurg. Phyllanthus, *Michelia champaca* Linn., and etc. Furthermore, in the area of Ban Tapnamtao, Ban Naprachao, Ban Huaiprik, and Ban Huaihang, there is *Elaleriospermum tapos* Bl. in large area. This type of tree with edible fruit is rarely found growing in a large area as it is in Mt. Nan. The wild animals seen in this area are goat-antelope, *Tapirus indicus*, cervidae, wild pig, mouse-deer, virerridae, civet and etc. including more than 150 types of birds.

Climatic characteristics

We collected climatic factors at Sanyen cloud forest, Mt. Nan from 18-20 April 2007. Sanyen cloud forest was located at 1270 m a.s.l. HOBO data logger was used to collect mean, maximum and minimum air temperature, relative humidity and solar radiation. We collected the same climatic data at Parah forest and Walailak University by using Davis weather station model Pro II Plus. Parah forest weather station was located at 220 m a.s.l. Walailak Weather station was located at 8 m a.s.l.

Vegetation characteristics



(a) (b) (c)

Figure 6 Vegetation characteristics (a) leaf photography, (b) tree height, and (c) the percentage of epiphyte cover around tree trunk with scales.

We studied vegetation characteristics from Klongkai station at 329 m in elevation to Sanyen cloud forest at 1279 m in elevation during 17-21 April 2007. We measured leaf size, tree height and the percentage of epiphyte cover tree trunk. For leaf size, we collected ten leaves/tree and five trees per study site. We selected leaves that were in good conditions from the first branch from the tree base. We took photographs of these leaves with a Canon A530, 5 million pixels in the laboratory against a white A4 paper (Figure 6a). The leaves on these photographs were then measured for leaf width, length and area using Adobe Photoshop and MultiSpec Win 32. For leaf thickness, we used a vernier caliper to measure its thickness at 0.01 cm resolution. We used a simple linear regression to find the association between leaf size and elevation.

For tree height, we selected a type of tree and measured a tree height of five trees that had a diameter at breast height (DBH) between 90-110 cm at each study site using clinometre and tape measurement. We found the tree at starting elevation and continuous measured tree height up to Sanyen cloud forest and Mt. Nom cloud forest with a total of 13 study sites at Sanyen and about 20 study sites at 1400. We measured tree height (H), the distance from the ground to bush (a) and the width of the bush in four directions (i.e. north, east, west, south) (Figure 6b). We used simple linear regression to find the association between tree height, bush size and elevation.

For the percentage of epiphyte cover, we selected five trees/study sites that had DBH between 100-130 cm and took photographs of epiphytes cover on tree trunk. We started my study sites at 384 m in elevation and collected every 100 m increase in elevation until we reached Sanyen and Mt. Nom cloud forests with a total of 20 study sites. We took photographs of these leaves with a Canon A530, 5 million pixels with a camera stand using a rectangular frame with scales on it (Figure 6c). We estimated the percentage of epiphyte cover/area and then used simple linear regression to find the association between the percentage of epiphyte cover/area and elevation.

Soil characteristics

We measured some soil characteristics in the field, collected some soil samples back and measured some soil characteristics in the laboratory. In the field, we used Kelway soil probe to measure soil pH and moisture. We placed this soil probe in the soil no deeper than 10 cm depth every 100 m interval starting from Klongkai station until we reached Sanyen cloud forest with a distance of 5600 m. At each study site, we measured soil pH and moisture three times within 1 m radius and measured latitude, longitude and elevation of the study sites using GPS model 76 CSX. We also collected soil samples at these following elevations: 300, 500, 700, 900, 1100, 1200, and 1300 m by using a soil auger. Because this soil contained a lot of rocks, we used a sieve number 10 to sieve the rocks out from our soil samples prior to weigh the soil. We weighed 550 g soil/sample, oven dried at 90 °C for 24 hrs, reweighed soil again and calculated the percent soil moisture. We weighed 50 g oven dried soil/sample, burned it at 550 °C for 1 hr, reweighed the soil and calculated for the percent soil organic content.

Hydrology characteristics

We measured water quality in all water body found along Klongkai station to Sanyen cloud forest. Water quality was composed of water temperature, conductivity and dissolved oxygen (DO) using METTLER TOLEDO Portable Lab™ 300 MX three times per study site.

Data Analysis

Parametric statistics were used when underlying assumptions were met, otherwise non-parametric tests were used. We compared Simple linear and non-linear regressions were used to find some association between (1) Sanyen cloud forest climatic data, Parah forest weather station and Walailak weather station on the same dates, (2) leaf size and elevation, (3) the percentage of epiphyte cover and elevation, (4) the percentage of soil moisture and the percentage of soil organic content and (5) water temperature, conductivity and DO and elevation. All significant tests were two-tailed.

Results and Discussions

Climatic Characteristics

The mean, maximum and minimum air temperature at Sanyen cloud forest were ($\overline{X} \pm SD$) = 20.12±0.89 °C; maximum temperature ($\overline{X} \pm SD$) =24.15±2.79 °C; minimum temperature ($\overline{X} \pm SD$) = 17.45±1.74 °C. As the air temperature increased, the percentage of RH decreased in all three locations (nonlinear regression: Sanyen cloud forest: $F_{3,573} = 1.20\text{x}10^4$, $P<0.001$, (Figure 7, Equation 1); Parah forest: $F_{3,255}$ = 7000, $P<0.001$, (Figure 7, Equation 2); Walailak University: $F_{3,573} = 2.349\text{x}10^6$, $P<0.001$, (Figure 7, Equation 3), where T represented air temperature. These results were clearly shown that Sanyen cloud forest was much cooler than Parah forest and Walailak University. The maximum temperature at Sanyen cloud forest was 28 °C.

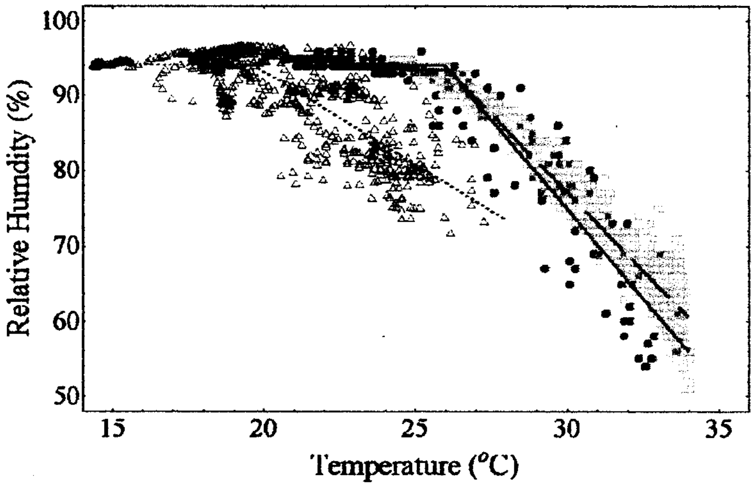


Figure 7 Climatic characteristic of Sanyen cloud forest, Mt. Nan from 18-20 April 2007. Relationship between relative humidity and temperature (°C): Δ (--) Sanyen cloud forest, ● (___) Parah forest and □ (__ __) Walailak University.

On the other hand, the maximum temperature at Parah forest and Walailak University were 33 and 34 °C. the percentage of RH at Sanyen cloud forest ranged from 72-100 percent. This indicates that Sanyen cloud forest contains more water vapour even in the summer time than lower elevation locations. As the air temperature at Sanyen cloud forest increased, the percentage of RH decreased with a shallow slope. On the other hand, as the air temperature at Parah forest and Walailak University increased, the percentage of RH decreased with steeper slopes than at Sanyen cloud forest.

At Sanyen cloud forest,

$$RH = 94.25, T < 19.62°C \quad (1)$$
$$RH = 94.25 - 2.48(T - 19.62), T \geq 19.62°C$$

At Parah forest,

$$RH = 94.15, T < 25.97°C$$
$$RH = 94.15 - 4.74(T - 25.97), T \geq 25.97°C \quad (2)$$

At Walailak University,

$$RH = 93.56, T < 26.07°C$$
$$RH = 93.56 - 4.15(T - 26.07), T \geq 26.07°C \quad (3)$$

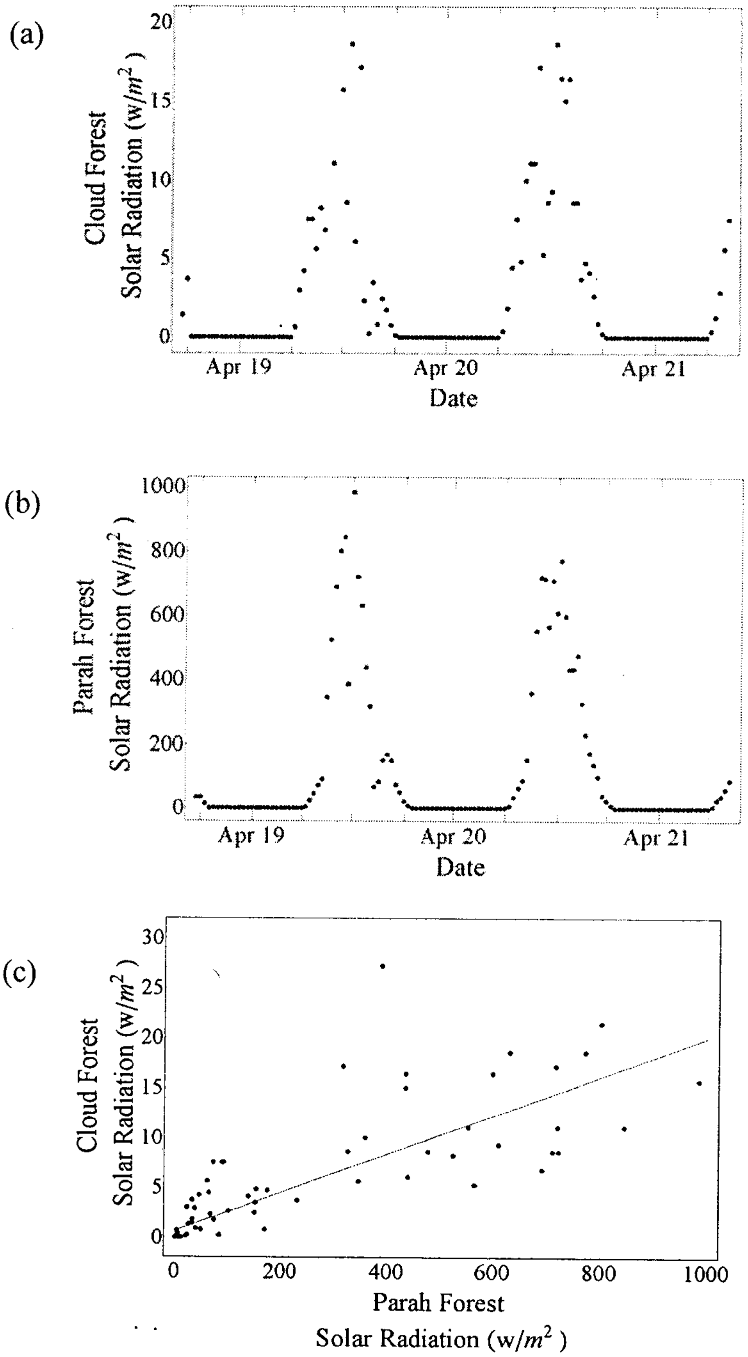


Figure 8 The amount of solar radiation (W/m^2), Mt. Nan from 18-20 April 2007. (a) at Sanyen cloud forest, (b) the amount of solar radiation (W/m^2) at Parah forest and (c) at Sanyen cloud forest and Parah forest.

The amount of solar radiation at Sanyen cloud forest was lower with a range of 0-19 W/m^2 than at Parah forest which was 0-1000 W/m^2 (Figure 8a,b).

The amount of solar radiation at Sanyen cloud forest was positively associated with the amount of solar radiation at Parah forest (Figure 8c).

The linear regression was as follow:

$y = 0.0194x + 0.630$, $R^2 = 0.702$, $F_{1,125} = 294.746$, $P < 0.001$

Tropical montane cloud forests have regular fogs or cloud immersion. This cloud immersion reduces a large amount of solar radiation. Our results support previous findings (Foster, 2001; González-Mancebo et al., 2004) that the amount of solar radiation was a lot less at Sanyen cloud forest when we compared with Parah forest and Walailak University. This large amount of reduction in solar radiation would reduce bio-productivity (Kitayama, 1995).

Vegetation Characteristics

There were no differences between leaf width, leaf length, leaf thickness and leaf area among different elevations:

leaf width:	$\overline{X} \pm SD = 6.26 \pm 1.35$, $F_{50,229} = 1.290$, ns;
length:	$\overline{X} \pm SD = 19.18 \pm 3.67$, $F_{76,203} = 1.070$, ns;
thickness:	$\overline{X} \pm SD = 0.007 \pm 0.0056$, $F_{2,277} = 0.0761$, ns;
area:	$\overline{X} \pm SD = 87.80 \pm 32.70$, $F_{20,259} = 0.949$, ns.

As the elevations increased, bush height and tree height decreased:

bush height:

$y = -0.013x + 23.351$, $R^2 = 0.091$, $F_{1,44} = 4.429$, $P < 0.05$ (Figure 9a).

tree height:

$y = -0.022x + 38.604$, $R^2 = 0.231$, $F_{1,44} = 13.203$, $P < 0.001$ (Figure 9b).

There was no association between bush width and bush ratio with elevations:

bush width:	$F_{1,44} = 0.323$, ns;
bush ratio:	$F_{1,44} = 1.473$, ns.

As the elevations increased, % epiphyte cover increased:

$y = 0.064x + 0.147$, $R^2 = 0.724$, $F_{1,94} = 246.93$, $P < 0.001$ (Figure 9c).

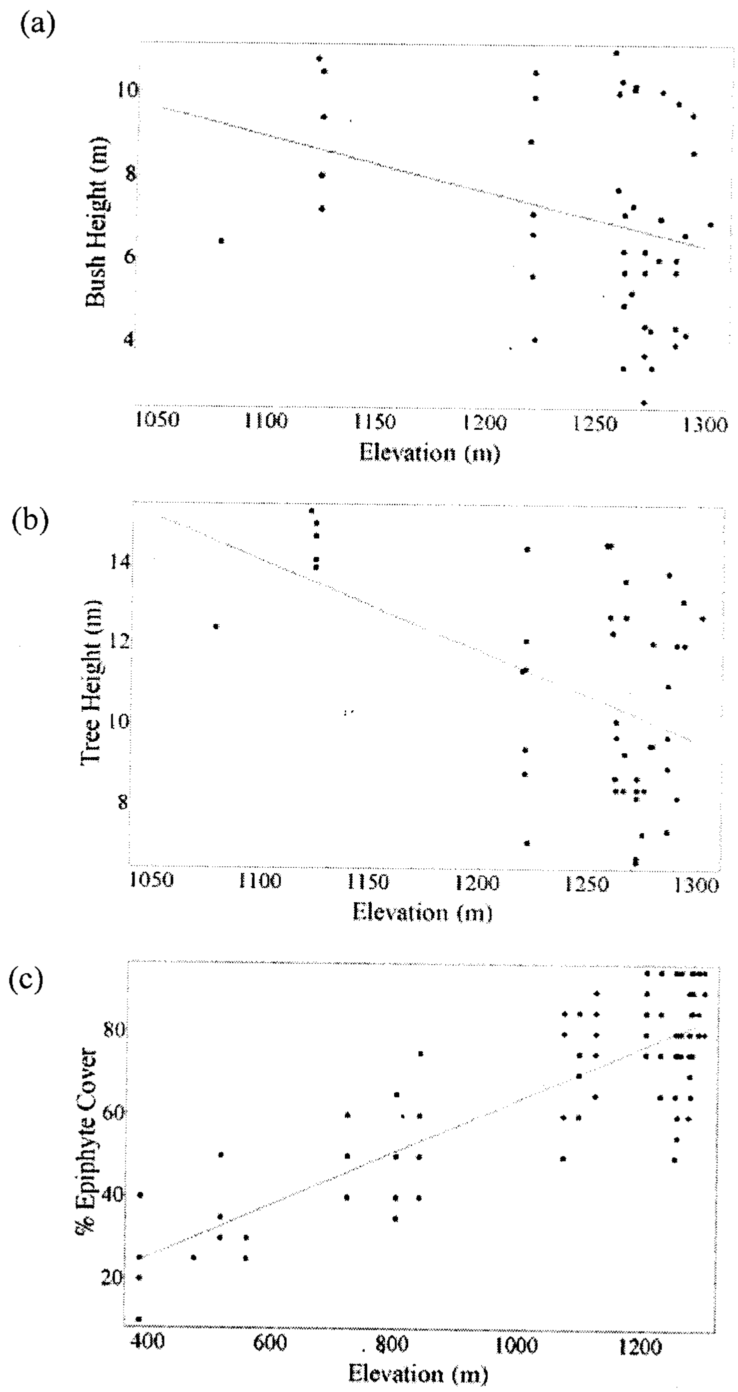


Figure 9 Vegetation characteristics from Klongkai station to Sanyen cloud forest during 17-21 April 2007. (a) bush height (m) and elevation (m), (b) tree height (m) and elevation (m) and (c) the percentage of epiphyte cover and elevation (m).

With an increasing in elevations, plant species change from lowland species to montane species with tree stature, and leaf size decreases but the epiphyte load tends to increase. Cloud forest trees are twisted, gnarled and often have umbrella-like crown (Frahm, 1990; González-Mancebo et al., 2004). Our results support previous findings. This high epiphyte load could have four important roles in cloud forest. First, the productivity of epiphytes in cloud forest can exceed other flora. Second, epiphytes could capture, store up to 50,000 l/ha (Hamilton et al., 1995) or 3000 l/ha (Kitayama, 1995) and slowly release water to canopy animals in cloud forest. Third, epiphytes capture, store and slowly release up to half the total input of NH_4^+, NO_3^- and other important ions and nutrients in cloud forests from water stripping from passing clouds. Finally, epiphytes provide home for invertebrates, amphibians, birds and even some primates (Köhler et al., 2006).

Soil Characteristics

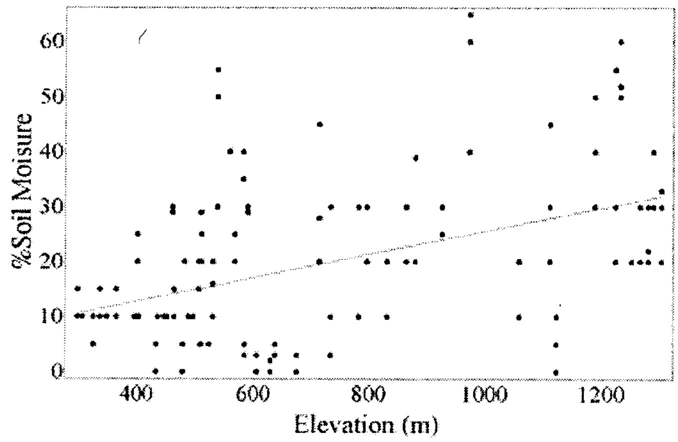
From the soil field data, as the elevation increased, % soil moisture increased: The linear regression was as follow:

$y = 0.021x + 4.370$, $F_{1,160} = 43.180$, $R^2 = 0.213$, $P<0.001$ (Figure 10a).

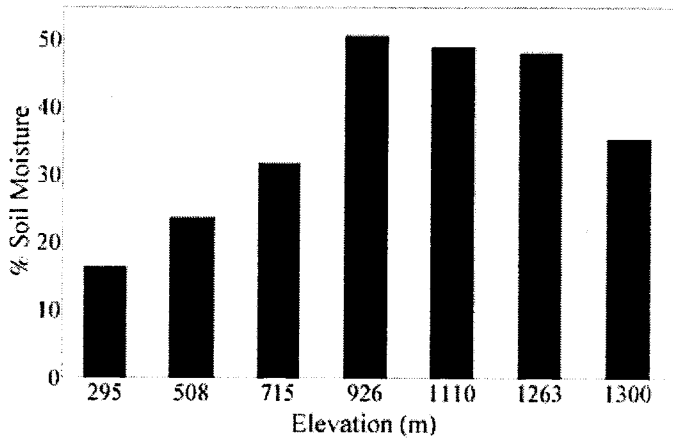
From the soil laboratory data, the percentage of soil moisture and the percentage of organic content were separated into two groups: above and below 900 m in elevation. The percentage of soil moisture and the percentage of organic content were higher in 900 m in elevation (Figure 10b,c).

Our results support previous findings (Frahm, 1990; Foster, 2001) that cloud forest soils were high in organic contents, and soil moisture. The results were clearly shown that after 900 m in elevation, there were a large increase in the percentage of soil moisture and the percentage of soil organic content. This indicates that Sanyen cloud forest might start from 900 m in elevation and reached its peak around 1300 m. The capacity of the soil to absorb and store a great deal of water provides the important services of erosion and flood control as well as dry weather stream flow (Foster, 2001).

(a)



(b)



(c)

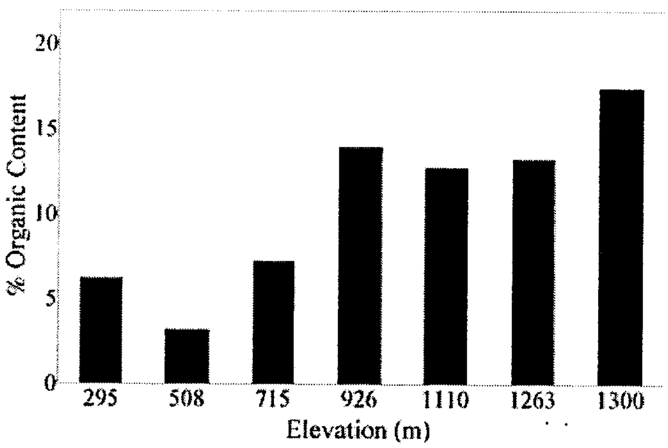


Figure 10 Soil characteristics and elevation (m) from Klongkai station to Sanyen cloud forest during 17-21 April 2007. (a) % soil moisture from field data, (b) Soil characteristics: % soil moisture from laboratory data and (c) % organic content.

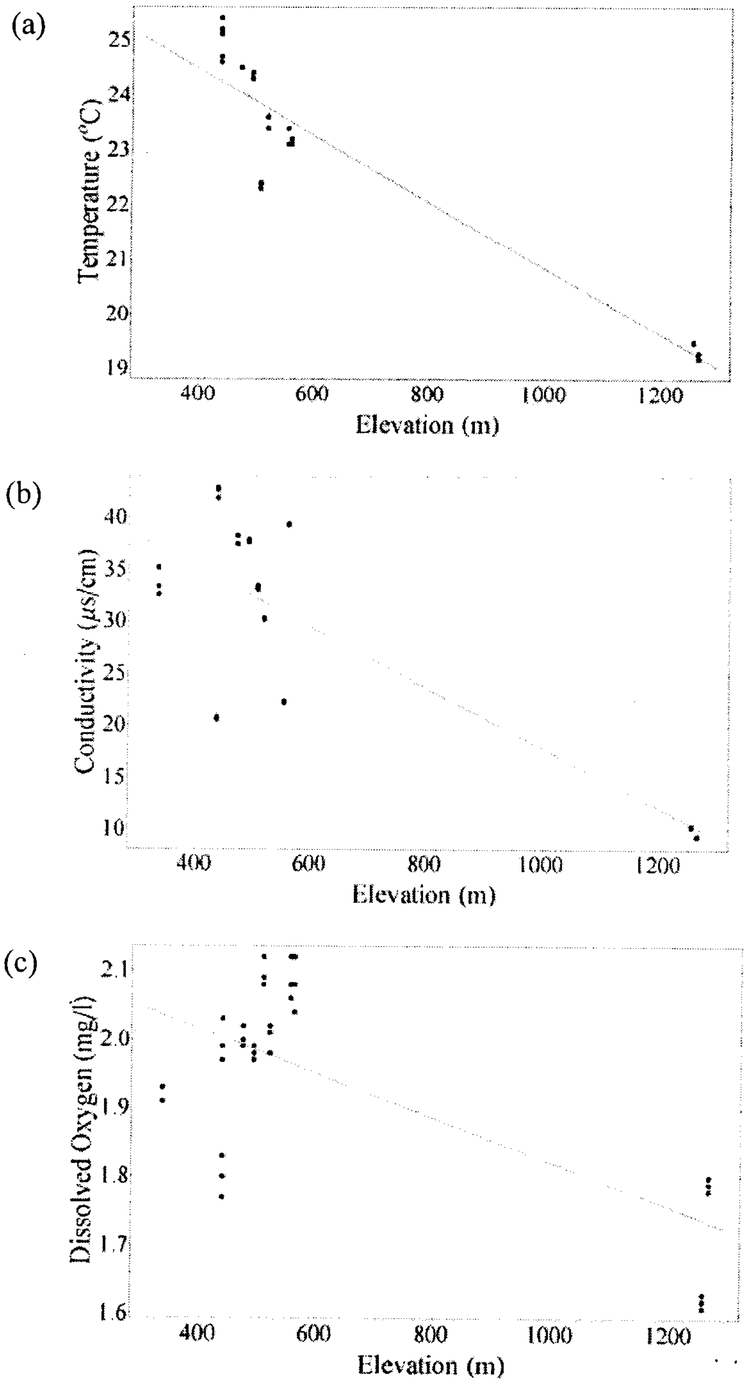


Figure 11 Hydrology characteristics and elevation (m) from Klongkai station to Sanyen cloud forest during 17-21 April 2007. (a) water temperature, (b) conductivity (μS/cm) and (c) Dissolved Oxygen (mg/l).

Hydrology Characteristics

As the elevations increased, water temperature, conductivity, and DO decreased (Linear regression):

water temperature: $y = -0.006x + 26.875$, $F_{1,28} = 230.015$, $R^2 = 0.891$, $P<0.001$ (Figure 11a).

conductivity: $y = -0.029x + 46.734$, $F_{1,31} = 58.2155$, $R^2 = 0.653$, $P<0.001$, (Figure 11b).

DO: $y = -0.0003x + 2.14$, $F_{1,31} = 28.947$, $R^2 = 0.483$, $P<0.001$ (Figure 11c).

Our results showed that water temperature, conductivity, and DO were lower at Sanyen cloud forest than at lower elevation water bodies. Water temperature showed a similar trend with air temperature. This could be because the cloud reduced the amount of solar radiation at the cloud forest. This study showed that conductivity was very low at Sanyen cloud forest. This could be because Sanyen cloud forest is the head of watershed; therefore, there would be less ions dissolved in the water body than at lower elevation water bodies. The amount of DO at Sanyen cloud forest was very low, especially at 1250 m in elevation. This water body was very shallow with approximately 10 cm deep with lots of algae at the bottom.

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Chapter III

Cloud Forest Vegetation and Soil Characteristics at Mt. Nom, Thailand

Publications

Sangarun, P., Jaroensutasinee, K. and Jaroensutasinee, M. (2009). Ecological Characteristics of the Tropical Montane Cloud Forests of Khao Nan. Abstract: Research and Thesis 2009, 13th BRT Annual Conference. Chaingmai, Thailand. 12th-14th October p. 32.

Sangarun, P., Pheera, W., Jaroensutasinee, K. and Jaroensutasinee, M. (2009). Cloud Forest Characteristics at Mt. Nom, Thailand. 35th Congress on Science and Technology of Thailand, Chonburi, Thailand. 15th-17th October, p. B0040.

Abstract

This study investigated the vegetation and soil characteristics of the tropical montane cloud forest in Southern Thailand. We collected soil samples along the Mt. Nom elevational transect at five sites and measured soil pH, the percentage of soil moisture and the percentage of organic content in the laboratory. We measured tree height, shrub width, leaf thickness, leaf area and the percentage of epiphytes cover on every *Lithocarpus bennettii* (Miq.) Rehd. tree found on Mt. Nom cloud forest trail started at 313 m a.s.l. and ended at 1274 m a.s.l. Our results showed that percent soil moisture and the percentage of soil organic content increased with increases in elevations. Soil pH ranged from 3.6 to 4.3 which indicated that soil at Mt. Nom was high acidic soil. As elevation increased, leaf thickness increased but leaf area decreased. There was no association between tree height and elevation. As elevation increased, shrub width decreased but the percentage of epiphyte cover increased.

Keywords: Cloud forest, Soil, Vegetation, Thailand

Introduction

Tropical montane cloud forests (TMCFs) are one of the world's most threatened ecosystems due to their high deforestation rate which are greater than all other tropical forests and climatic warming (Doumenge et al., 1995; Hamilton et al., 1995; Bruijnzeel and Hamilton, 2000; Bubb et al., 2004; Cayuela et al., 2006; Téllez-Valdés et al., 2006). These TMCFs typically have high levels of endemism, low rates of net primary production and play an essential role in the hydrologic cycles of tropical mountains (Stadtmüller, 1987; Tanner et al., 1990; Bruijnzeel and Proctor, 1995; Grubb, 1995; Foster, 2001). The main climatic characteristics of cloud forests include frequent cloud presence, usually high relative humidity and low irradiance (Foster, 2001). TMCFs typically occur at elevations between 1,500 to 3,300 m a.s.l., occupying an altitudinal belt of approximately 800 to 1,000 m at each site. The lowermost occurrence of low-statured cloud forest (300–600 m a.s.l.) is reported from specific locations like small islands, were the cloud base may be very low and the coastal slopes are exposed to both, high rainfall and persistent wind-driven clouds (Bruijnzeel and Proctor, 1995).

In montane tropical forests, tree stature and leaf sizes decrease but ephiphyte load increase with elevation (Ohsawa, 1995). Cloud forest trees are twisted, gnarled, stunted trees with stilt-rooted, thick leaves and often assume an umbrella-like crown (Grubb and Whitmore, 1966; Werner and Balasubramaniam, 1992; Beard, 1994; Werner, 1998; Foster, 2001). Leaves are thicker, harder and smaller than in surrounding vegetation. Many studies have reported a variety of soils at TMCFs throughout the world (Roman and Scatena, 2007; Arteaga et al., 2008). However, soil chemical properties at TMCFs are difficult to generalise (Bruijnzeel and Proctor, 1995). Little has been done on vegetation, soil and their effects on TMCFs in Thailand or south-east Asia in general. The lack of understanding of the cloud forest characteristics make it difficult to predict what the impacts of climate change will be on the cloud forest and its endemic species. This study is the first to investigate vegetation and soil characteristics of TMCFs at Mt. Nom cloud forest, Mt. Nan National Park, Thailand.

Methodology

Mt. Nan National Park is located at latitude 8.76908 °N longitude 99.80352 °E, and situated at Noppitam sub-district, Thasala district, and Sichon district in Nakhon Si Thammarat province, Thailand with an area of 406 km^2 (Figure 12). Geographical characteristics of Mt. Nan National Park is a high mountainous range in the North-South direction which is a part of Nakhon Si Thammarat mountain range. The forest at Mt. Nan National Park is a tropical mountain forest which is an important watershed source of Nakhon Si Thammarat province. More than 90 percentage of Mt. Nan National Park still is a primary tropical evergreen forest that is a main watershed source and a home for various species of endangered species.

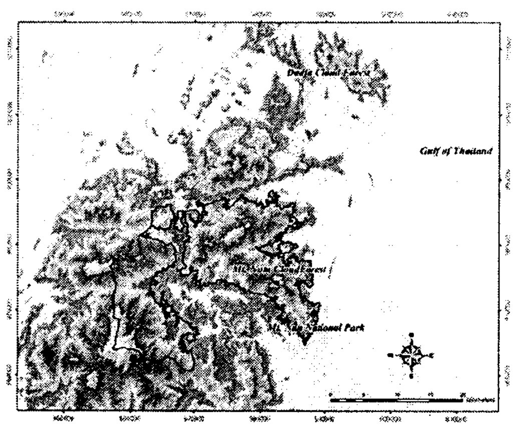

Figure 12 Mt. Nan National Park boundary and the location of Mt. Nom.

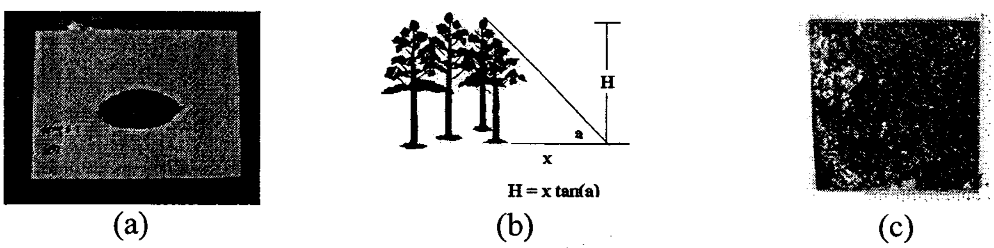

Figure 13 Vegetation characteristics (a) leaf photography, (b) tree height and (c) % epiphyte cover around tree trunk with scales.

For vegetation characteristics, we measured leaf thickness, leaf area, tree height, shrub width and the percentage of epiphyte cover tree trunk of every

Lithocarpus bennettii (Miq.) Rehd. tree found on Mt. Nom along the elevational transect started at 313 m a.s.l. and ended at 1274 m a.s.l. We chose to study the vegetation characteristics on *Lithocarpus bennettii* (Miq.) Rehd. tree because this tree species was canopy dominant along Mt. Nom elevational transect. We only measured *Lithocarpus bennettii* (Miq.) Rehd. trees that had the diameter at breast height between 30-35 cm.

We collected five dry leaves/tree and measured leaf thickness by using a micrometer at 0.001 mm resolution in the field. We took photographs of these leaves with a Canon A530, five million pixels in the field with white A4 paper (Figure 13a). These photographs were analysed for leaf area using Adobe Photoshop and MultiSpec Win 32. We used a clinometer and a 50 m tape to measure tree height (H), and the width of the shrub in four directions (i.e. north, east, west, south) (Figure 13b). For the percentage of epiphyte cover, we took photographs of epiphytes cover on *Lithocarpus bennettii* trunk with a Canon A530, five million pixels with a camera stand using a rectangular frame with scales on it (Figure 13c).

Soil samples that were contained a lot of pebbles were sieved with sieve mesh size 2 mm prior to weighing soil samples. We weighed 200 g soil/sample, oven dried at 90 °C for 24 hrs, reweighed soil again and calculated the percentage of soil moisture. We weighed 50 g oven dried soil/sample, burned it at 550 °C for 1 hr, reweighed the soil and calculated for the percentage of soil organic content. For determining soil pH, 40 g of fresh soil was suspended in 40 ml of de-ionised water. After 24 h, the pH (H_2O) was measured.

Parametric statistics tests were used when underlying assumptions were met. One-way ANOVA and Bonferroni post-hoc tests were used to test climate factor differences among NCF, DCF and NHQ. Linear regressions were used to test (1) the association between leaf thickness, leaf area, tree height, shrub width, the percentage of epiphyte cover and elevation and (2) the association between the percentage of organic content, the percentage of soil moisture and soil pH with elevation. All significant tests were two-tailed.

Results and Discussion

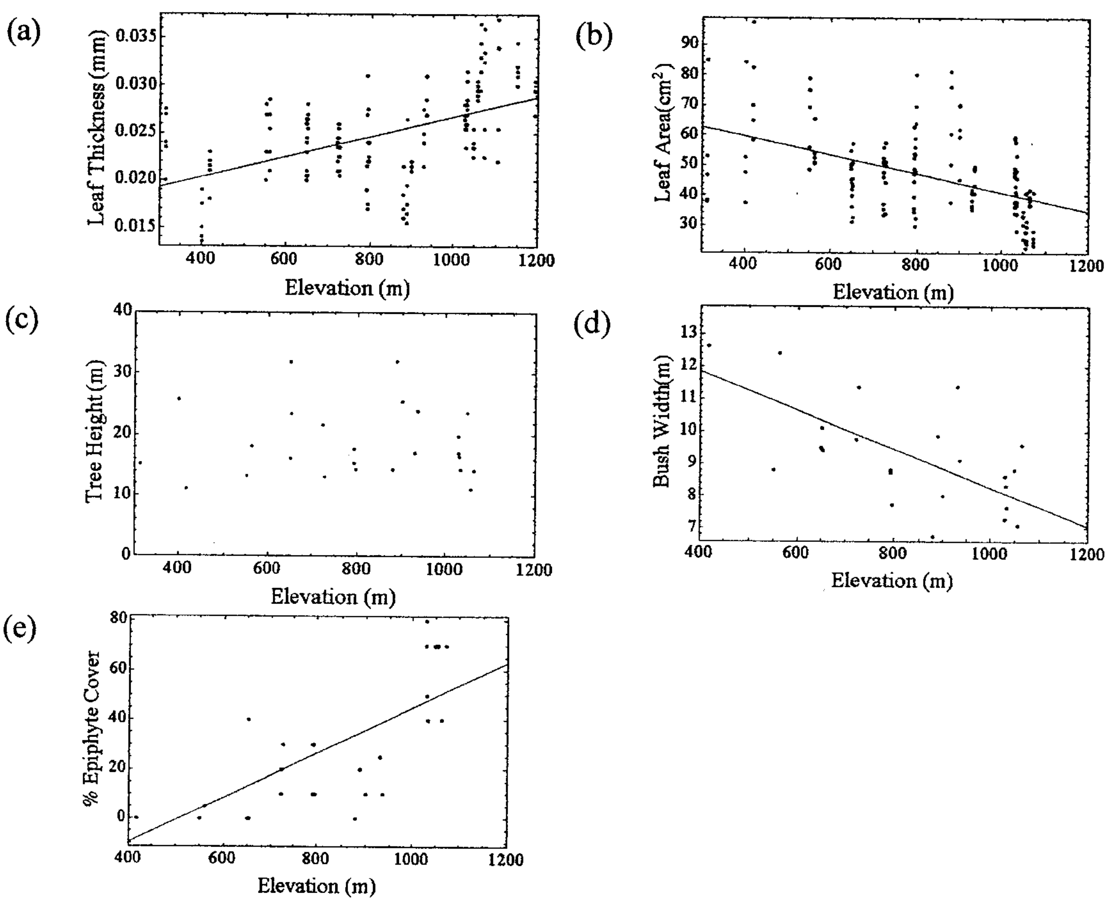

Figure 14 Vegetation characteristics of Mt. Nom cloud forest from 16 January – 19 February 2009 at different elevations. (a) leaf thickness (mm), (b) leaf area (cm^2), (c) tree height (m), (d) bush width (m) and (e) the percentage of epiphyte cover.

The results showed that as elevation increased, leaf thickness increased but leaf area decreased (leaf thickness: $y = 1.067 \times 10^{-5} x + 0.016$, $R^2 = 0.274$, $F_{1,148} = 55.944$, $P < 0.001$; leaf area: $y = - 0.032x + 72.698$, $R^2 = 0.232$, $F_{1,143} = 43.276$, $P < 0.001$, Figure 14a,b). There was no association between tree height and elevation ($F_{1,23} = 0.0029$, ns, Figure 14c). As elevation increased, shrub width decreased but the percentage of epiphyte cover increased ($y = - 0.006x - 14.248$, $R^2 = 0.54$, $F_{1,23} = 27.000$, $P < 0.001$; the percentage of epiphyte cover: $y = 0.091x – 46.175$, $R^2 = 0.57$, $F_{1,28} = 37.335$, $P < 0.001$, Figure 14e). As the elevation increased, the percentage of organic content and the percentage of soil moisture increased (linear regression: the percentage of organic content: $y = 0.020x - 2.076$, $R^2 = 0.485883$, $F_{1,13} = 12.286$, $P < 0.005$; % soil moisture: $y = 0.048x - 6.037$, $R^2 = 0.456$, $F_{1,13} = 10.911$, $P < 0.01$, Figure 15a,b). There was no association between soil pH and elevation ($F_{1,13} = 1.748$, ns, Figure 15c).

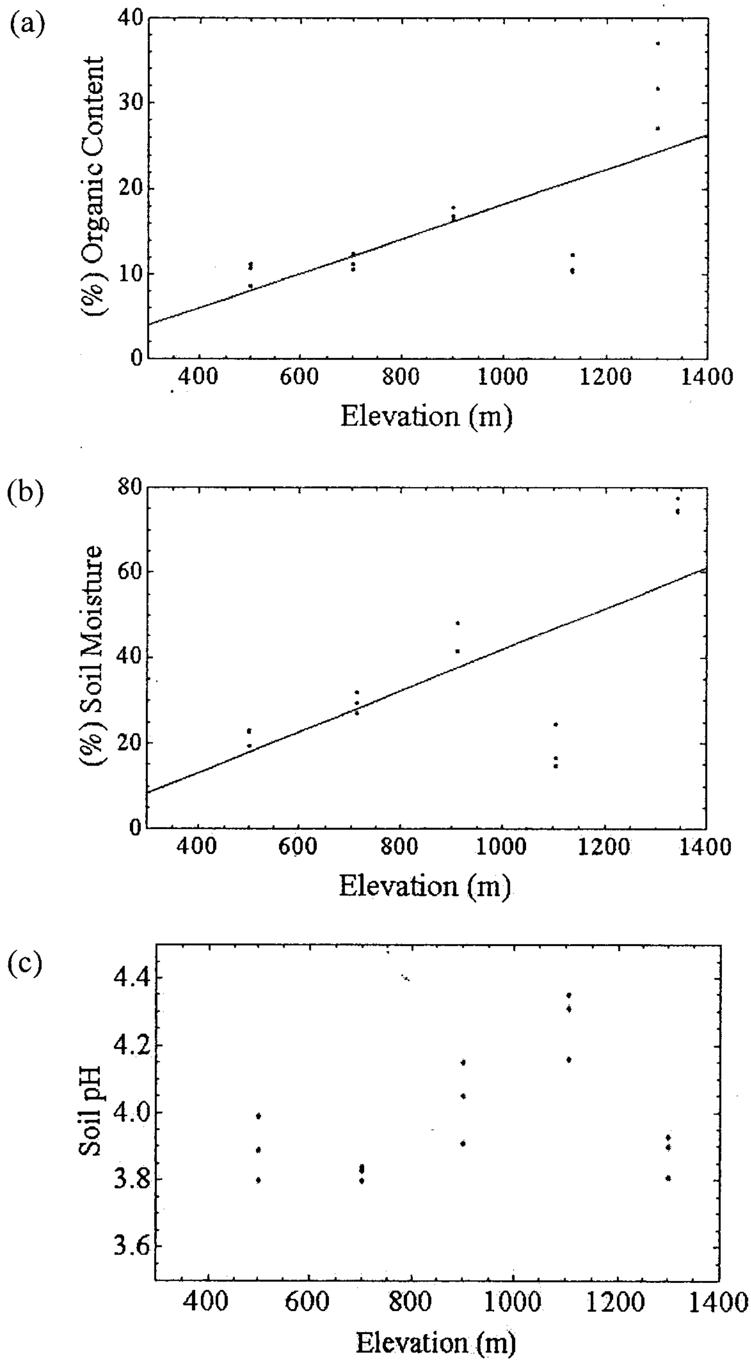

Figure 15 Soil characteristics of Mt. Nom cloud forest in different elevation (m). (a) % organic content, (b) % soil moisture and (c) soil pH.

One reason for the lack of studies in TMCFs in Thailand is their inaccessibility and unfavourable environment for humans. Fortunately, their inaccessibility and harsh climate, with high rainfall and relative humidity, has also limited their exploitation. Since TMCFs are usually enveloped in clouds and fog, carrying out field work is not an easy task. Nevertheless, an increasing amount of research is being conducted in these ecosystems.

Richards (Richards, 1952) showed that relative humidity in tropical forest rises with increasing elevation. Our results support Richards (Richards, 1952)'s study that temperature decreased but the percentage of relative humidity increased with increasing elevation. Moreover, temperature and %relative humidity at 1300 m a.s.l. had the highest variation than other elevations. This indicates that Mt. Nom cloud forest had more severe environment than tropical rain forests. The high relative humidity in TMCFs make invasion of leaves by fungi and epiphytes easy (Grubb, 1977).

TMCFs are generally complex with abundant mosses, lichens and epiphytes (Grubb, 1977; Frahm, 1990; Veneklaas and Van Ek., 1990). Our results support the previous studies (Stadtmüller, 1987; Grubb; Kitayama, 1995) that % epiphyte abundance and leaf thickness increasing, while leaf area and shrub width decreasing with increasing elevation. Grubb (Grubb) suggested that leaf thickness and long leaf life meant that less production should be invested in woody parts in TMCFs than in temperate deciduous forest or conifer forest (Grubb). Moreover, low air temperature and lack of bright sunlight at TMCFs also are slow down the plant growth. Our results support this that shrub width decreased with increasing elevation. Leaf thickness causing by the thick outer walls may serve to minimise invasion by fungi (Grubb). The decline in leaf area with elevation could be an adaptation maximising the ratio of carbon dioxide absorbed to water lost (Grubb).

Kitayama (Kitayama, 1995) reported that the tree height decreases with increasing elevation in Mt. Kinabalu, Sabah, in Malaysia (Kitayama). However, our results did not support Kitayama (Kitayama)'s finding that we did not find any association between tree height and elevation (Kitayama). Because of Mt. Kinabalu was located at the elevation over than 4000 m.a.s.l.that higher than Mt.Nom cloud forest.

Cloud water deposition often increases with elevation, and it is widely accepted that this cloud water increases acid loading to TMCFs ecosystems. Cloud water deposition can be four times more acidic than bulk precipitation (Sigmon et al., 1989; Clark et al., 1998). Since cloud cover tends to increase with elevation, a positive relationship between forest acidification and elevation is expected (Sigmon et al ; Hendershot et al., 1992). Our results did not support previous studies (Hendershot et al ; Foster, 2001) that we did not find soil pH increased with increasing elevation. However, our results showed that soil pH at 1300 m a.s.l. where the cloud forest presents had lower soil pH than at 1100 m a.s.l.

High acidity (pH 2-4) at TMCFs was reported in many studies (Hardon, 1936; Barshad and Rojas-Cruz, 1950; Askew, 1964; Burnham, 1974; Bautista-Cruz and Castillo, 2005; Schawe et al., 2007). However, other researchers found pH values over 5 (Edwards and Grubb, 1982; Bracho and Sosa, 1987; Vance and Nadkarni, 1992; Bruijnzeel and Proctor, 1995). The analysis of the latter group shows that in all the cases the soils occurred on parent material initially rich in bases: limestone, basic volcanic tephras, or it was enriched with volcanic ash. Therefore, extreme acidity is typical for MCF soils formed on parent rock poor in bases (Arteaga et al., 2008; Targulian and Rosas, 2008).

Forest floor moisture content at the higher elevation was significantly higher, which most likely resulted from higher wet deposition from cloud cover (Mendoza-Vega et al., 2003). Since cloud water concentrations average about three and a half times higher than bulk precipitation (Neal et al., 2005), soil organic content commonly increases with increasing precipitation and with decreasing temperature for any particular level of precipitation (Post, 1982). The significant positive correlation coefficient found between altitude above sea level and the amounts of soil organic content in our study may suggest that a proportion of the variation in the amounts of soil organic content might be explained by the climate and high dissolved organic content in cloud water.

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Chapter IV

Cloud Forest Climatic Characteristics of Tropical Montane Cloud Forest at Mt. Nom, Thailand

Publication

Sangarun, P., Pheera, W., Jaroensutasinee, M. and Jaroensutasinee, K. (2009). Cloud Forest Climatic Characteristics of Tropical Montane Cloud Forest at Mt. Nom, Thailand. *NECTEC Technical Journal*, 9, 30-34.

Abstract

This study investigated the climatic characteristics of the tropical montane cloud forest in Southern Thailand. We installed automatic weather stations at three study sites: Mt. Nom cloud forest, Dadfa Cloud Forest and Mt. Nan Head Quarter. We installed HOBO data loggers along the Mt. Nom elevational transect at five sites (i.e. 500. 700, 900, 1100, and 1300 m a.s.l.) for measuring temperature and relative humidity. Our results showed that Mt. Nom cloud forest had the lowest temperature, dew point, heat index, solar radiation, solar energy and UV index than Dadfa cloud forest and Mt. Nan Head Quarter. Temperature decreased but relative humidity increased with increasing elevation.

Keywords: Cloud forest, Climate, Weather station, Thailand

Introduction

Tropical montane cloud forests (TMCFs) are one of the world's most threatened ecosystems due to their high deforestation rate which are greater than all other tropical forests and climatic warming (Doumenge et al., 1995; Hamilton et al., 1995; Bruijnzeel and Hamilton, 2000; Bubb et al., 2004; Cayuela et al., 2006; Téllez-Valdés et al., 2006). These TMCFs typically have high levels of endemism, low rates of net primary production and play an essential role in the hydrologic cycles of tropical mountains (Stadtmüller, 1987; Tanner et al., 1990; Bruijnzeel and Proctor, 1995; Grubb, 1995; Foster, 2001). Deforested TMCFs takes centuries to recover due to its slow grow rate. These ecosystems are complex, relatively rare, extremely vulnerable to climate changes and very long-term human impacts (Byer and Weaver, 1977; Scatena, 1995; Foster).

TMCFs occur in mountainous altitudinal band frequently enveloped by orographic clouds (Bruijnzeel and Proctor, 1995; Still et al., 1999). This forest obtains moisture from deposited fog water in addition to bulk precipitation (Foster, 2001; Weathers, 1999; Chang et al., 2002). The main climatic characteristics of cloud forests include frequent cloud presence, usually high relative humidity and low irradiance (Foster, 2001). TMCFs typically occur at elevations between 1,500 to 3,300 m a.s.l., occupying an altitudinal belt of approximately 800 to 1,000 m at each site. The lowermost occurrence of low-statured cloud forest (300–600 m a.s.l.) is reported from specific locations like small islands, were the cloud base may be very low and the coastal slopes are exposed to both, high rainfall and persistent wind-driven clouds (Bruijnzeel and Proctor).

TMCFs are important in their effects on hydrological balances at regional scales and the biodiversity that they support; tree species richness may be low on tropical mountains but epiphytic abundance and diversity are higher than in other types of forest (Richards, 1984). In montane tropical forests, fog represents an increasingly important water source as rainfall and temperature decrease and relative humidity increases with increasing elevation (Sugden and Robins, 1979; Cavelier and Goldstein, 1989).

Little has been done on climatic factors and their effects on TMCFs in Thailand or south-east Asia in general. The lack of understanding of the cloud forest characteristics make it difficult to predict what the impacts of climate change will be on the cloud forest and its endemic species. This study is the first to investigate the climatic characteristics of TMCFs at Mt. Nom cloud forest, Mt. Nan National Park, Thailand.

Proposed Techniques

Mt. Nan National Park is located at latitude 8.76908 °N, longitude 99.80352 °E, and situated at Noppitam sub-district, Thasala district, and Sichon district in Nakon Si Thammarat province, Thailand with an area of 406 km^2. Geographical characteristics of Mt. Nan National Park is a high mountainous range in the North-South direction which is a part of Nakhon Si Thammarat mountain range. The forest at Mt. Nan National Park is a tropical mountain forest which is an important watershed source of Nakhon Si Thammarat province. More than 90% of Mt. Nan National Park still is a primary tropical evergreen forest that is a main watershed source and a home for various species of endangered species.

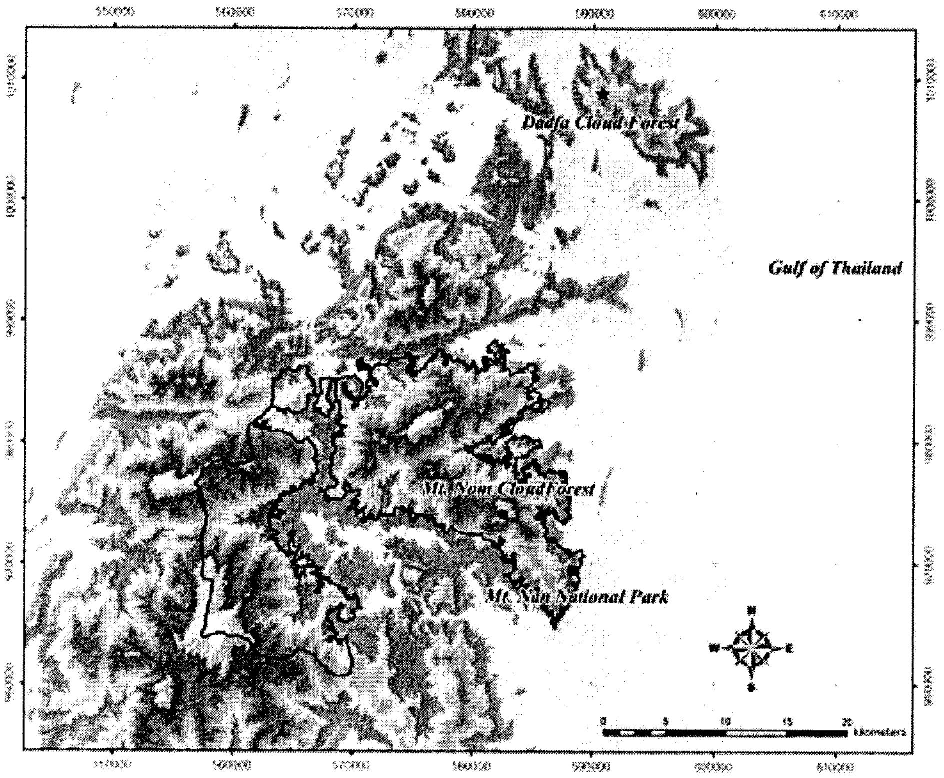

Figure 16 Study sites: Mt. Nom cloud forest, Dadfa Cloud forest and Mt. Nan Headquarters where the automatic weather stations were installed. Black line represents Mt. Nan National Park boundary.

We installed Davis weather stations model Vantage Pro II Plus to collect climatic data every 30 min at three locations: Mt. Nom cloud forest (NCF), Dadfa cloud forest (DCF) and Mt. Nan Head Quarter (NHQ). NCF was located at latitude 8.48698 °N longitude 99.45000 °E, and elevation 1,274 m a.s.l. (Figure 16). NHQ was located at latitude 8.76908 °N longitude 99.80352 °E, and elevation 182 m a.s.l. (Figure 16). DCF was located at latitude 9.125360 °N, longitude 99.825531 °E, and elevation 680 m a.s.l. (Figure 16). Davis weather stations were collected nine climatic data: air temperature, relative humidity, dew point, wind speed, heat index, daily rainfall, solar radiation, solar energy and UV index. We placed temp/humidity HOBO Pro V2 data loggers along the elevational transect on the north-south slope of Mt. Nom, five sites at 500, 700, 900, 1100, and 1300 m a.s.l. Climatic data at these three sites were collected during 16 January to 19 February 2009.

Parametric statistics tests were used when underlying assumptions were met. One-way ANOVA and Bonferroni post-hoc tests were used to test climate factor differences among NCF, DCF and NHQ. Linear regressions were used to test the association between temperature and relative humidity at NCF, DCF and NHQ. All significant tests were two-tailed.

Results and Discussion

NCF had the lowest temperature, dew point, heat index, solar radiation, solar energy and UV index than DCF and NHQ (temperature: $F_{2,4573} = 2515.024$, $P < 0.001$; dew point: $F_{2,4573} = 4900.758$, $P < 0.001$; heat index: $F_{2,4573} = 2839.951$, $P < 0.001$; solar radiation: $F_{2,4573} = 5.815$, $P < 0.005$; solar energy: $F_{2,4573} = 5.815$, $P < 0.005$ and UV index: $F_{2,4573} = 59.536$, $P < 0.001$, Figure 17a,c,e,g,h,i). DCF had the highest relative humidity, and NCF was an intermediate relative humidity than NHQ ($F_{2,4573} = 167.825$, $P < 0.001$, Figure 17b). NCF had the highest wind speed that DCF and NHQ ($F_{2,4573} = 603.656$, $P < 0.001$, Figure 17d). There was no different in the amount of daily rainfall among these three study sites ($F_{2,4573} = 0.621$, ns, Figure 17f). NHQ had higher evapotranspiration than DCF ($F_{2,4573} = 3.970$, $P < 0.05$, Figure 17j).

As elevation increased, temperature decreased but relative humidity increased (temperature: $y = -0.004x + 22.849$, $R^2 = 0.192$, $F_{1,200258} = 4804.22$, $P < 0.001$; relative humidity: $y = 0.003x + 88.612$, $R^2 = 0.011$, $F_{1,200258} = 215.875$, $P < 0.001$, Figure 18a,b). As air temperature at NCF, DCF and NHQ increased, relative humidity decreased (Eq. 1-5, Figure 19a-c). The relationship between temperature and relative humidity at NCF and DCF differed from NHQ (Figure 19a-c).

NCF fog free day

$$RH_{ncf} = 4.11(42.16 - T_{ncf}) \quad ; (T_{ncf} > 17.82) \qquad (4)$$
$$RH_{ncf} = 100 \quad ; (T_{ncf} \leq 17.82)$$

NCF fog bound day

$$RH_{ncf} = 27.25(20.52 - T_{ncf}) \quad ; (T_{ncf} > 16.85) \qquad (5)$$
$$RH_{ncf} = 100 \quad ; (T_{ncf} \leq 16.85)$$

DCF fog free day

$$RHdcf = 4.95(41.32-Tdcf) \quad ; (Tdcf > 21.13) \tag{6}$$

$$RHdcf = 100 \quad ; (Tdcf \leq 21.13)$$

DCF fog bound day

$$RHdcf = 30.09(23.43-Tdcf) \quad ; (Tdcf > 20.11) \tag{7}$$

$$RHdcf = 100 \quad ; (Tdcf \leq 20.11)$$

Nan Head Quarter

$$RHnhq = 4.29(45.12-Tncf) \quad ; (Tnhq > 21.81) \tag{8}$$

$$RHnhq = 100 \quad ; (Tnhq \leq 21.81)$$

Where RHncf, RHnhq and RHdcf were relative humidity at three study sites and Tncf, Tnhq and Tncf were air temperature data at Mt. Nom cloud forest, Mt. Nan Head Quarter and Dadfa cloud forest, respectively.

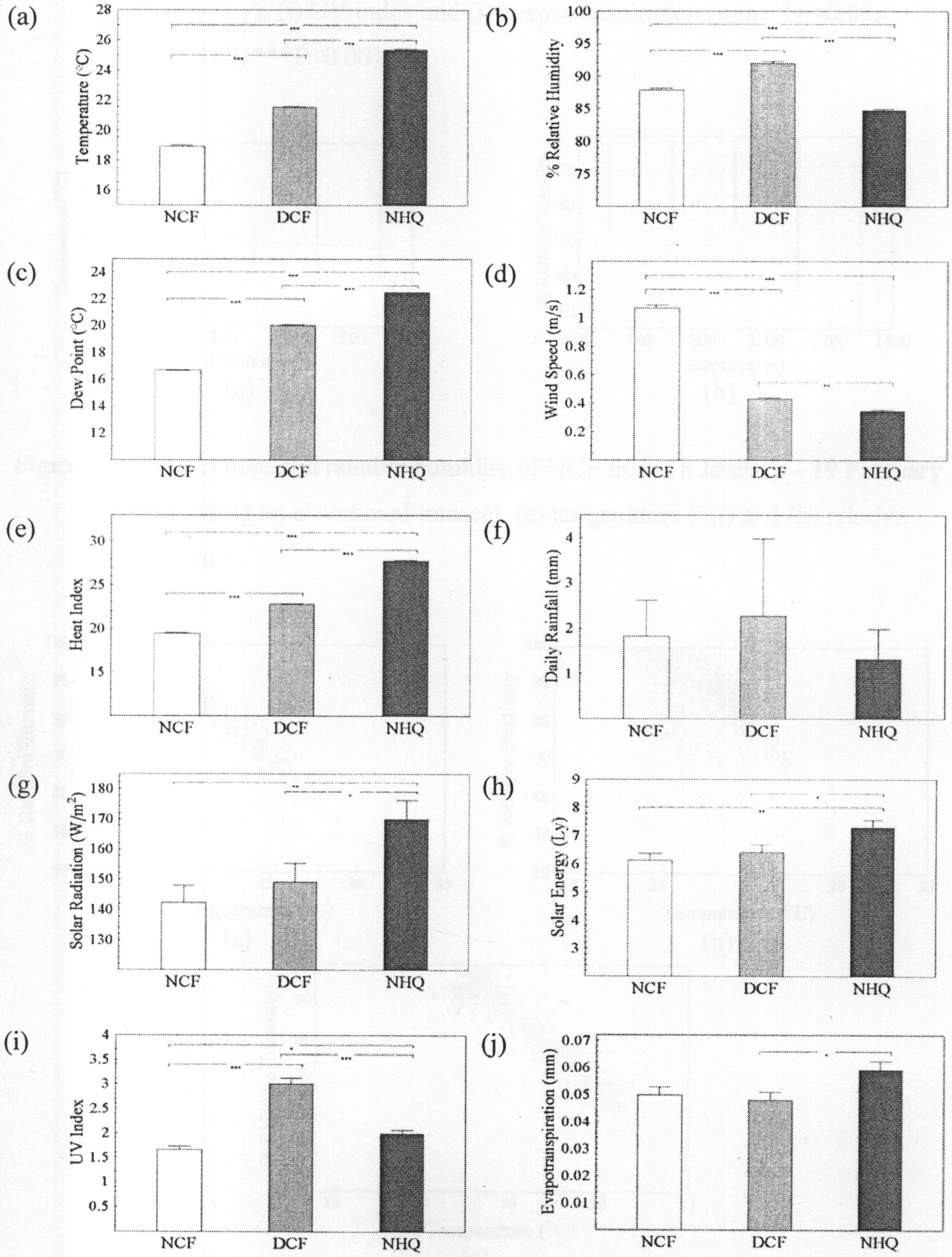

Figure 17 Mean (±SE) of climatic factors at Mt. Nom Cloud Forest (NCF), Dadfa Cloud Forest (DCF) and Mt. Nan Head Quarter (NHQ). (a) temperature (°C), (b) relative humidity, (c) dew point (°C), (d) wind speed (m/s), (e) heat index, (f) daily rainfall (mm), (g) solar radiation (W/m^2), (h) solar

energy (Ly), (i) UV index and (j) evapotranspiration (mm). *P<0.05, **P<0.01, ***P<0.001.

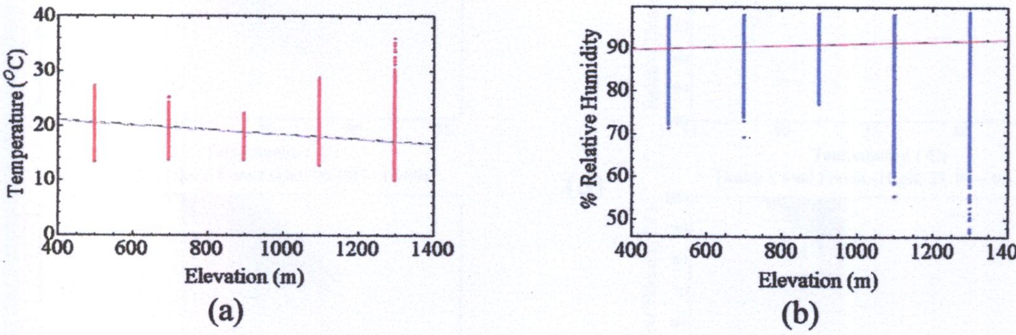

Figure 18 Temperature and relative humidity of NCF from 16 January – 19 February 2009 along an elevational transect. (a) temperature (°C) and (b) relative humidity.

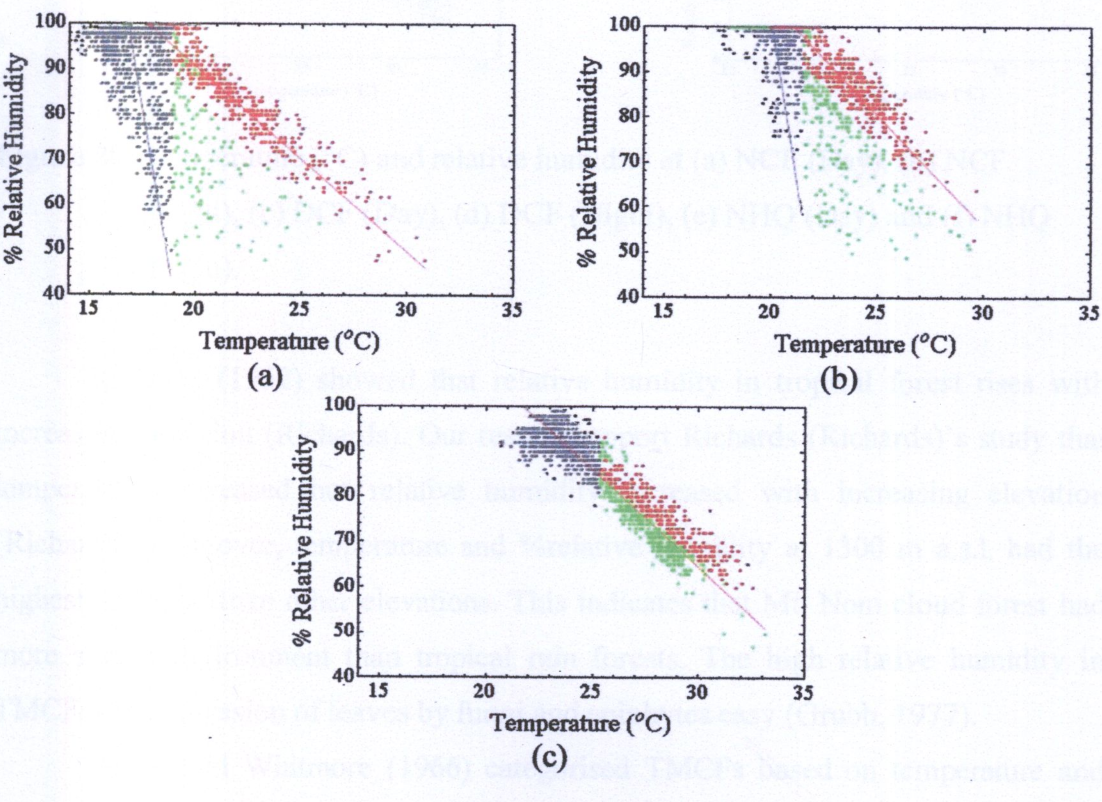

Figure 19 Temperature (°C) and relative humidity at (a) NCF , (b) DCF and (c) NHQ.

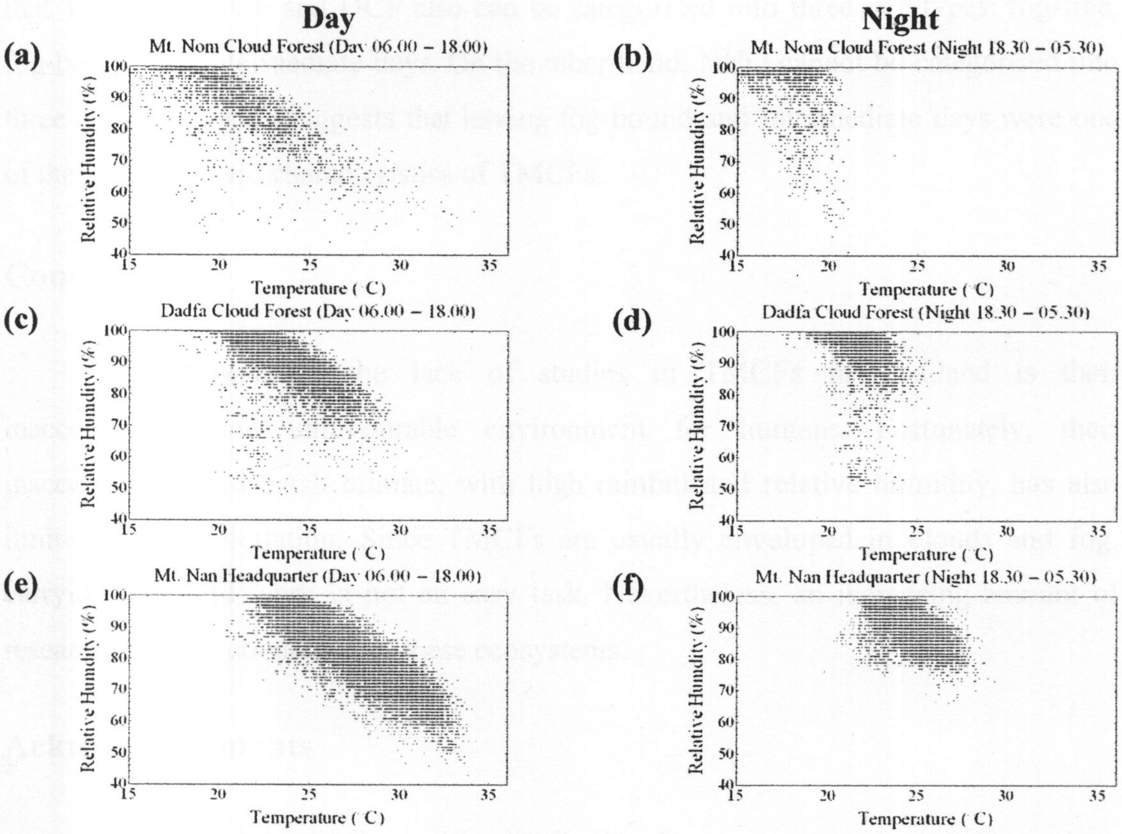

Figure 20 Temperature (°C) and relative humidity at (a) NCF (Day), (b) NCF (Night), (c) DCF (Day), (d) DCF (Night), (e) NHQ (Day) and (f) NHQ (Night).

Richards (1952) showed that relative humidity in tropical forest rises with increasing elevation (Richards). Our results support Richards (Richards)'s study that temperature decreased but relative humidity increased with increasing elevation (Richards). Moreover, temperature and %relative humidity at 1300 m a.s.l. had the highest variation than other elevations. This indicates that Mt. Nom cloud forest had more severe environment than tropical rain forests. The high relative humidity in TMCFs make invasion of leaves by fungi and epiphytes easy (Grubb, 1977).

Grubb and Whitmore (1966) categorised TMCFs based on temperature and relative humidity data into three day types: fog-bound, fog-free and intermediate days. They defined fog-bound day as having no bright sunshine for at least half the daylight hours and fog-free day as having no fog in the daylight hours and at least 4 hr bright sunshine. Our results support Grubb and Whitmore's (Grubb and Whitmore) study that TMCFs at NCF and DCF also can be categorised into three day types: fog-free, fog-bound and intermediate days. On the other hand, NHQ cannot be categorised into three day types. This suggests that having fog-bound and intermediate days were one of the main climatic characteristics of TMCFs.

Conclusion

One reason for the lack of studies in TMCFs in Thailand is their inaccessibility and unfavourable environment for humans. Fortunately, their inaccessibility and harsh climate, with high rainfall and relative humidity, has also limited their exploitation. Since TMCFs are usually enveloped in clouds and fog, carrying out field work is not an easy task. Nevertheless, an increasing amount of research is being conducted in these ecosystems.

Acknowledgements

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Chapter V

Computational Classification of Cloud Forest Using Atmospheric Data from Field Sensor

Publication

Sangarun, P., Pheera, W., Jaroensutasinee, K. & Jaroensutasinee, M. 2010. Computational Classification of Cloud Forest Using Atmospheric Data from Field Sensors. Proceedings of ANSCSE, 14th Mae Fah Luang University. Chaing Rai, Thailand. 23rd-26th March, D00016.

Abstract

This study attempted to quantify cloud forest exhibit distinct atmospheric characteristic features so that we can computationally classify them. In this work, we installed automatic weather station (Davis weather station model Vantage Pro II Plus) at nine study sites grouped into three classes: (1) four cloud forest sites (Duan Hok, Dadfa, Mt. Nom, and Doi Intanon stations), two tropical forests (Huilek and Khao Nan headquarters stations) and three coastal sites (Walailak University, Khanom and Muang Nakhon Si Thammarat stations). Atmospheric data were composed of temperature, rainfall, humidity, solar radiation, solar energy, UV index, and heat index during January to October 2009. Our results indicated that such computational classifications can be achived and hence indices can be constructed to allow us to monitor the effects of climate change on these cloud forests.

Keywords: Pattern Detection, Atmospheric data, Cloud Forest, Automatic Weather Station, Field Sensor

Introduction

There are many studies that have been done on classification of forest types and boundaries. The evaluation of forest type from ecological classification was studied by sampling vegetation data in field (Nolet et al., 1995). The forest classification for Thailand was made by Maxwell (2001, 2004), who pointed out that most classification of vegetable have relied on trees and/or rainfall as the chief indicators of forest type and that other factor such as vegetation dynamics or the floristic composition of the ground vegetation, have largely been ignored (Wong, et al., 2006). Few have been done by using atmospheric data. Most of them use temperature and relative humidity data to classify the forest types, especially tropical rainforest. However, none has been done on cloud forest classification.

A bimodal distribution most commonly arises as a mixture of two different unimodal distributions. The unimodal distribution was distributions having only one mode. In recent years, bimodal distribution has been applied in ecological studies in South Australia (Grace and Curran, 1993). The daily maximum temperature frequency distribution was modeled by using bimodal distribution that show the different mode and found the level of significance in most cases exceeded 0.01 higher than using single normal distribution. This study is among the first to apply the bimodal distribution on temperature data from the nine weather station sites.

Tropical montane cloud forest (TMCFs) occurs in mountainous altitudinal band frequently enveloped by orographic clouds (Bruijnzeel and Proctor, 1995). This forest obtains more moisture from deposited fog water in addition to bulk precipitation (Weathers, 1999; Foster, 2001; Chang et al., 2002). The main climatic characteristics of cloud forests includes frequent cloud presence, usually high relative humidity (RH) and low irradiance (Foster); Chang et al). TMCFs normally found at altitudes between 1,500 to 3,300 m a.s.l., occupying an altitudinal belt of approximately 800 to 1,000 m at each site. The lowermost occurrence of low-statured cloud forest (300–600 m a.s.l.) is reported from specific locations like small islands, where the cloud base may be very low and the coastal slopes are exposed to both, high rainfall and persistent wind-driven clouds (Bruijnzeel and Proctor, 1995). On small tropical islands, TMCFs can be found at lower altitudes. TMCFs obtain more moisture from deposited fog water in addition to precipitation (Bruijnzeel and Proctor, 1995; Still, 1999; Weathers, 1999). All tropical forests are under threat but cloud forests are uniquely threatened both by human pressures and by climate change impacting on temperature, rainfall and the formation of clouds in mountain areas (Bubb et al., 2004).

Many studies have been done on cloud forest climatic characteristics throughout the world. Most of the studies were focusing on only two main climatic factors: temperature, and relative humidity. Unfortunately, this parameter is not always available particularly in remote areas, where there are no meteorological stations installed in these locations. For this reason, several researchers have been interested in developing several approaches for generating this parameter, some more recent works are interesting to predict this parameter using the artificial intelligence techniques. This study attempted to quantify temperature so that we can computationally classify habitat types.

Methodology

Study Site

In this study, there were nine study sites grouped into three classes: (1) four cloud forest sites (Duan Hok, Dadfa, Mt. Nom, and Doi Intanon stations), two tropical forests (Huilek and Khao Nan headquarters stations) and three coastal sites (Walailak University, Khanom and Muang Nakhonsithammarat stations) (Figure 21).

Data Collection

We installed automatic weather station (Davis weather station model Vantage Pro II Plus) at nine study sites. There were different installation periods at each study site as followings: Duan Hok (March 2007), Dadfa (January 2009), Mt. Nom (January 2009), Khanom (September 2007), Walailak University (August 2006), Mt. Nan Headquarters (September 2007), Huilek (November 2006), Dafa (January 2009) and Doi Intanon stations (March 2008). We used the data logger for data storage interval time of 30 min for temperature, humidity, wind speed, wind direction, solar radiation, rainfall and atmospheric pressure.

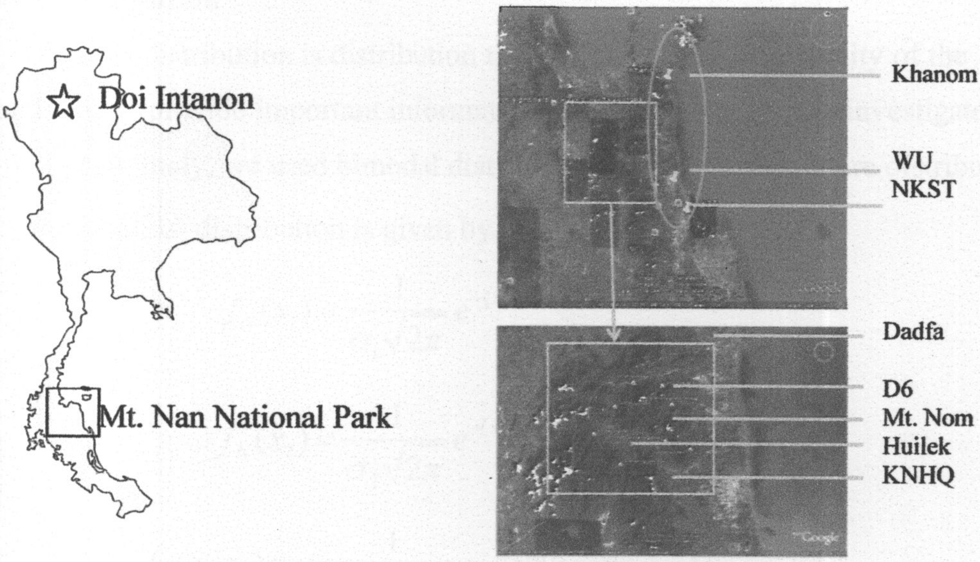

Figure 21 Study Sites: Mt. Nom cloud forest, Dadfa Cloud forest, D6 Cloud Forest, Doi Intanon Cloud Forest Mt. Nan Headquarters (KNHQ), Huilek, Khanom, Walailak University (WU) and Muang Nakhon Si Thammarat (NKST) where the automatic weather stations were installed.

Normal Distribution

The distribution most frequency encountered in meteorology and climatology is the normal distribution. Many variables studied in climatology are averaged or integrated quantities of some type. The law of large numbers that random variables of this type are nearly normally distributed regardless of the distribution of the variables that are averaged or integrated (Von Storch et al., 1999).

The form of the normal distribution is entirely determined by the mean and the variance. Thus we write $X \approx N(\mu,\sigma^2)$ to indicate that x has a normal distribution with parameter μ and σ^2.

The normal density function is given by

$$f_N(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{-(x-\mu)^2/2\sigma^2} \quad (9)$$

Bimodal Distribution

Bimodal distribution is distribution that has two peaks. Bimodality of the distribution may provide important information about the nature of the investigated variable. In this study, we used bimodal distribution to fit the temperature distribution.

The bimodal distribution is given by

$$f_N(x_1) = \frac{1}{\sigma_1\sqrt{2\pi}} e^{-(x_1-\mu_1)^2/(2\sigma_1^2)} \tag{10}$$

$$f_N(x_2) = \frac{1}{\sigma_2\sqrt{2\pi}} e^{-(x_2-\mu_2)^2/(2\sigma_2^2)} \tag{11}$$

$$f_N(x_1, x_2) = \frac{1}{2\pi\sigma_1\sigma_2\sqrt{1-\rho^2}} \exp[-\frac{z}{2(1-\rho^2)}] \tag{12}$$

$$z = \frac{(x_1-\mu_1)^2}{\sigma_1^2} - \frac{2\rho(x_1-\mu_1)(x_2-\mu_2)}{\sigma_1\sigma_2} + \frac{(x_2-\mu_2)^2}{\sigma_2^2} \tag{13}$$

$$\rho = \frac{V_{12}}{\sigma_1\sigma_2} \tag{14}$$

where μ_1, μ_2 and σ_1^2, σ_2^2 are the mean and variance of variables.

With the systematic accumulation of various climatic data and weather records for long period, analytical distribution models which fit the observed distributions well have been proposed by many climatologists and statisticians (Suzuki, 1980). The following theoretical distribution models have been proposed:

Temperature: Normal distribution, Pearson I types.

Precipitation: Gamma, Log-Normal, Kappa distribution.

Relative Humidity: Beta distribution.

Wind speed: Gamma, Weibull, Log-Normal distribution.

Wind rose: Circular distribution model and an empirical non-negative PDF.

Some other climatic elements: Poisson and binomial distribution.

Poisson distribution

A Poisson experiment is a statistical experiment that has the following properties:

1) The experiment results in outcomes that can be classified as successes or failures.
2) The average number of successes (μ) that occurs in a specified region is known.
3) The probability that a success will occur is proportional to the size of the region.
4) The probability that a success will occur in an extremely small region is virtually zero. (http://stattrek.com/Lesson2/Poisson.aspx)

A Poisson random variable is the number of successes that result from a Poisson experiment. The probability distribution of a Poisson random variable is called a Poisson distribution. We can compute the Poisson probability based on the following formula:

$$f(k;\mu) = \frac{e^{-\mu}(\mu)^k}{k!} \qquad (15)$$

where x is the actual number of successes that result from the experiment, and e is approximately equal to 2.71828. The mean of the distribution is equal to μ.

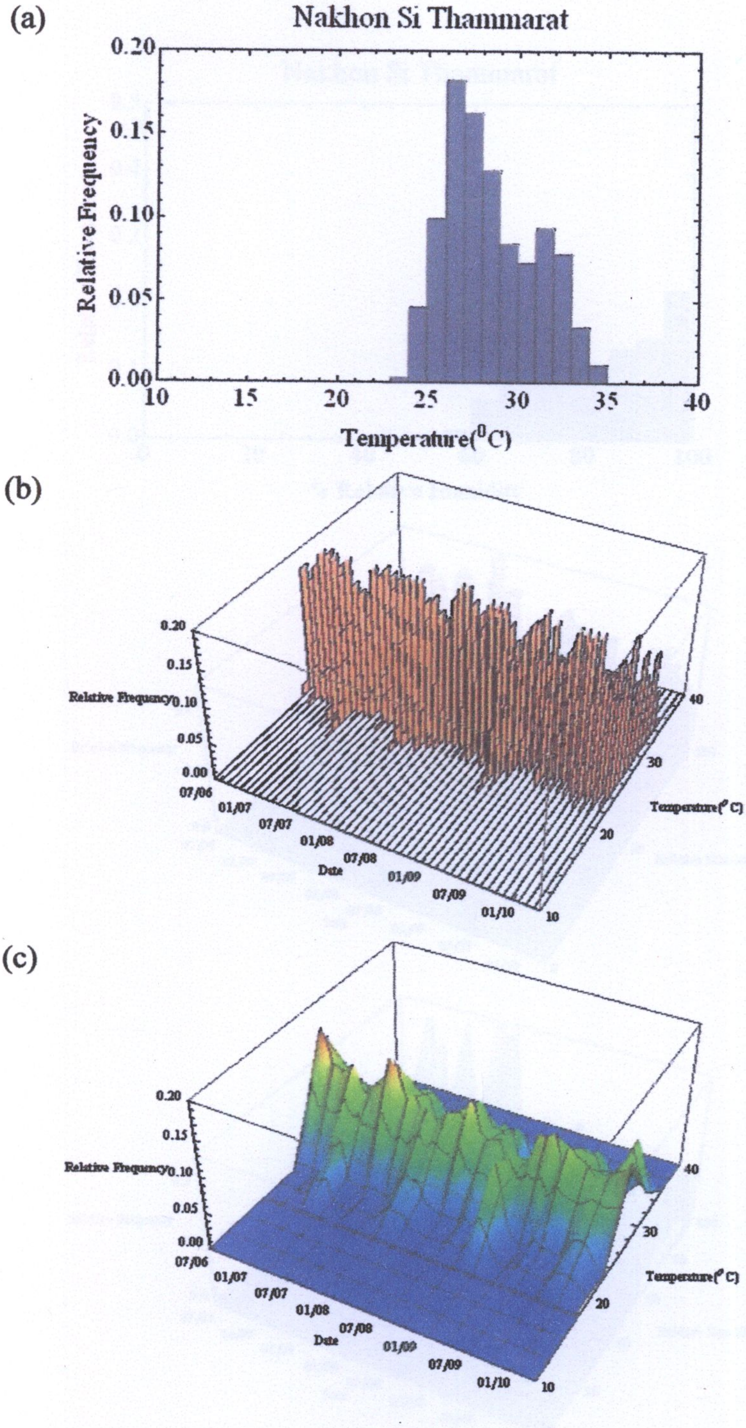

Figure 22 Temperature distribution at Nakhon Si Thammarat study site. (a) 2D histogram (b) 3D histogram and (c) 3D histogram of temperature data interpolation.

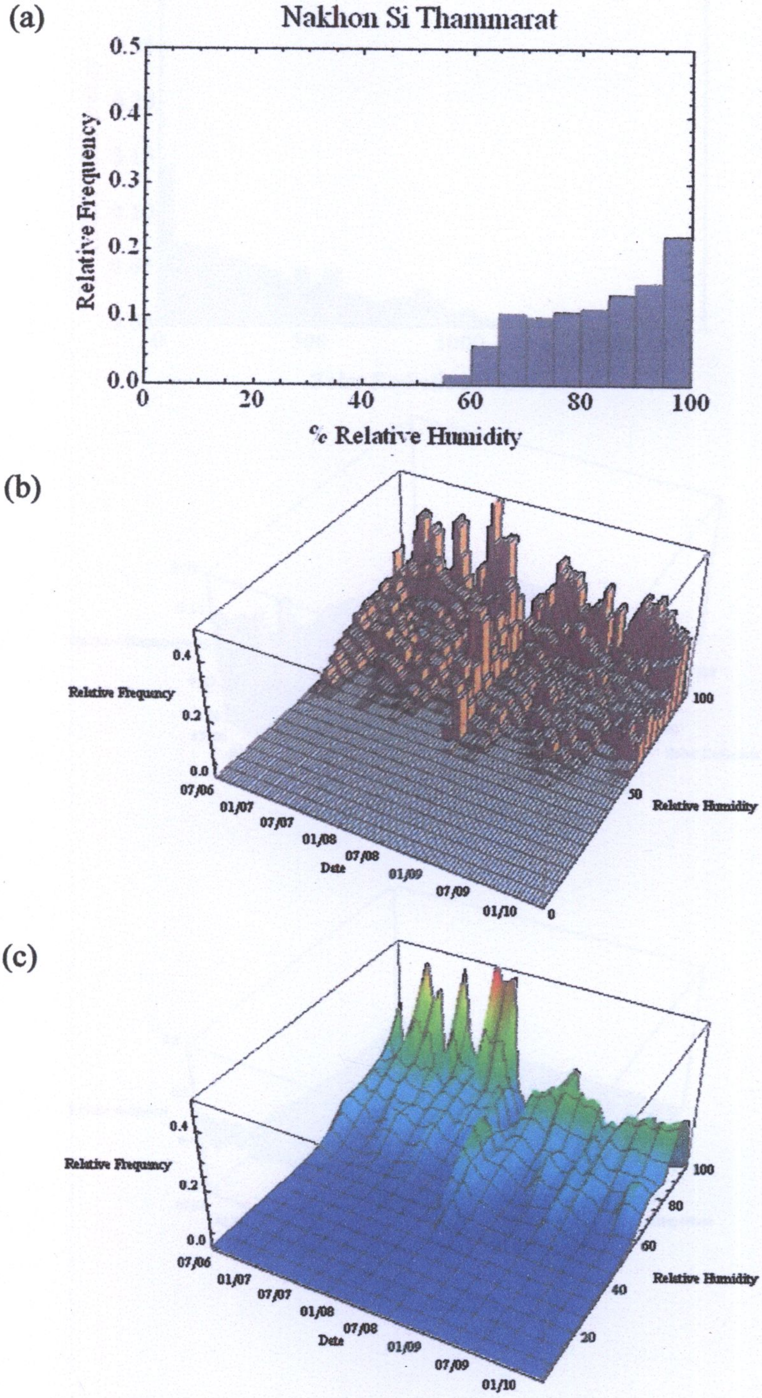

Figure 23 The percentage of relative humidity distribution at Nakhon Si Thammarat study site. (a) 2D histogram (b) 3D histogram and (c) 3D histogram of percentage of relative humidity data interpolation.

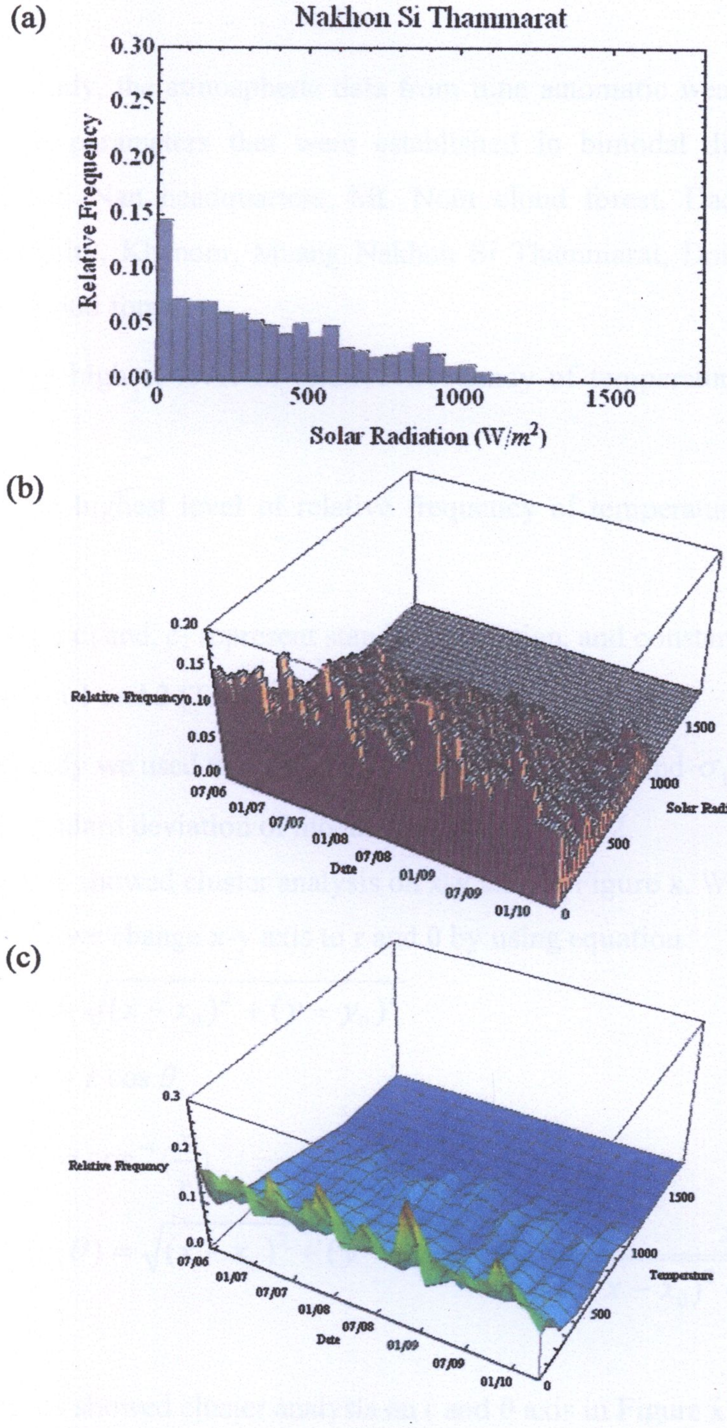

Figure 24 The solar radiation distribution at Nakhon Si Thammarat study site. (a) 2D histogram (b) 3D histogram and (c) 3D histogram of percentage of solar radiation data interpolation.

Cluster Analysis

In this study, the atmospheric data from nine automatic weather station were used within the parameters that were established in bimodal distribution fitting consisting of Mt. Nan headquarters, Mt. Nom cloud forest, Dadfa cloud forest, Walailak University, Khanom, Muang Nakhon Si Thammarat, Doi Intanon, Huilek and Duan Hok cloud forest:

μ_1 = the highest level of relative frequency of temperature distribution of peak 1

μ_2= the highest level of relative frequency of temperature distribution of peak 2

σ_1 , σ_2 , c_1 and, c_2 represent standard deviation, and constant values of modal distribution 1 and 2 (Table 4).

In this study we used two parameter that were μ_1 - μ_2 and σ_1 that σ_1 was the highest of standard deviation of modal distribution 1and 2.

The results showed cluster analysis on x-y axis in Figure x. We can't see the group of them, so we change x-y axis to r and θ by using equation

$$r = \sqrt{(x - x_0)^2 + (y - y_0)^2}$$

$$x = r\cos\theta$$

$$\theta = \cos^{-1}(\frac{x}{r})$$

$$(r,\theta) = \sqrt{(x - x_0)^2 + (y - y_0)^2}, \cos^{-1}(\frac{x}{\sqrt{(x - x_0)^2 + (y - y_0)^2}})$$

The results showed cluster analysis on r and θ axis in Figure x.

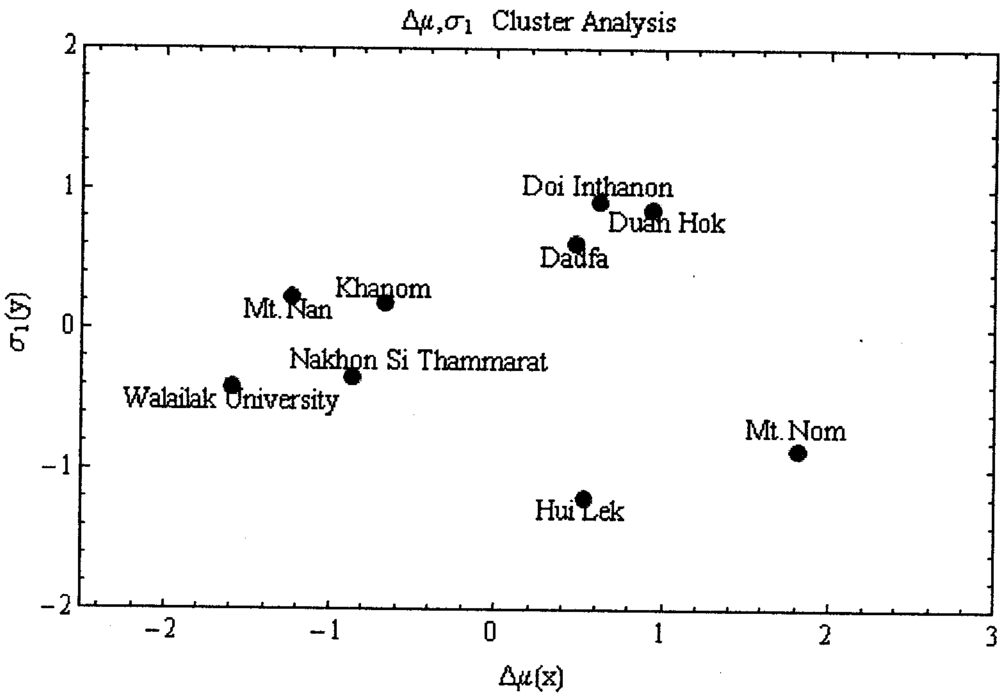

Figure 25 The results a cluster analysis of atmospheric data from nine automatic weather station. X-axis is $\Delta\mu(x)$ and Y-axis is $\sigma(y)$

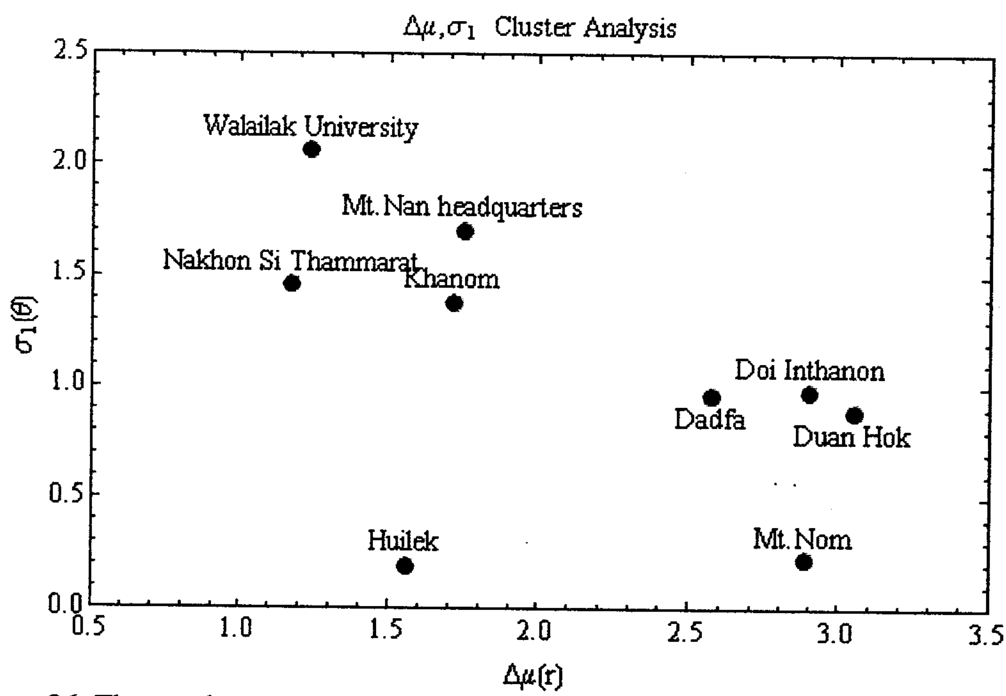

Figure 26 The results a cluster analysis of atmospheric data from nine automatic weather station. X-axis is $\Delta\mu(r)$ and Y-axis is $\sigma(\theta)$

Results

Bimodal Distribution

A bimodal distribution was composed of two subpopulations each of which is normal. The tails of the bimodal distribution fitted the observed distribution well (Table 4, Figure 22a-i). Khanom and Walailak sites had higher μ_1, and μ_2 than other sites (Table 4). Mt. Nom and Duan Hok cloud forest had lower mean temperatures than at tropical forest sites (Mt. Nan and Hui Lek) (Table 4). On the other hand, Dadfa cloud forest had slightly higher temperature than Mt. Nom and Duan Hok cloud forests. Mt. Nom, Duan Hok and Dadfa cloud forest had σ_1 less than 1 (Table 4). On the other hand, this could not be applied to high latitude cloud forest like Doi Intanon (Table 4).

Temperature Relative Frequency

The temperature distribution of Khanom, Walailak University and Muang Nakhon Si Thammarat weather stations were similarly (Figure 22a-c). The relative frequency of the first peak was approximately 0.16 which was lower than tropical forest and cloud forest sites (Figure 22a-c). The temperature distribution of Mt. Nan Headquarters and Hui Lek weather stations were similarly (Figure 22d,e). The relative frequency of the first peak was approximately 0.20 which was intermediate (Figure 22d,e). The temperature distribution of Mt. Nom, Duan Hok, and Dadfa weather stations were similarly (Figure 22f-h). The relative frequency of the first peak was approximately 0.28 which was highest among three habitat types (Figure 22f-i). The temperature distribution of Doi Intanon weather station was different from the rest (Figure 22i). The relative frequency of the first peak was approximately 0.40 and the second peak of 0.23 (Figure 22g). The distributions of cloud forest sites had two marked maxima (Figure 22f-i).

The Percentage of Relative Humidity Relative Frequency

The percentage of relative humidity distribution of Khanom, Walailak University, Muang Nakhon Si Thammarat and Mt. Nan Headquarters weather stations were similarly (Figure 23a-d). The relative frequency of the first peak was approximately 0.22-0.28 which was lower than cloud forest sites (Figure 23f-i).

The percentage of relative humidity distribution of Huilek, Mt. Nom, Duan Hok, and Dadfa weather stations were similarly (Figure 23f-h). The relative frequency of the first peak was approximately 0.43-0.58 (Figure 23f-i).

The percentage of relative humidity distribution of Doi Intanon weather station was different from the rest (Figure 23i). The relative frequency of the first peak was approximately 0.47, the second peak was 0.02 and the third peak was approximately 0.03 (Figure 23g).

Heat Index relative frequency

The heat index distribution of Khanom, Walailak University and Muang Nakhon Si Thammarat weather stations were similar (Figure 24a-c). The relative frequency of the first peak was approximately 0.13 which was lower than tropical forest and cloud forest sites (Figure 24a-c). The heat index distribution of Mt. Nan Headquarters and Hui Lek weather stations were similar (Figure 24d,e). The relative frequency of the first peak was approximately 0.15-0.20 which was intermediate (Figure 24d,e). The temperature distribution of Mt. Nom, Duan Hok, and Dadfa weather stations were similar (Figure 24f-h). The relative frequency of the first peak was approximately 0.22-0.28 which was the highest among three habitat types (Figure 24f-i). The heat index distribution of Doi Intanon weather station was different from the rest (Figure 23i). The relative frequency of the first peak was approximately 0.04 and the second peak was 0.23 (Figure 24g). The distributions of cloud forest sites had two marked maxima (Figure 24f-i).

Temperature distribution

The results showed the highest of relative frequency of temperature varied between months. The mean temperature in September to November was lower than mean temperature in March to August (Figure 25a-i). At high temperature, the temperature distribution was higher than at low temperature.

The temperature distribution at Khanom, and Walailak University sites were similar. The highest of relative frequency were approximately 23-25 °C (Figure 25 a,b,c). The temperature distribution was higher than 35 °C.

The temperature distribution of Mt. Nom Headquarters and Huilek sites were similar. The highest of relative frequency were approximately 22-23 °C (Figure 25 d,e). The temperature distribution was lower than 35 °C.

The temperature distribution of Dadfa, Duan Hok and Mt. Nom were similar. The highest of relative frequency were approximately 18-20 °C (Figure 25 f,g,h). The temperature distribution was lower than 30 °C.

There were three peaks of the temperature distribution of Doi Intanon weather station. The first peak occurred in winter (October to February). The mean of the temperature was 8 °C (Table 4, Figure 25i). The second peak and the third peak showed the mean temperature in rainy and summer season that were 12.7 °C and 15.5 °C, respectively.

Table 5 The mean temperature, heat index and relative humidity of nine study sites.

Study site	Temperature (°C) ±SD	Heat Index (°C) ±SD	% Relative Humidity	n
Khanom	27.34 ± 2.70	30.83 ± 4.39	81.24 ± 10.62	16342
Walailak	27.58 ± 3.11	30.02 ± 4.76	80.76 ± 13.76	43165
Nakhon Si	27.73 ± 2.79	30.46 ± 4.50	81.55± 12.84	57435
Mt. Nan	25.64 ± 2.44	29.12 ± 4.11	86.27± 10.35	25198
Huilek	23.80 ± 2.82	26.39 ± 4.19	91.78 ± 9.43	48159
Dadfa	21.43± 2.18	24.31 ± 2.39	92.29 ± 8.70	15734
Duan Hok	20.85 ± 1.37	21.26 ± 1.90	94.31 ± 6.82	28280
Mt. Nom	19.32 ± 2.46	19.95 ± 2.82	89.55 ± 11.15	7706
Doi Intanon	13.10 ± 2.21	11.74 ± 2.57	80.19 ± 27.45	8832

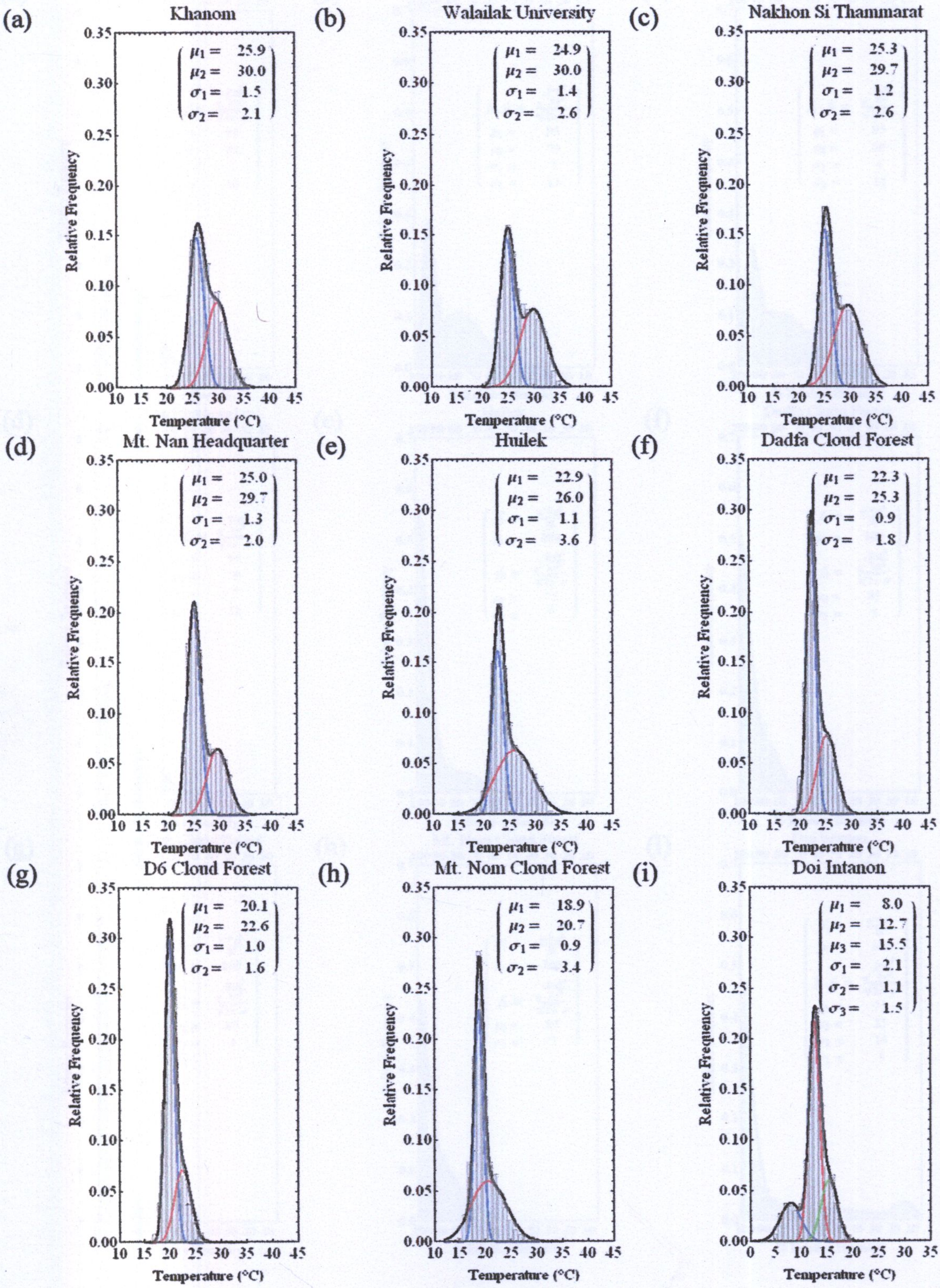

Figure 27 Temperature distribution with bimodal curve at nine study sites. (a-c) coastal sites, (d-e) tropical forests and (f-i) cloud forests.

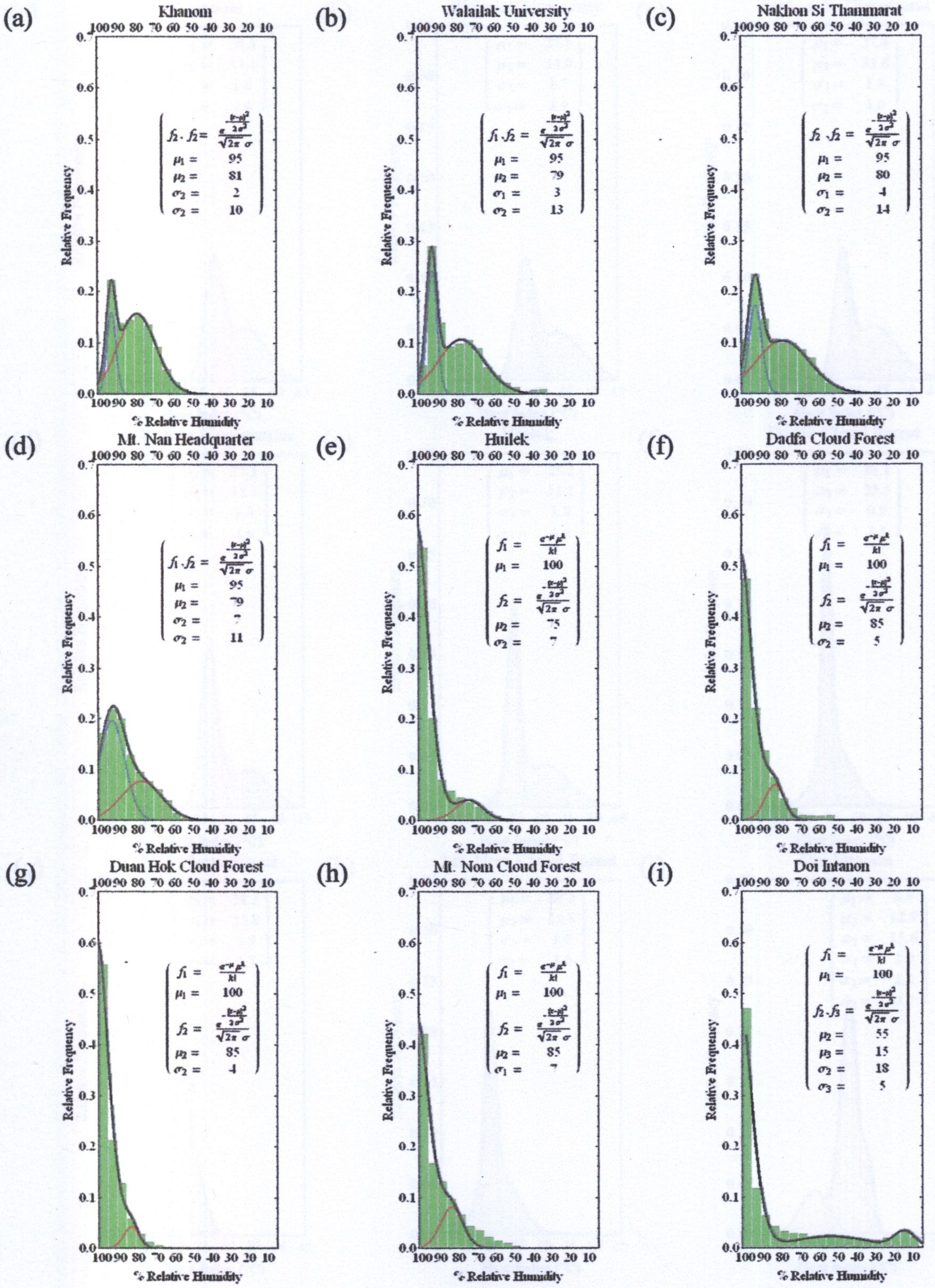

Figure 28 The percentage of relative humidity distribution with bimodal curve at nine study sites. (a-c) coastal sites, (d-e) tropical forests and (f-i) cloud forests.

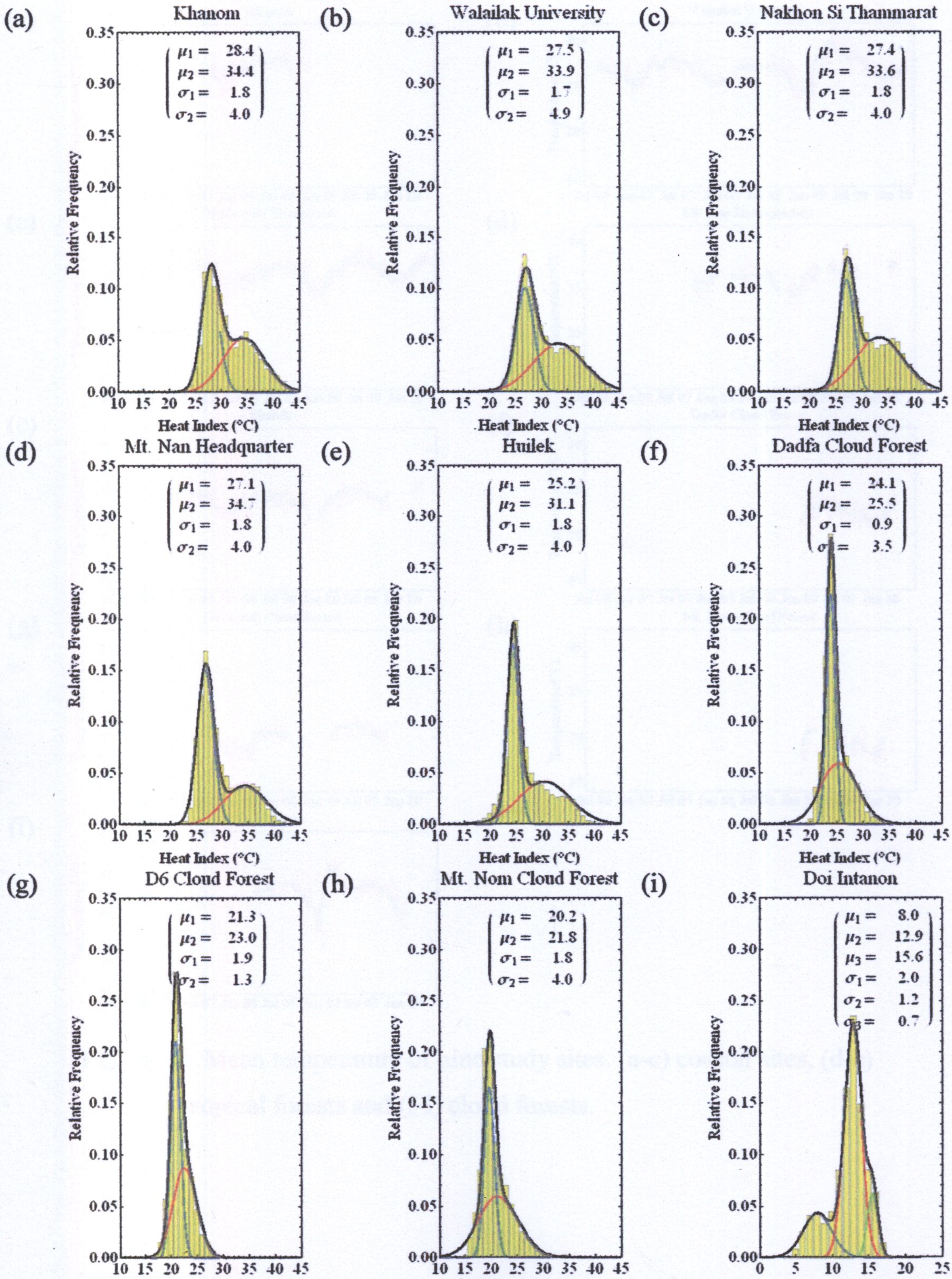

Figure 29 Heat Index distribution with bimodal curve at nine study sites. (a-c) coastal sites, (d-e) tropical forests and (f-i) cloud forests.

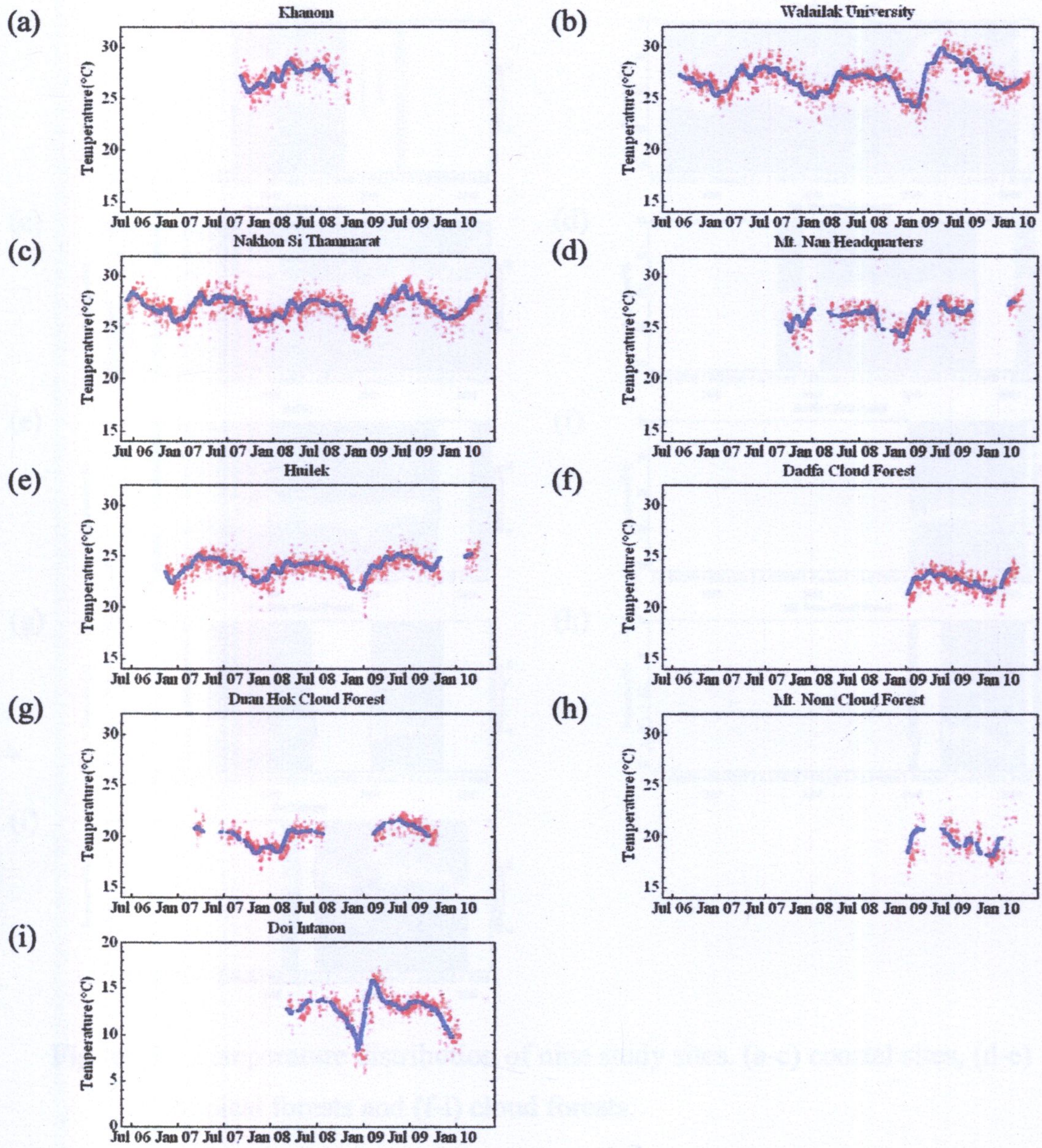

Figure 30 Mean temperature of nine study sites. (a-c) coastal sites, (d-e) tropical forests and (f-i) cloud forests.

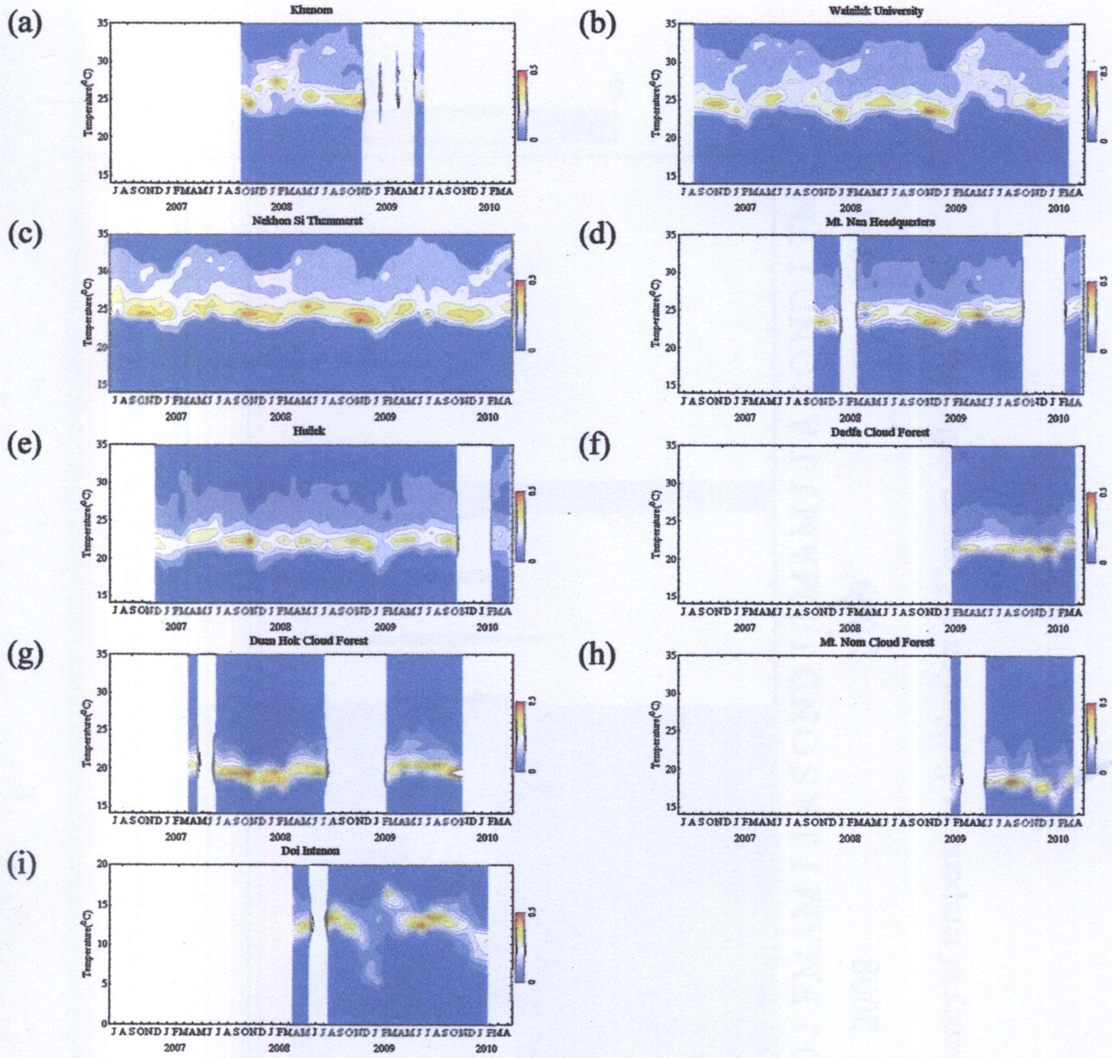

Figure 31 Temperature distribution of nine study sites. (a-c) coastal sites, (d-e) tropical forests and (f-i) cloud forests.

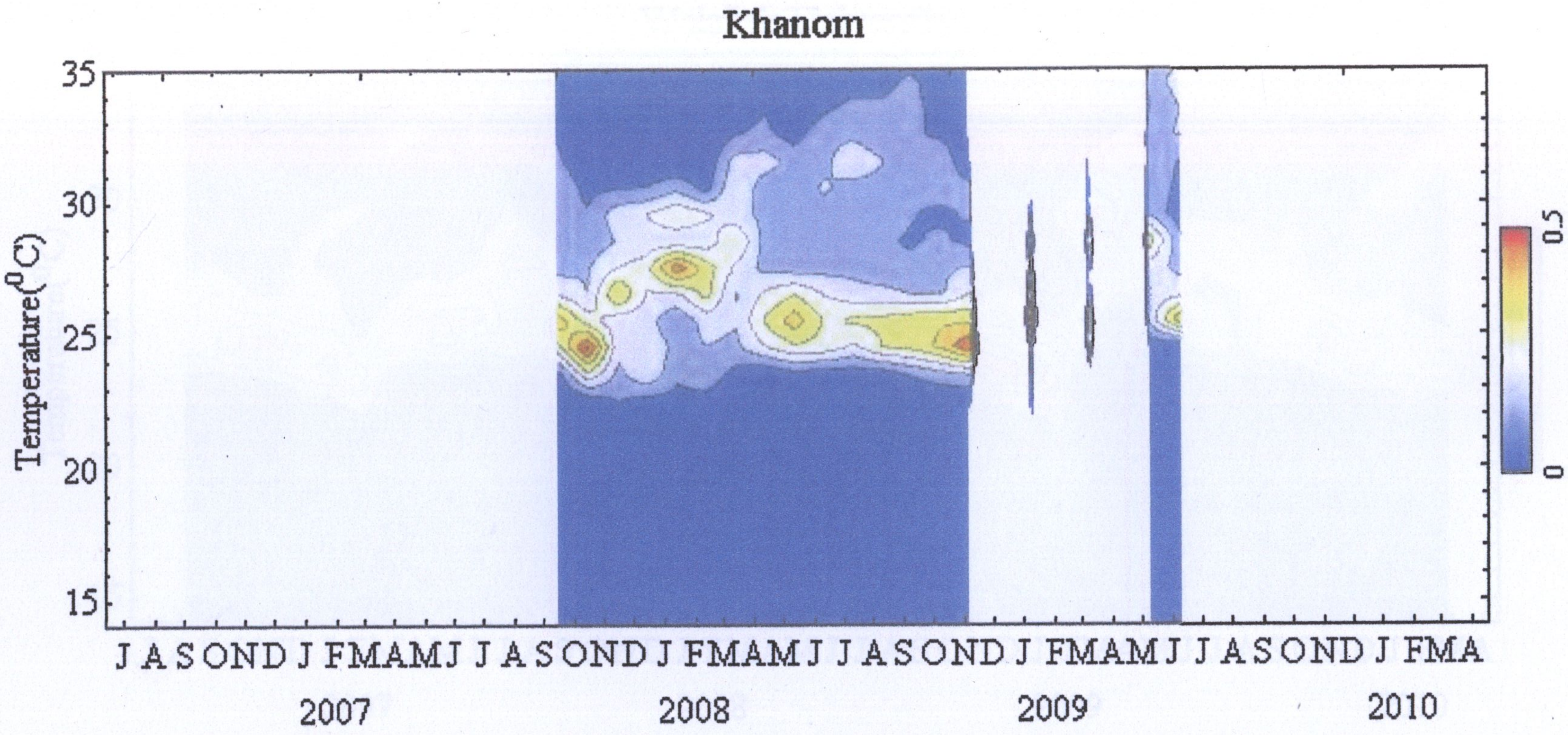

Figure 32 The relative frequency of temperature distribution of Khanom study site

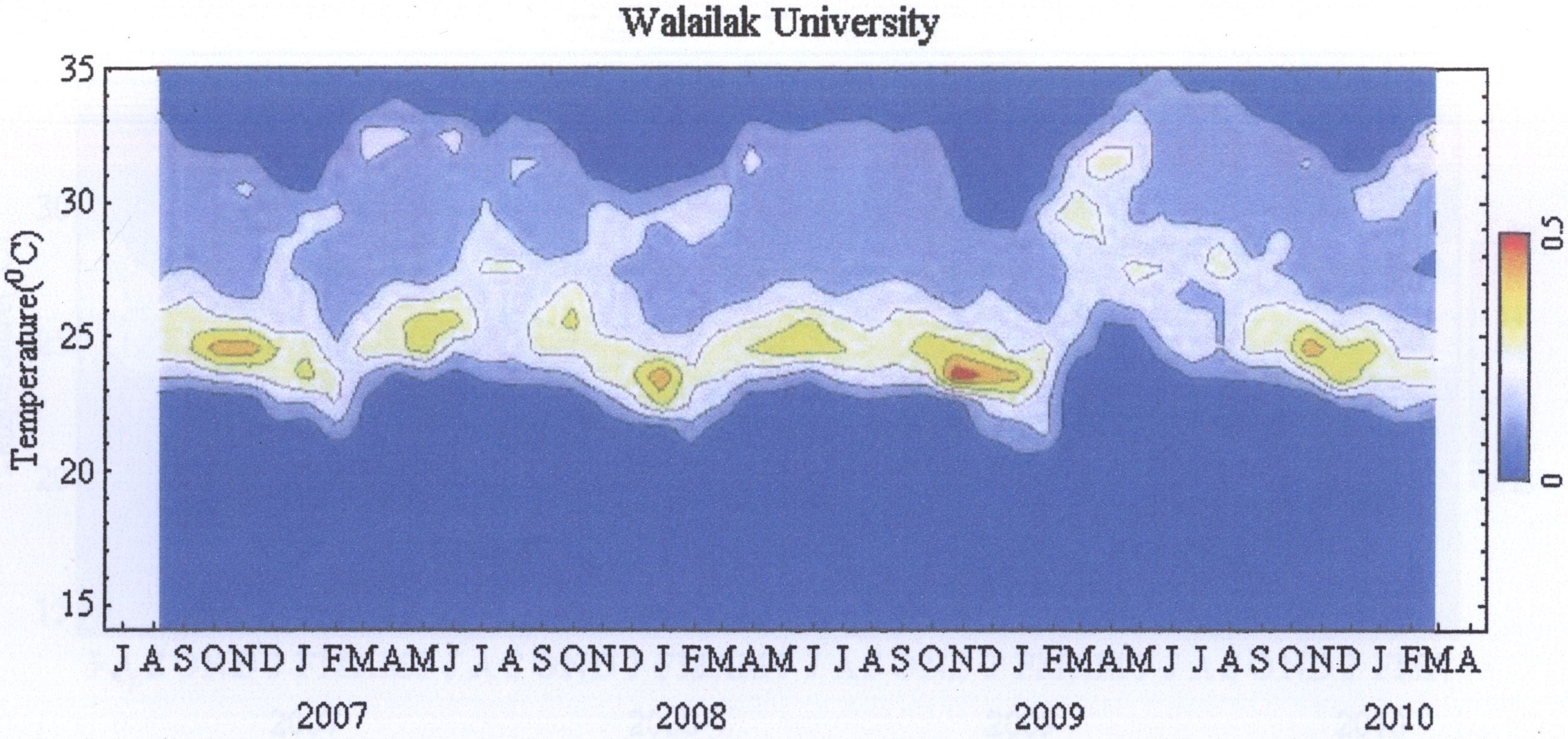

Figure 33 The relative frequency of temperature distribution of Walailak University study site.

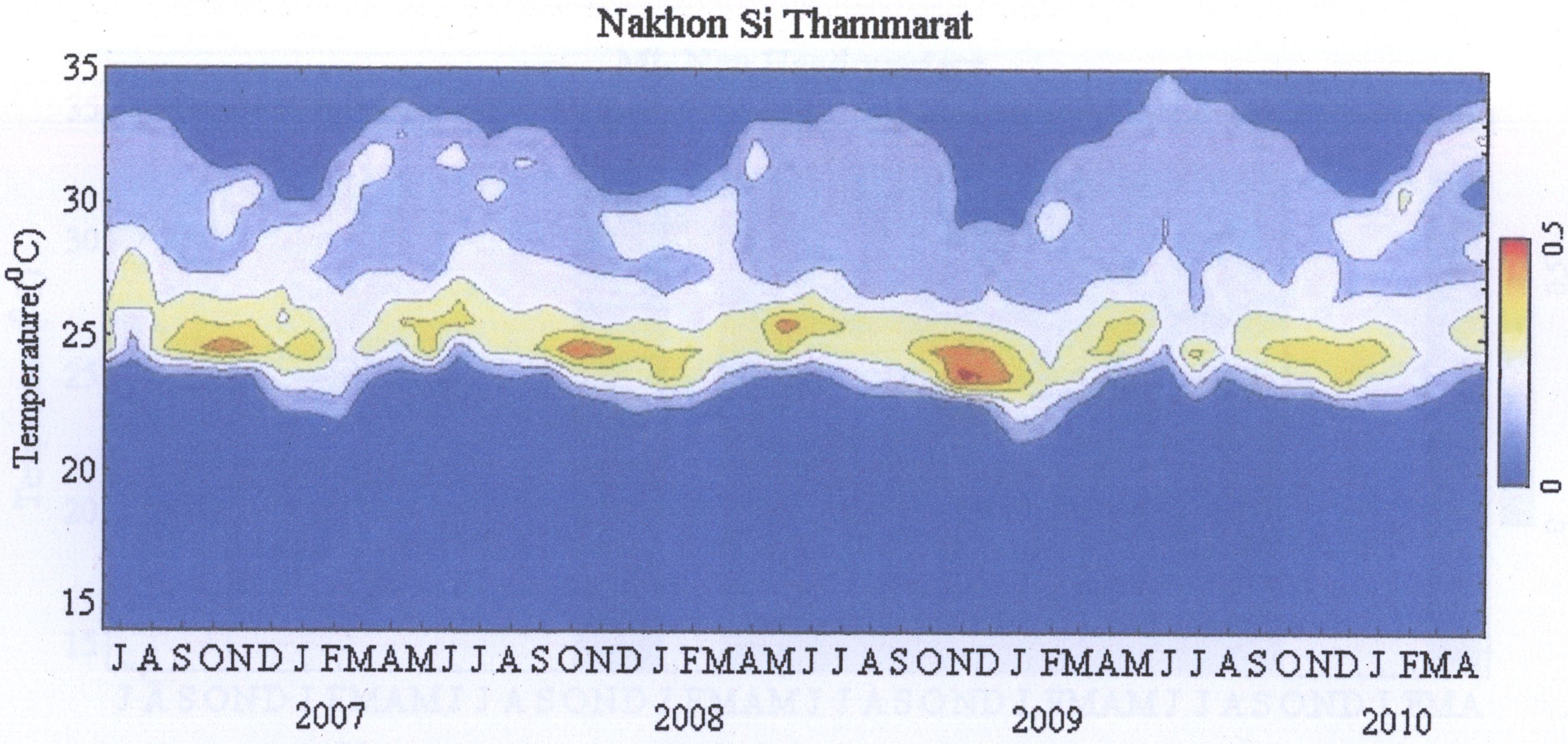

Figure 34 The relative frequency of temperature distribution of Nakhon Si Thammarat study site.

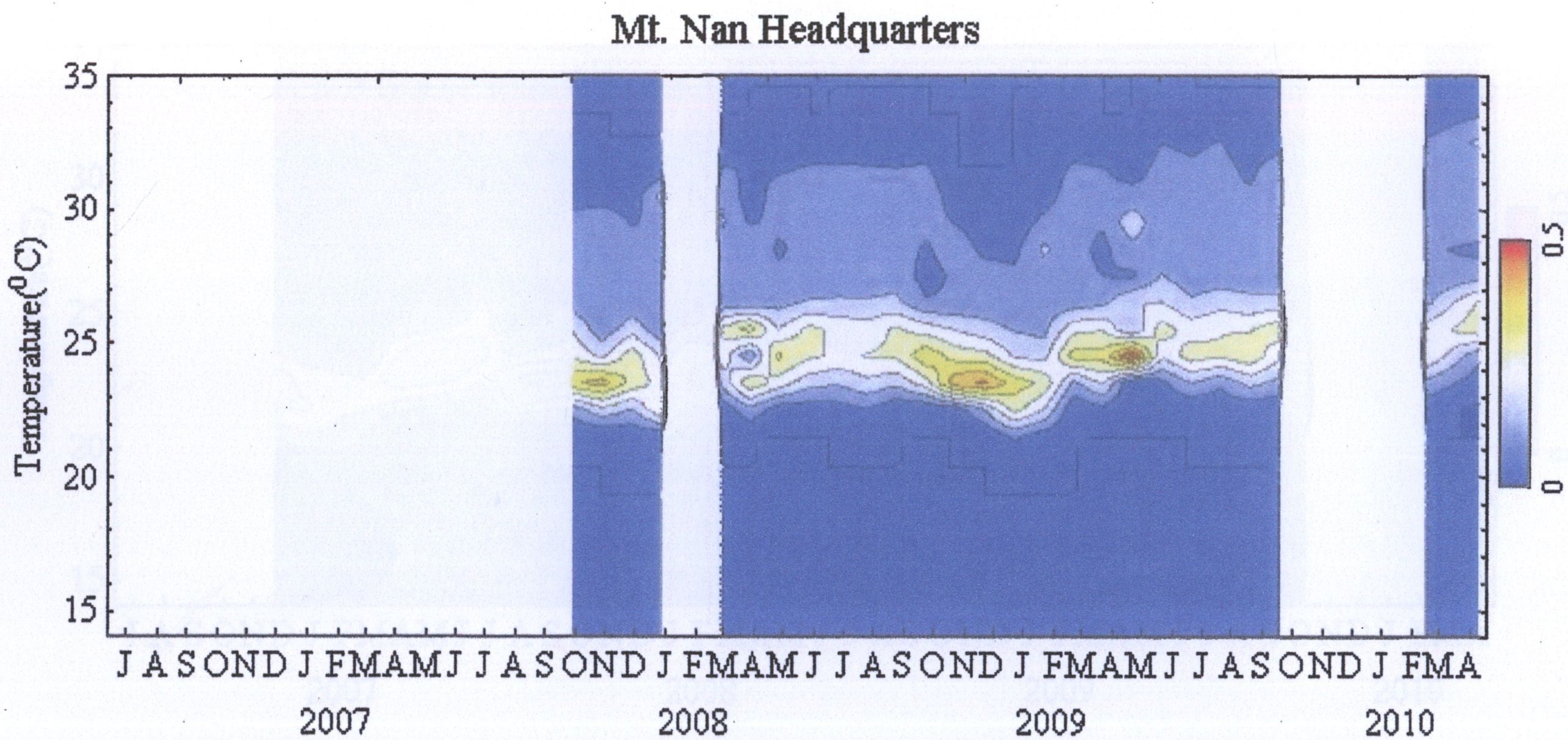

Figure 35 The relative frequency of temperature distribution of Mt. Nan Headquarters study site.

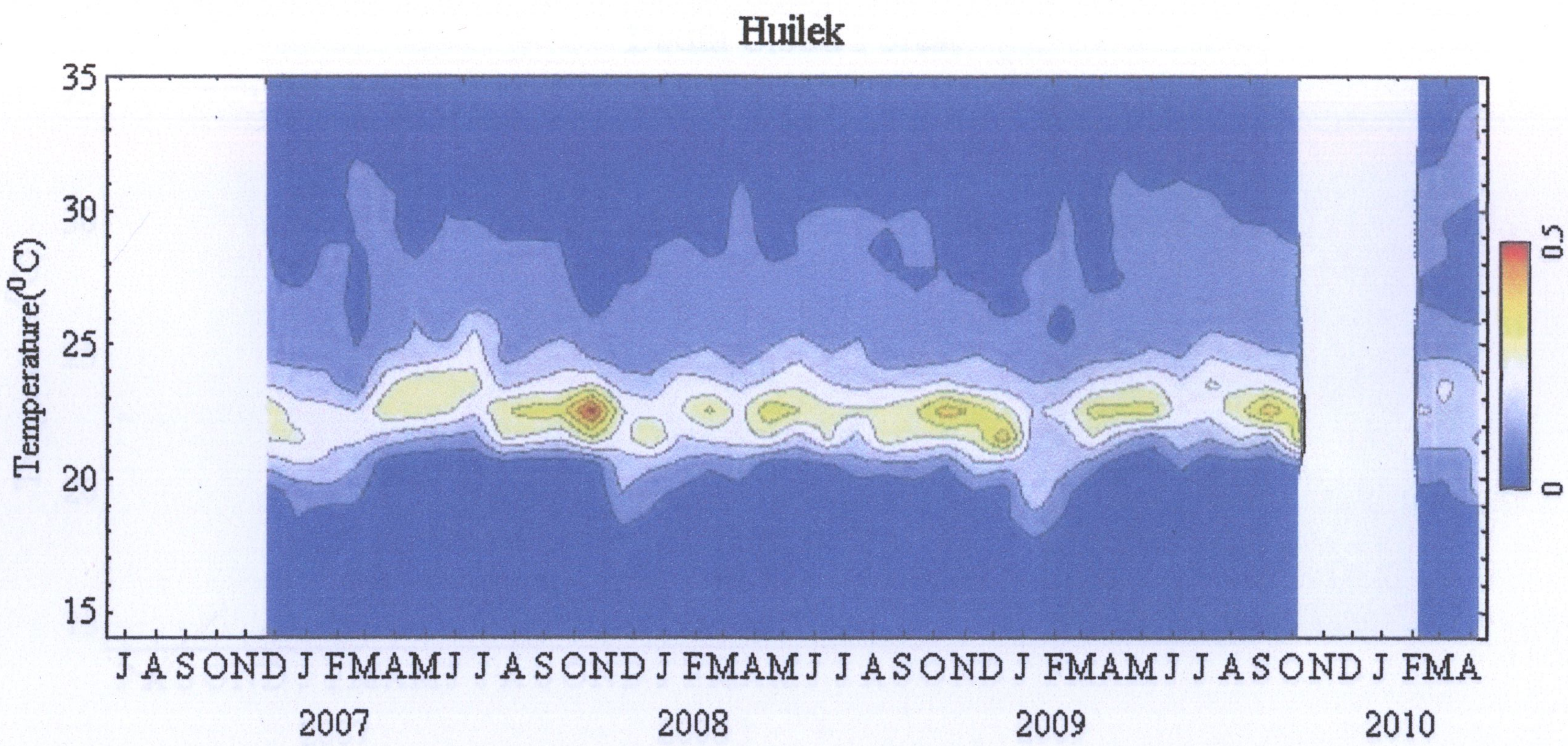

Figure 36 The relative frequency of temperature distribution of Huilek study site.

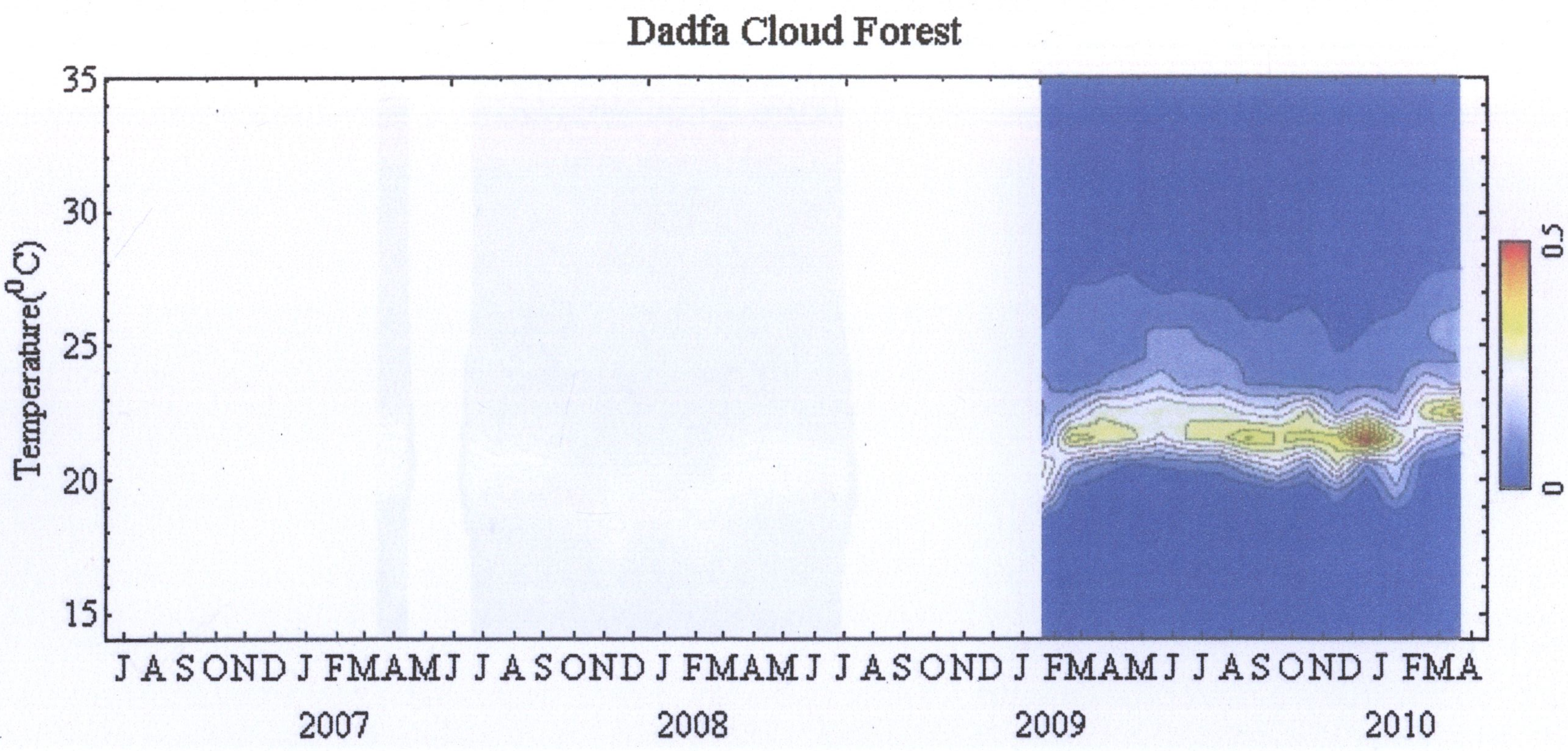

Figure 37 The relative frequency of temperature distribution of Dadfa cloud forest study site.

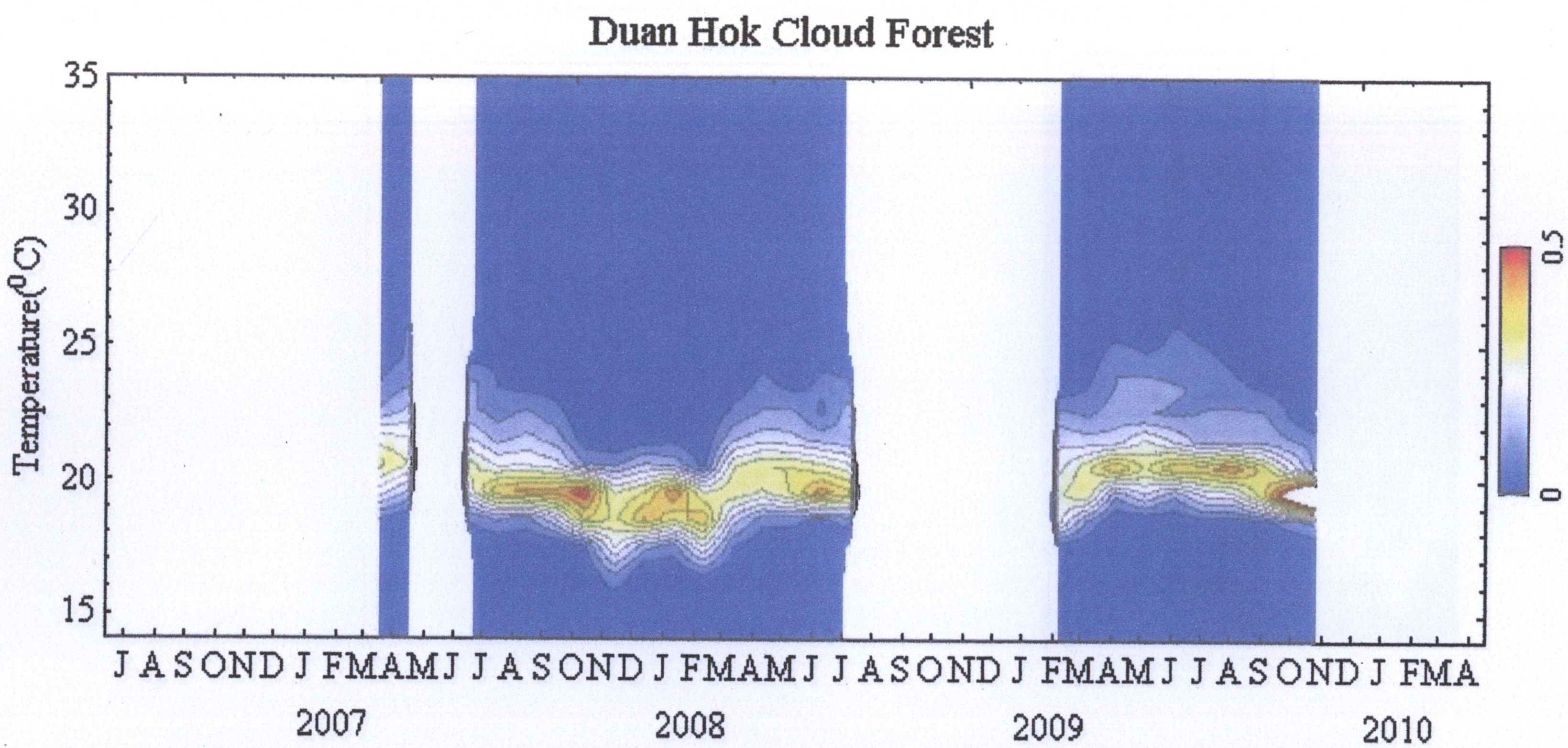

Figure 38 The relative frequency of temperature distribution of Duan Hok cloud forest study site.

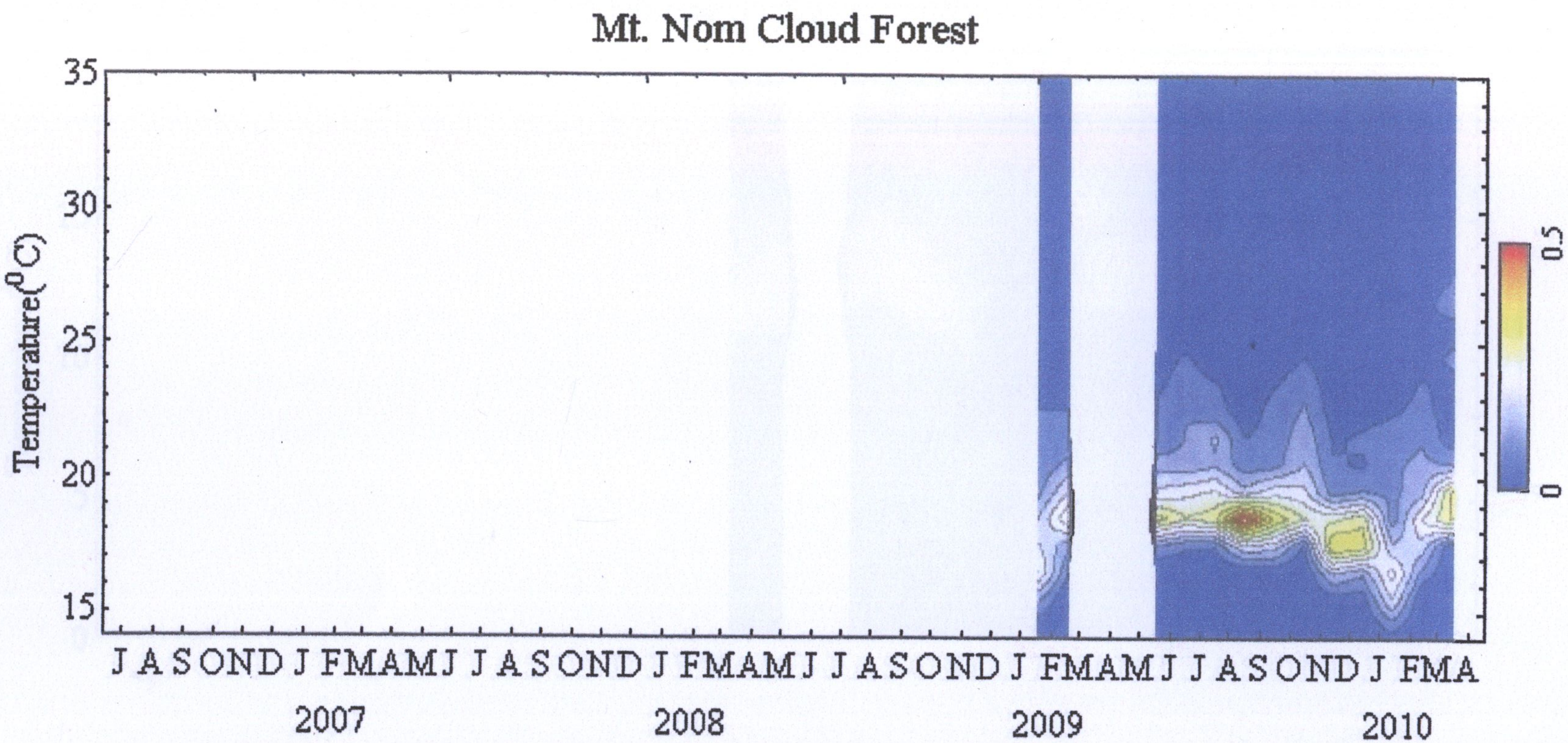

Figure 39 The relative frequency of temperature distribution of Mt. Nom cloud forest study site.

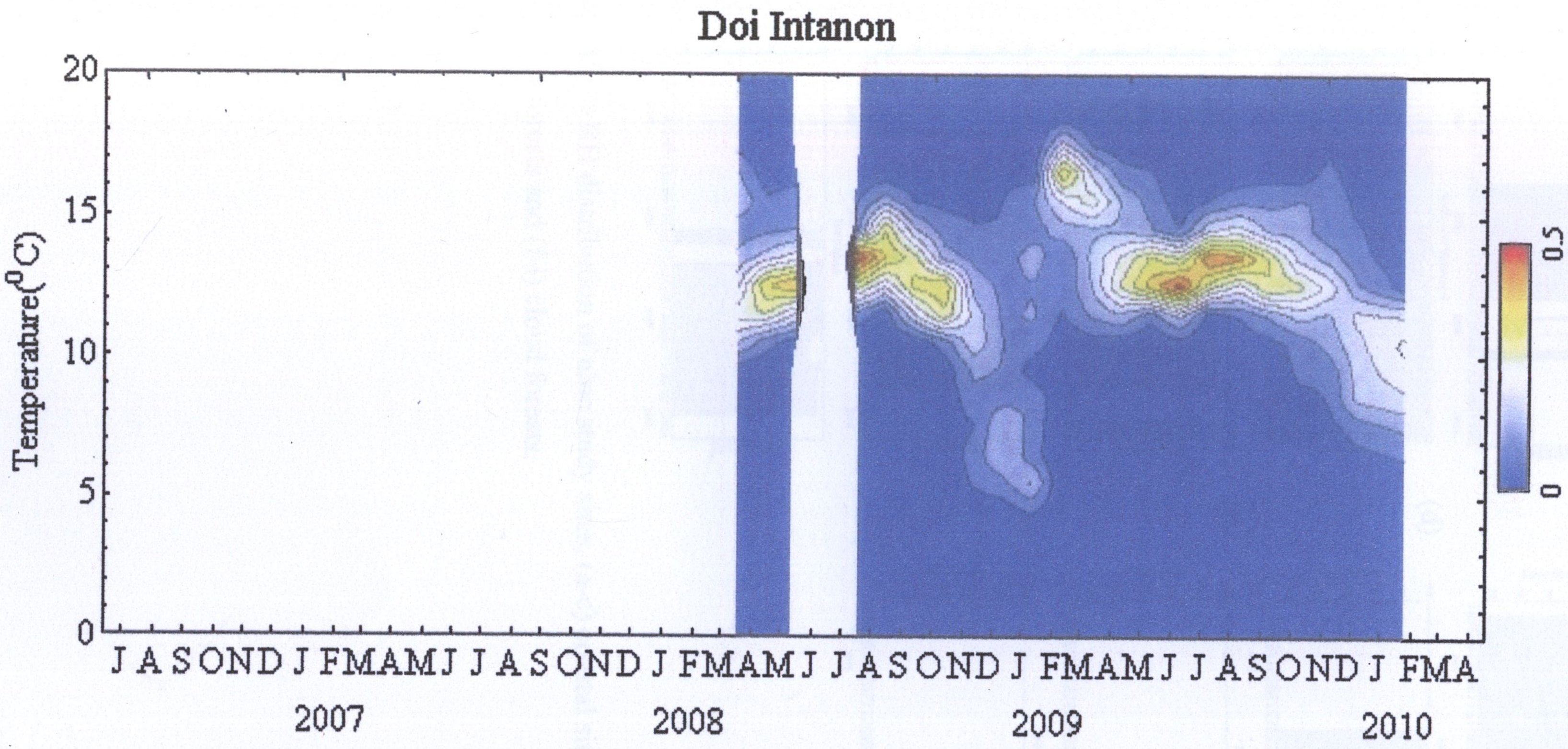

Figure 40 The relative frequency of temperature distribution of Doi Intanon study site.

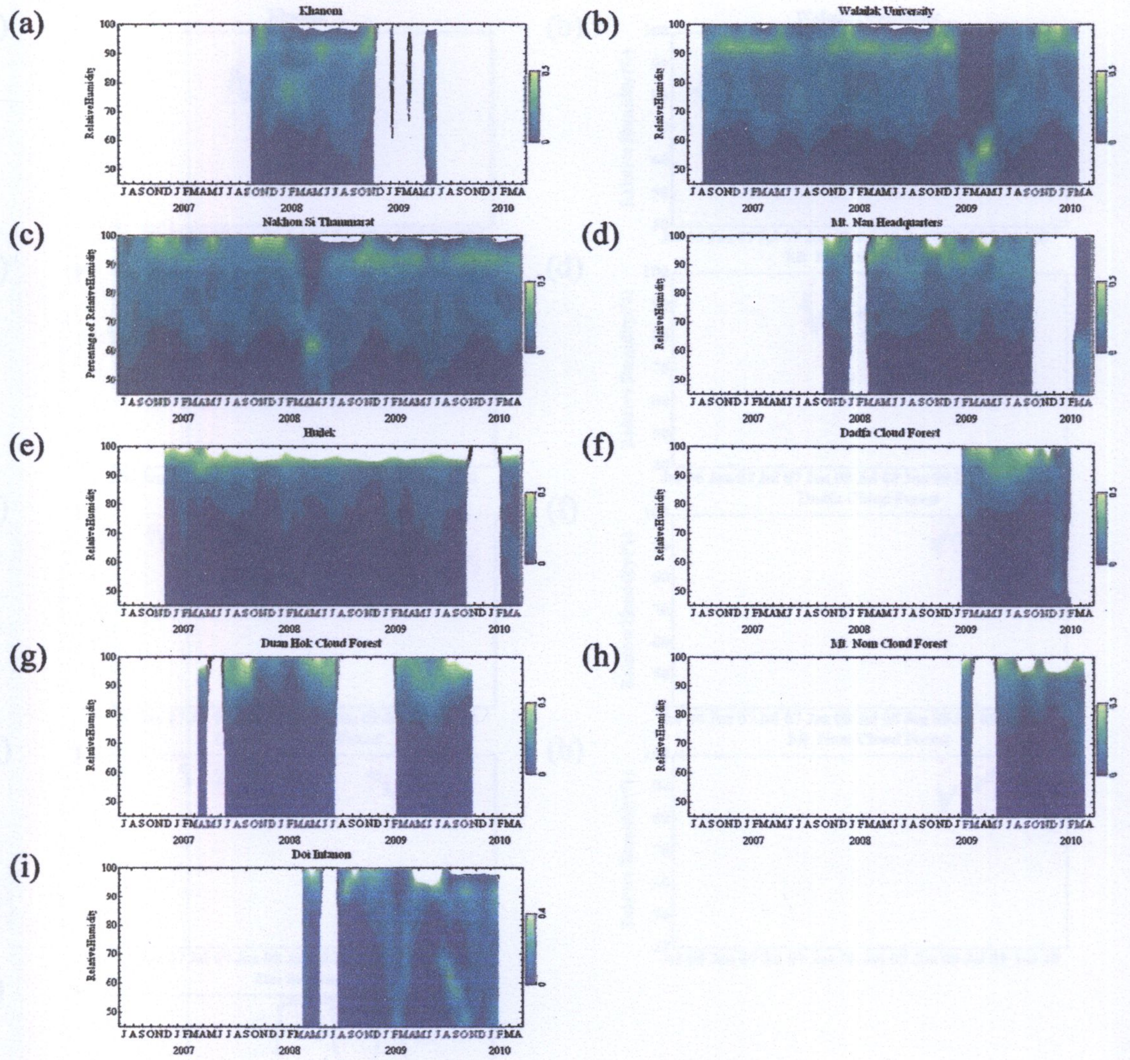

Figure 41 % RH distribution of nine study sites. (a-c) coastal sites, (d-e) tropical forests and (f-i) cloud forests.

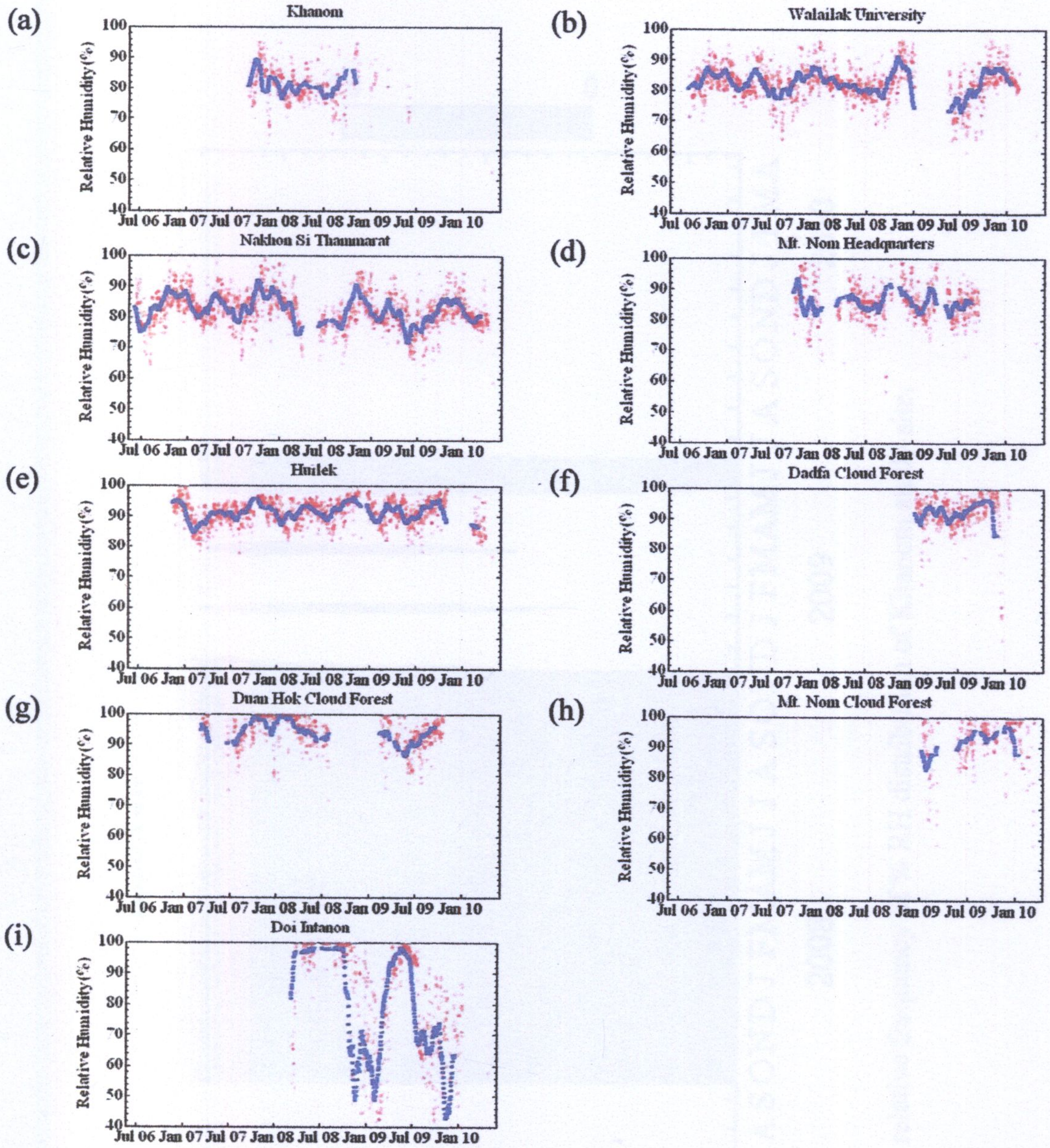

Figure 42 % RH distribution of nine study sites. (a-c) coastal sites, (d-e) tropical forests and (f-i) cloud forests.

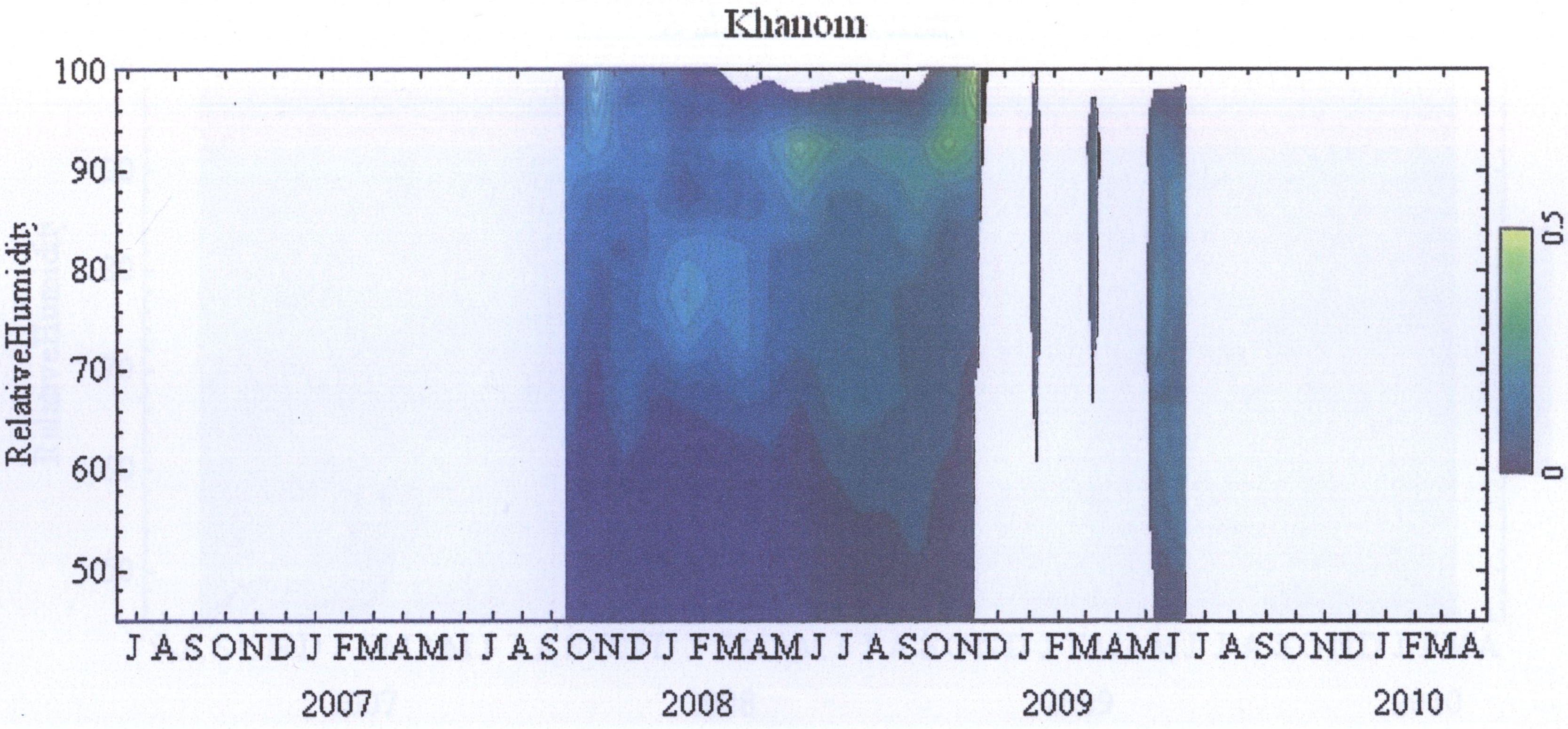

Figure 43 The relative frequency of % RH distribution of Khanom study site.

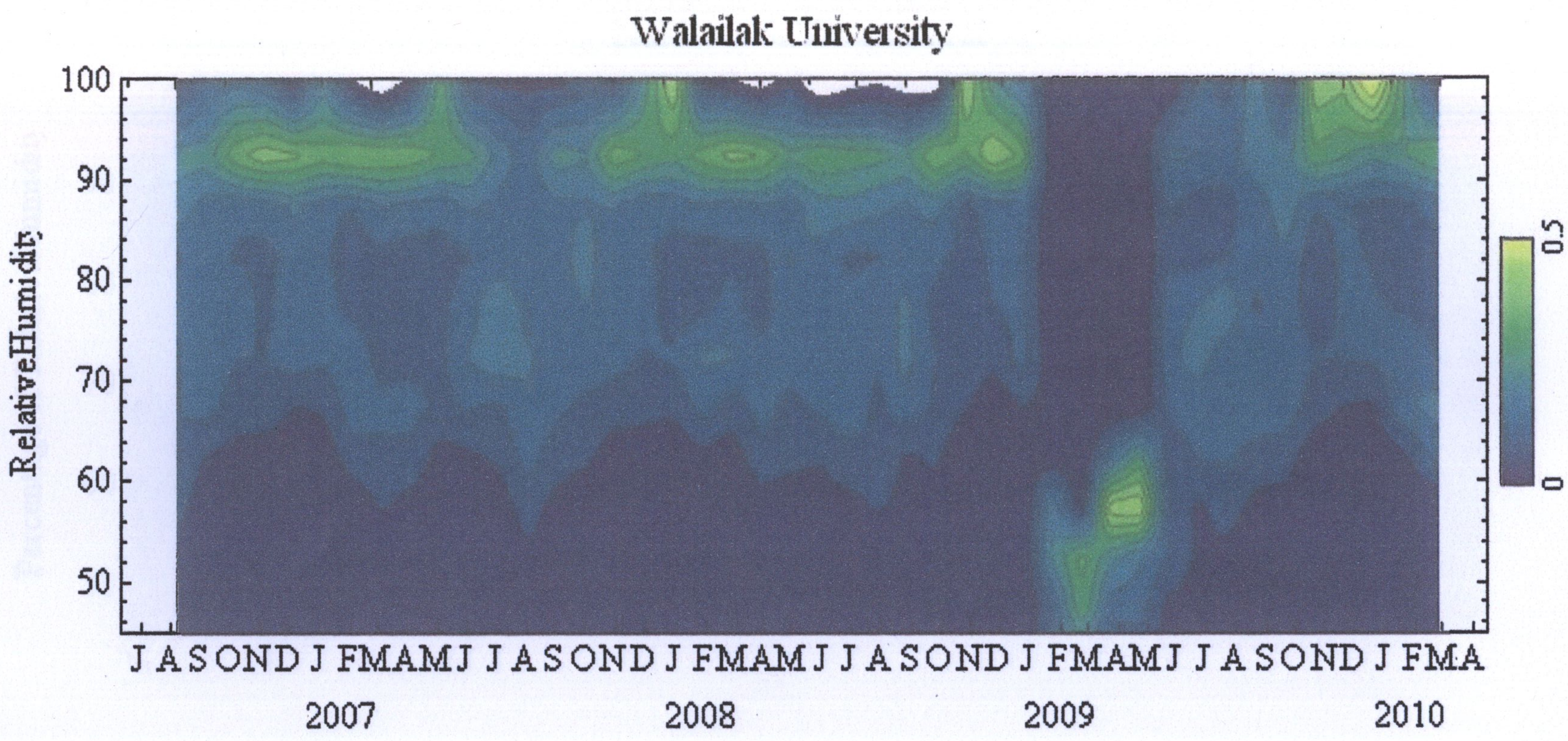

Figure 44 The relative frequency of % RH distribution of Walailak University study site.

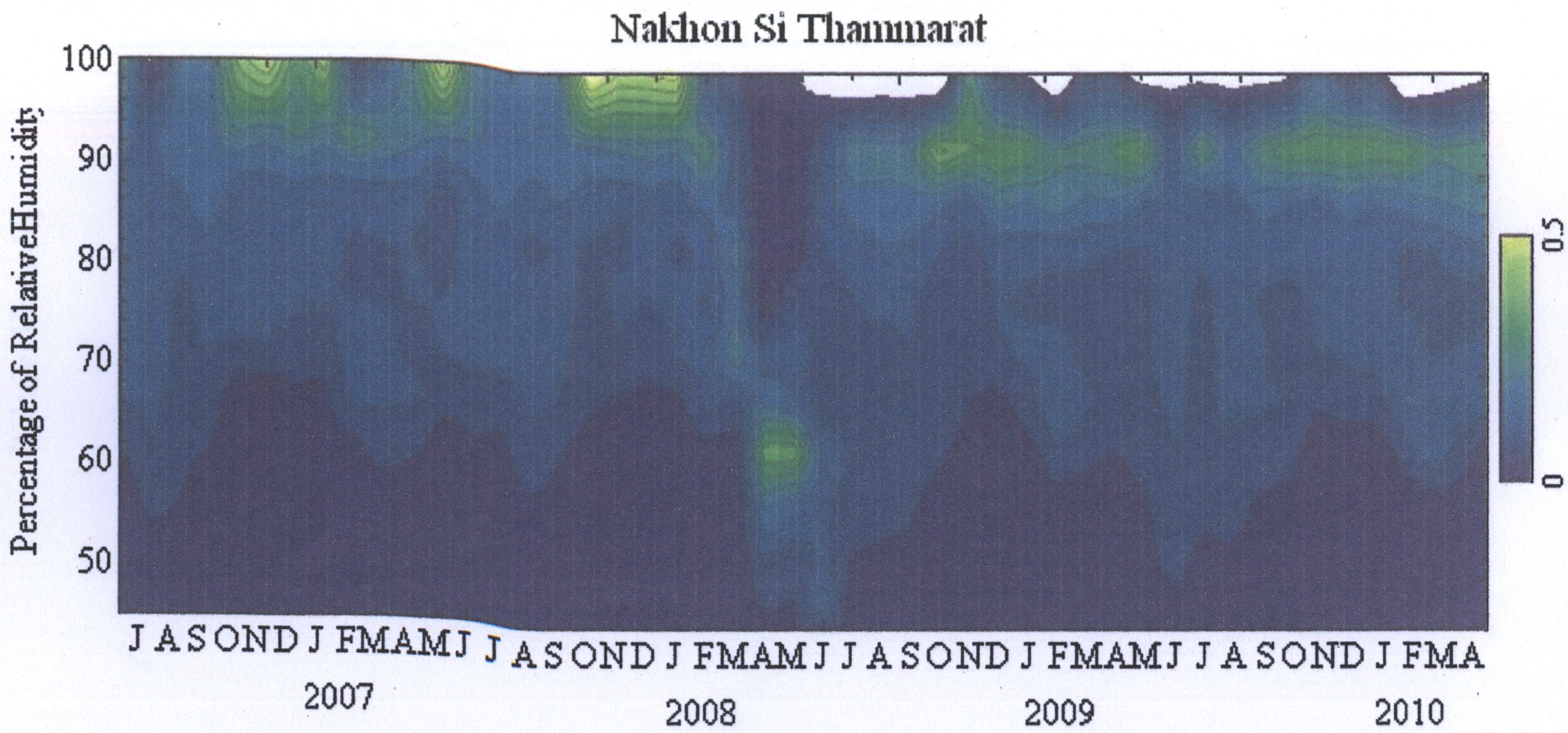

Figure 45 The relative frequency of % RH distribution of Nakhon Si Thammarat study site.

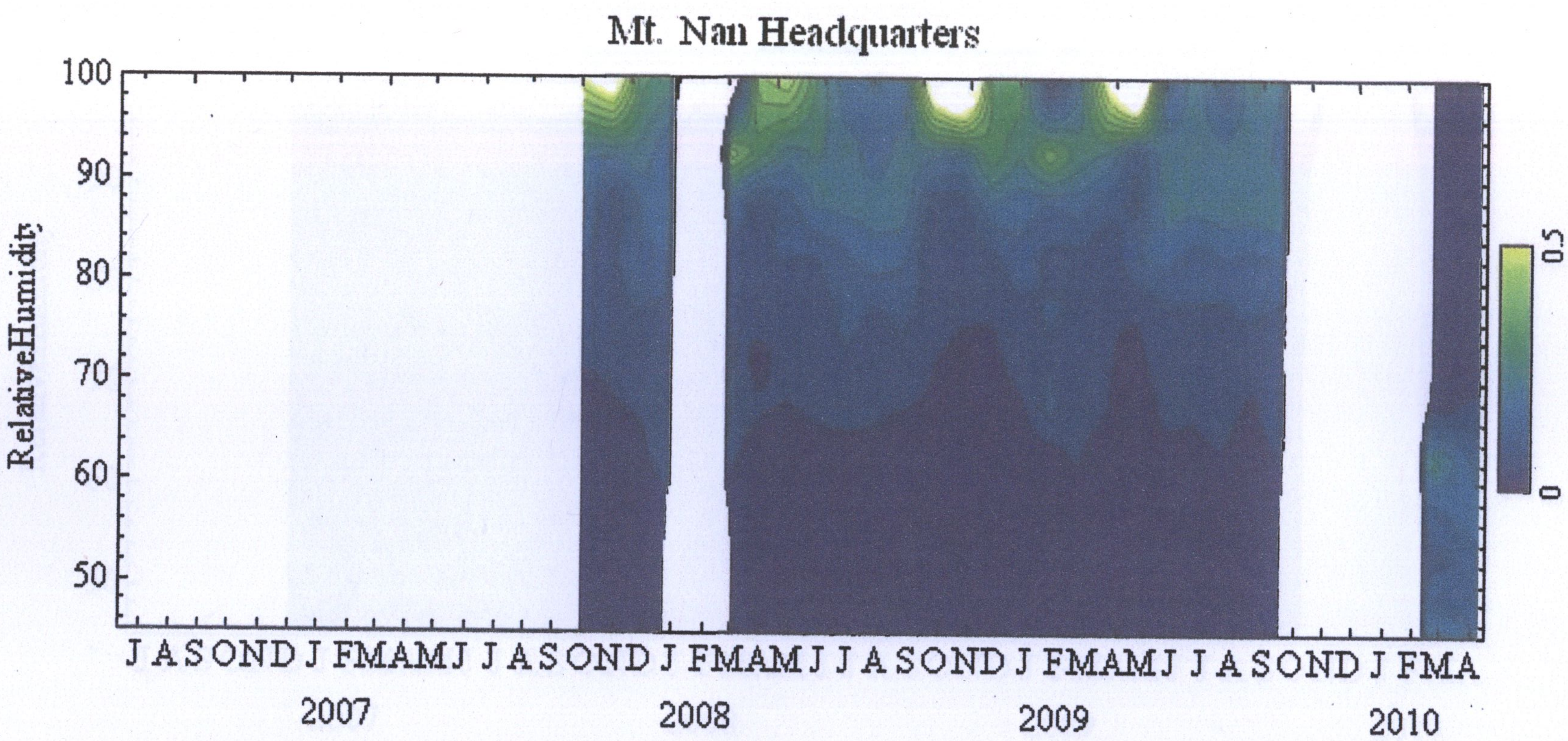

Figure 46 The relative frequency of % RH distribution of Mt. Nan Headquarters study site.

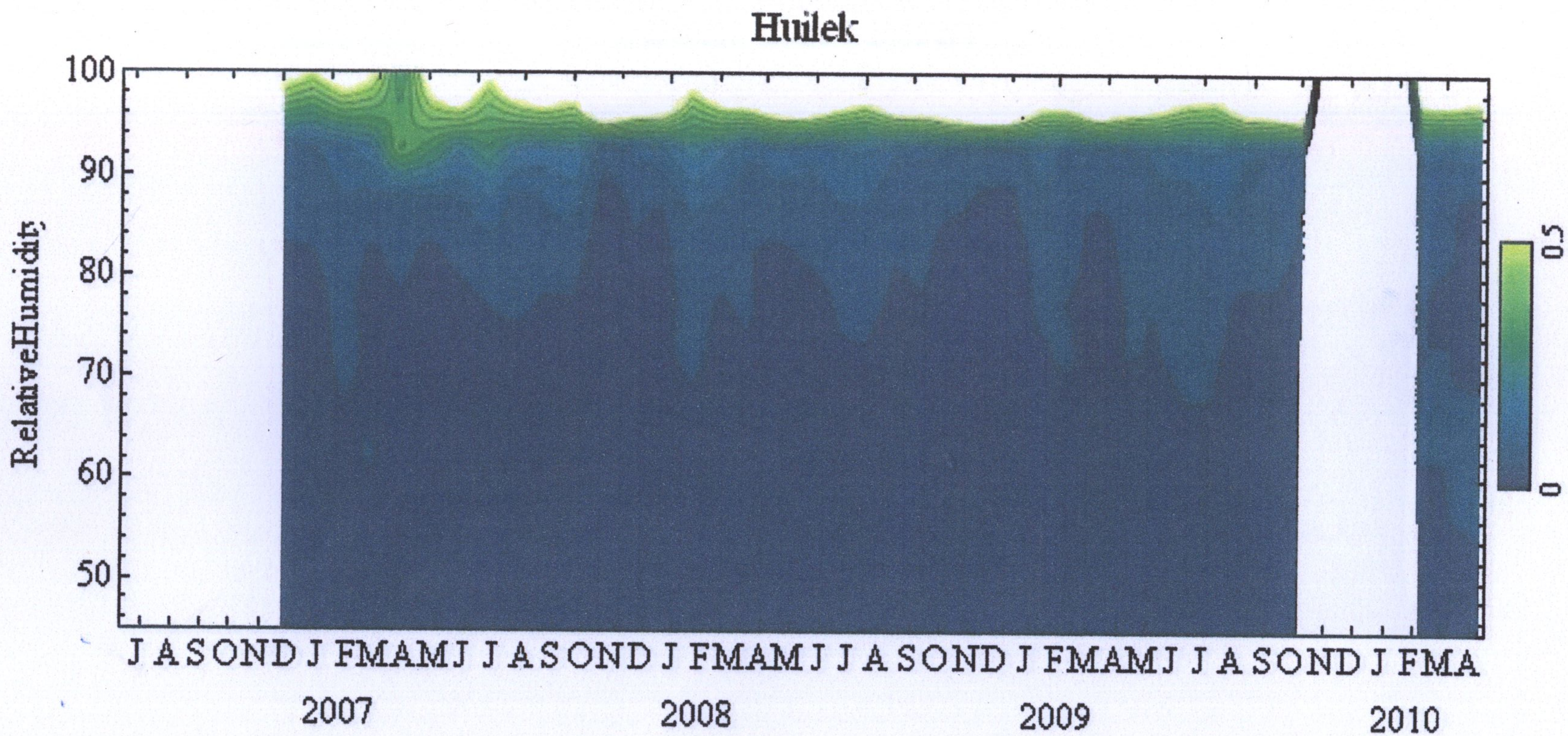

Figure 47 The relative frequency of % RH distribution of Huilek study site.

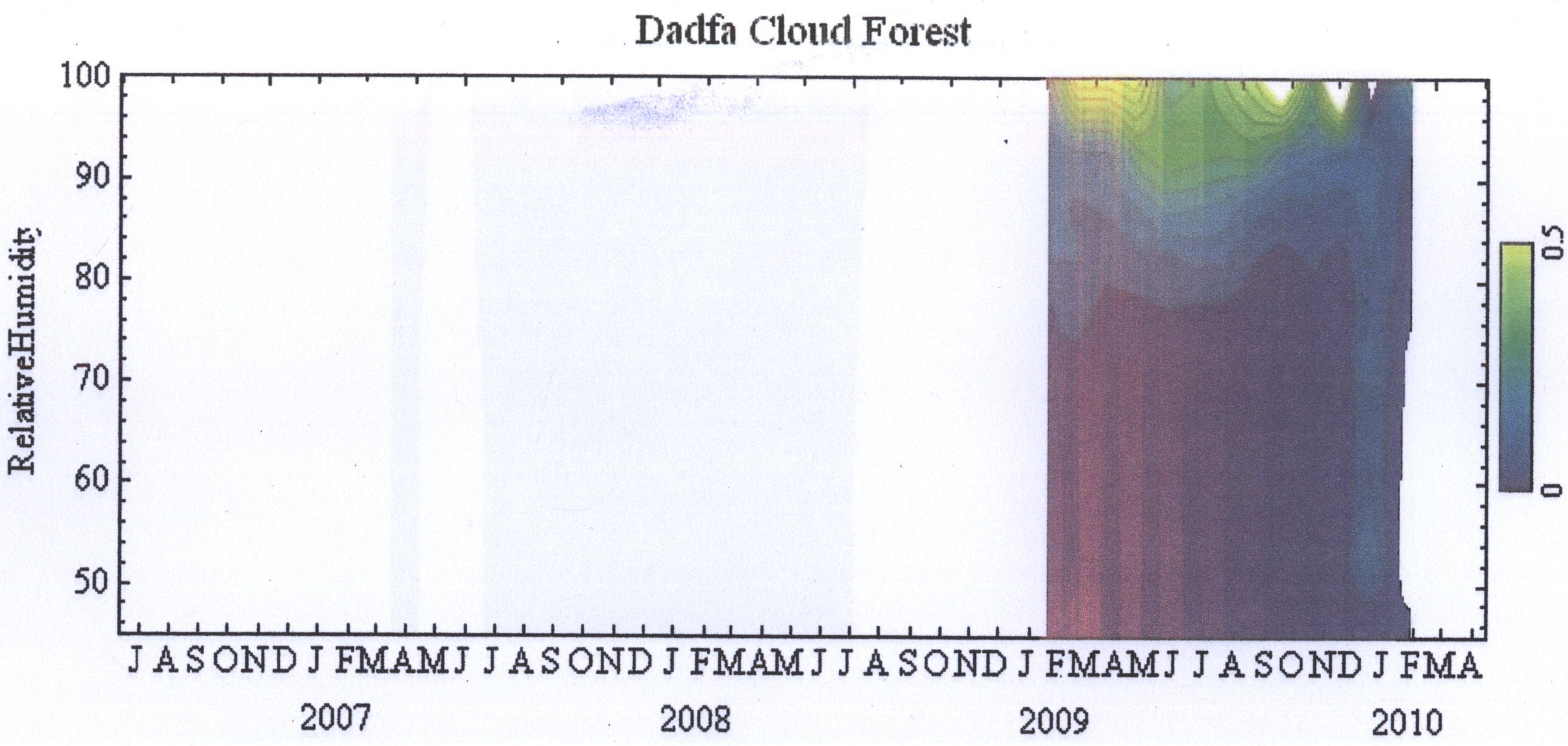

Figure 48 The relative frequency of % RH distribution of Dadfa Cloud Forest study site.

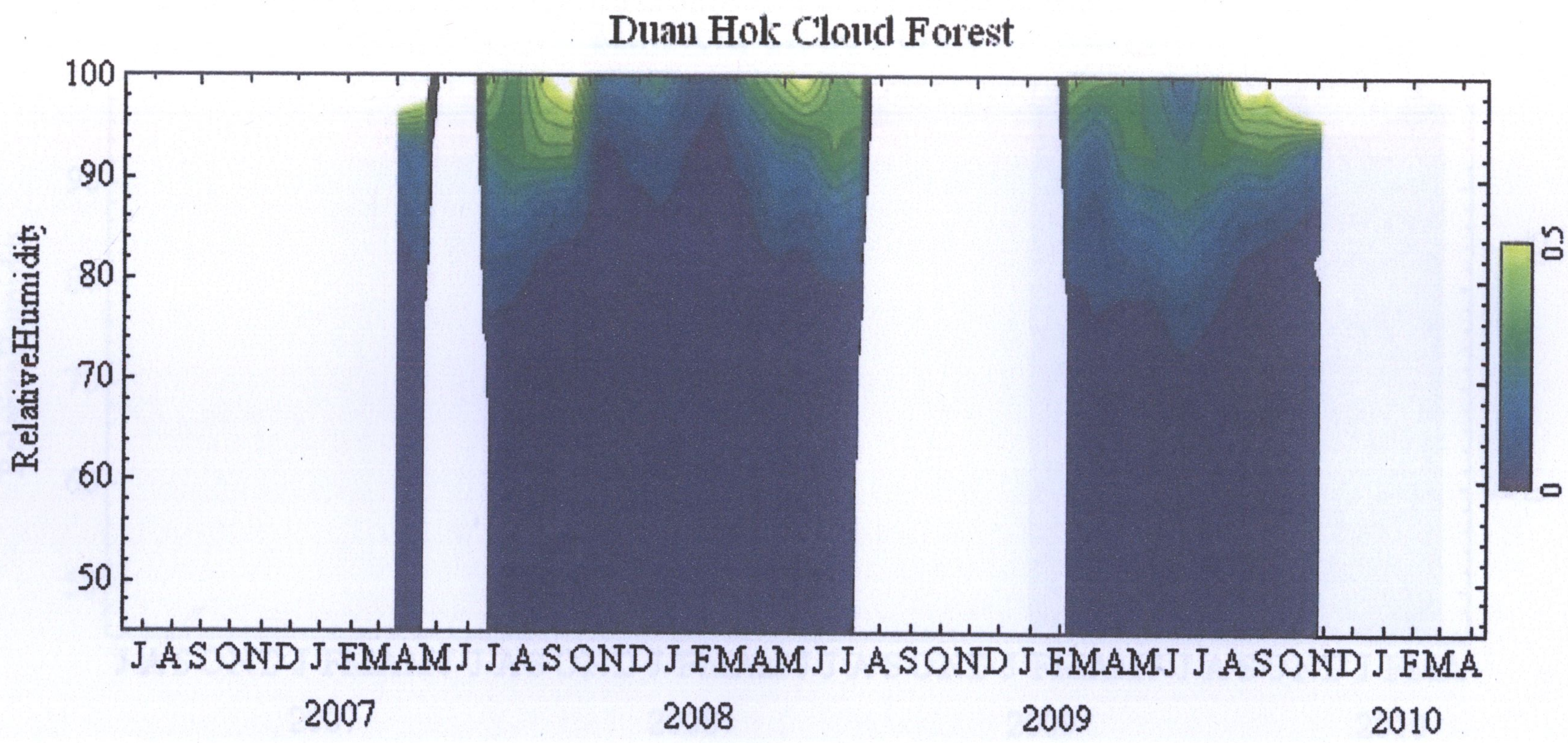

Figure 49 The relative frequency of % RH distribution of Duan Hok Cloud Forest study site.

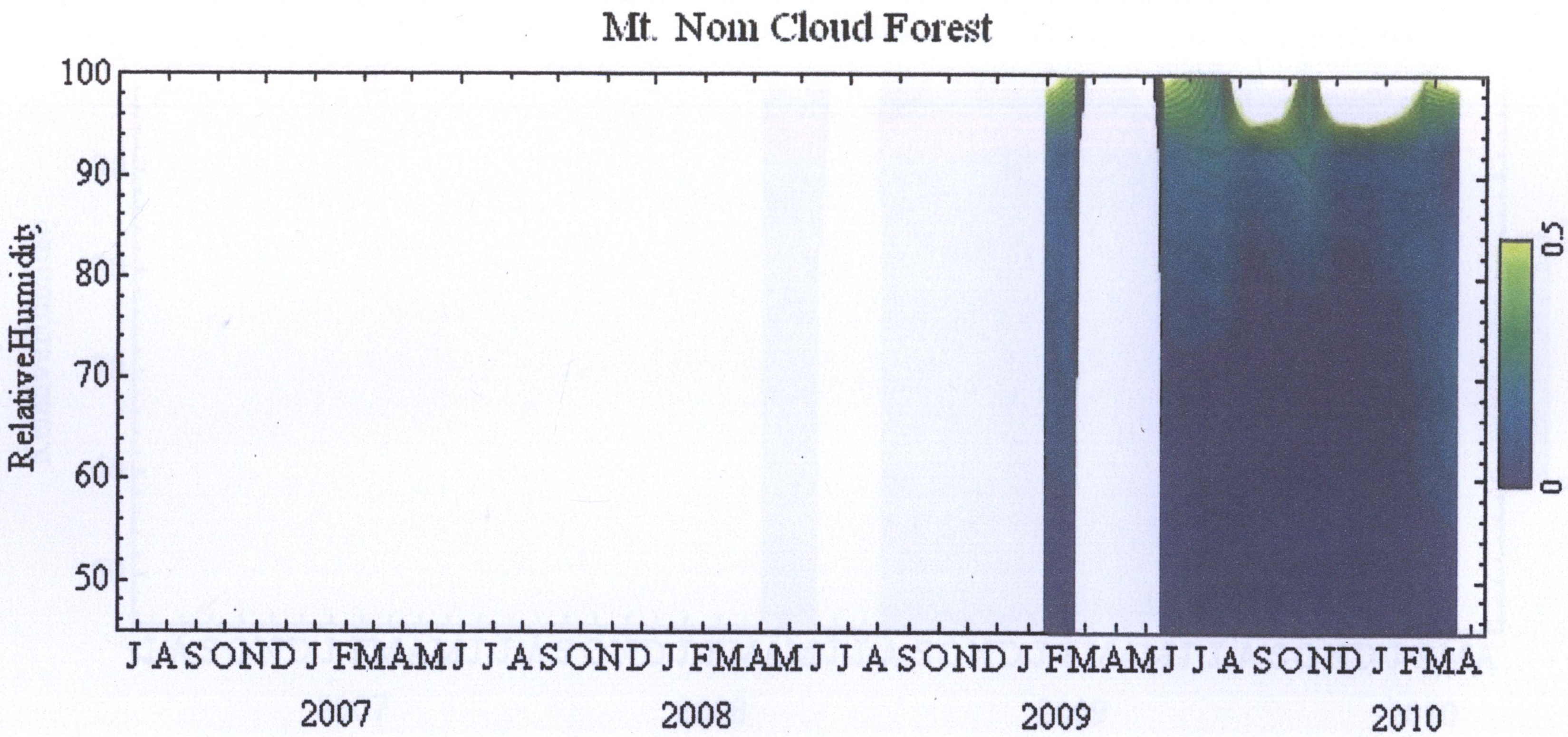

Figure 50 The relative frequency of % RH distribution of Mt. Nom Cloud Forest study site.

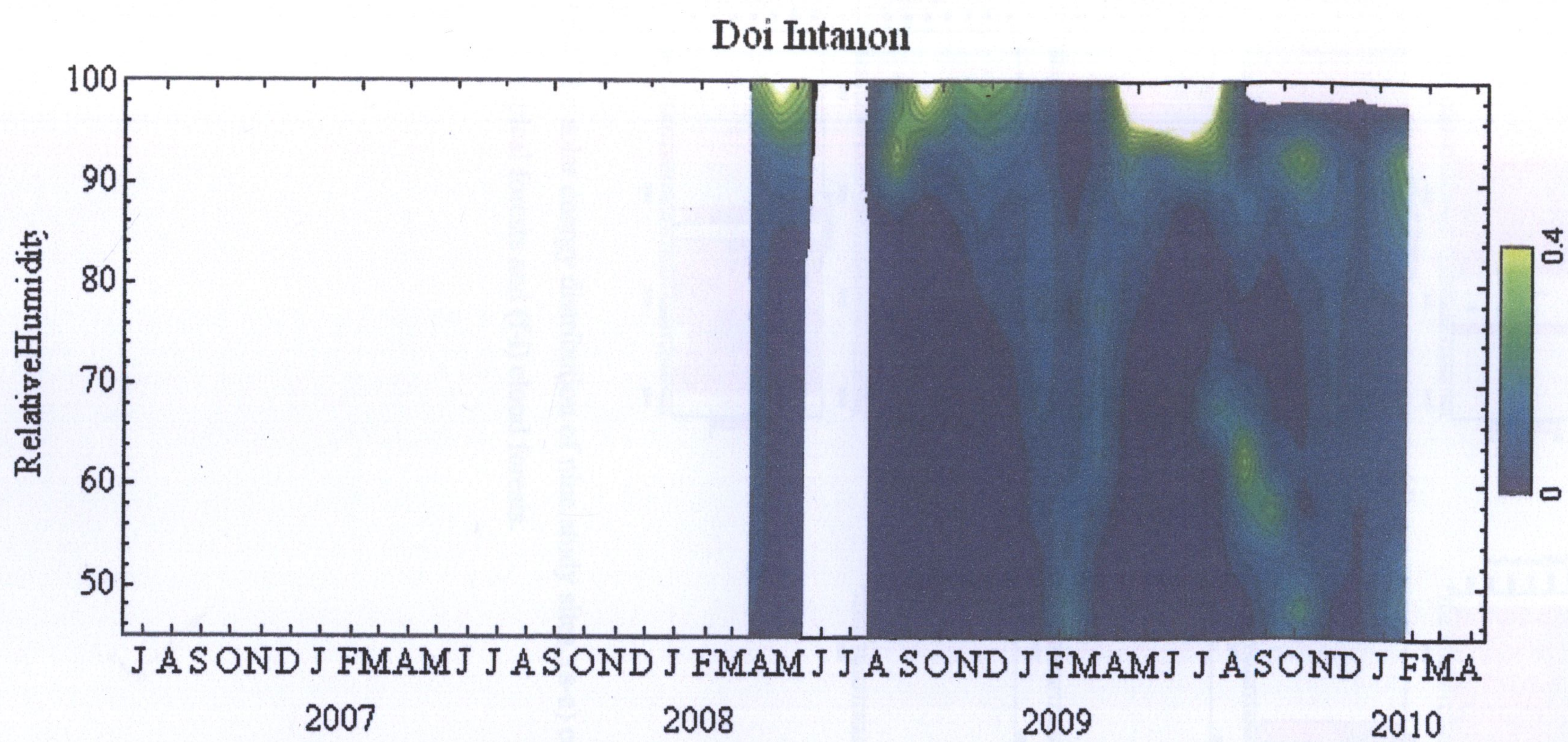

Figure 51 The relative frequency of % RH distribution of Doi Intanon study site.

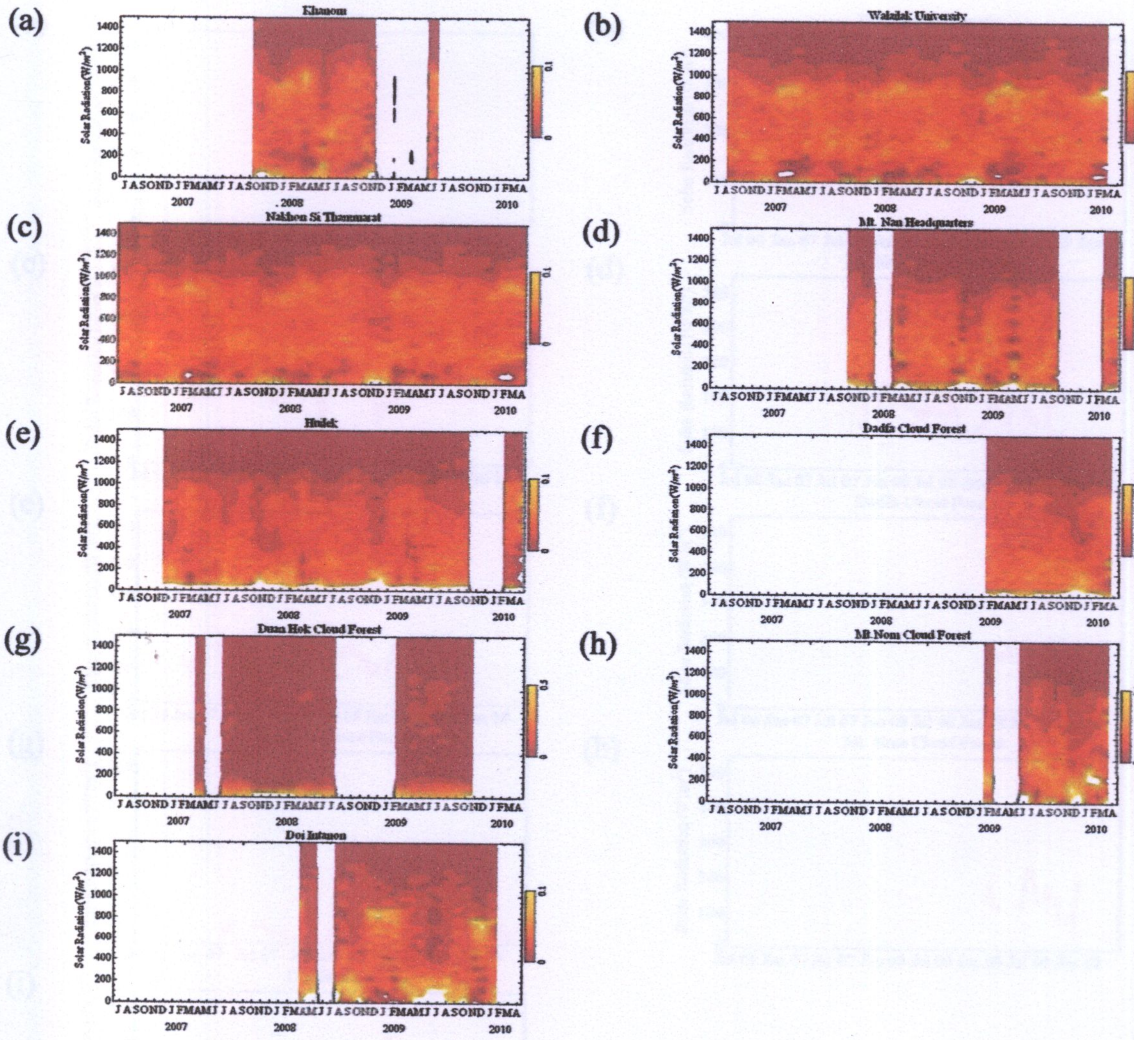

Figure 52 The solar energy distribution of nine study sites. (a-c) coastal sites, (d-e) tropical forests and (f-i) cloud forests.

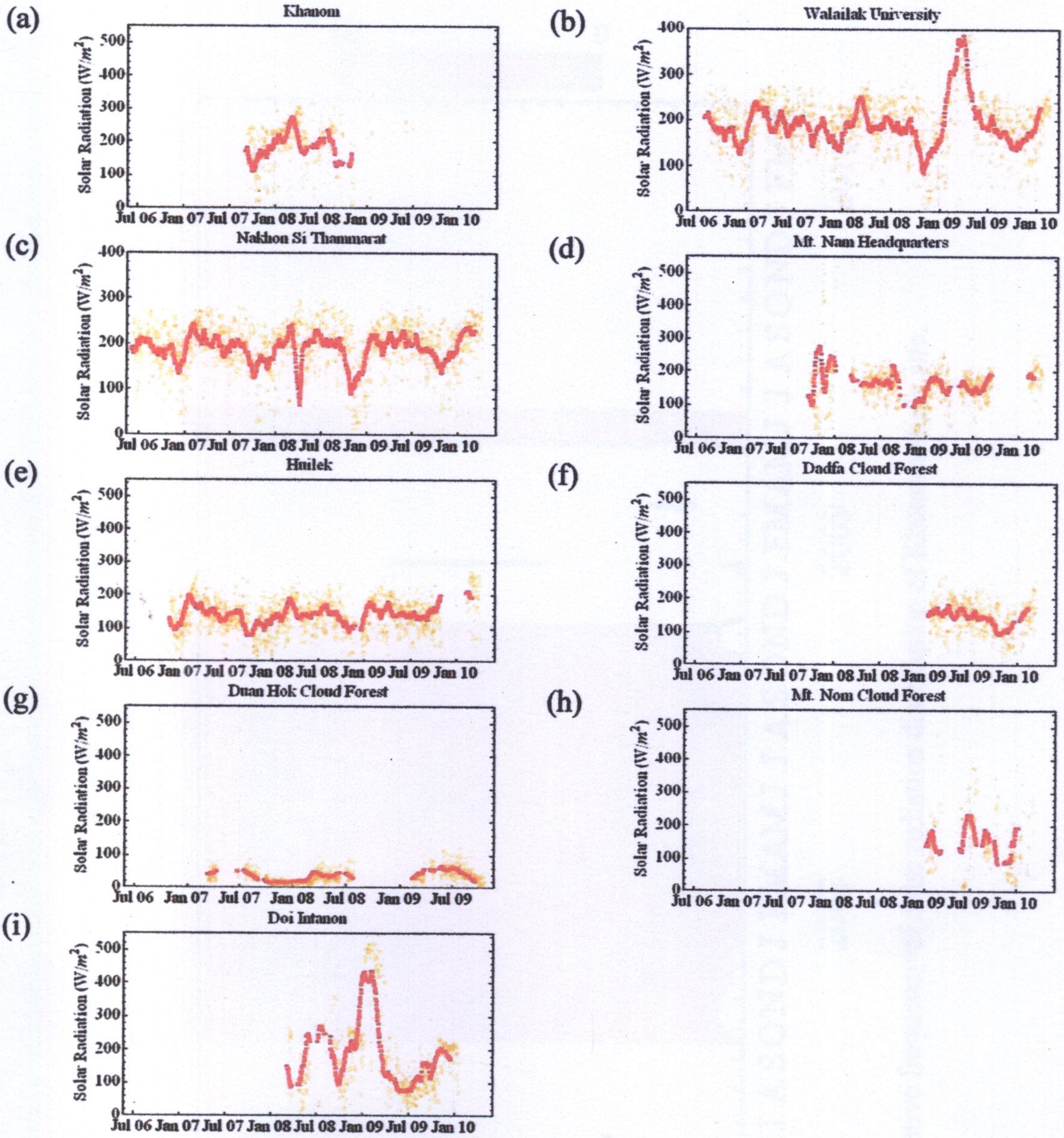

Figure 53 The solar energy distribution of nine study sites. (a-c) coastal sites, (d-e) tropical forests and (f-i) cloud forests.

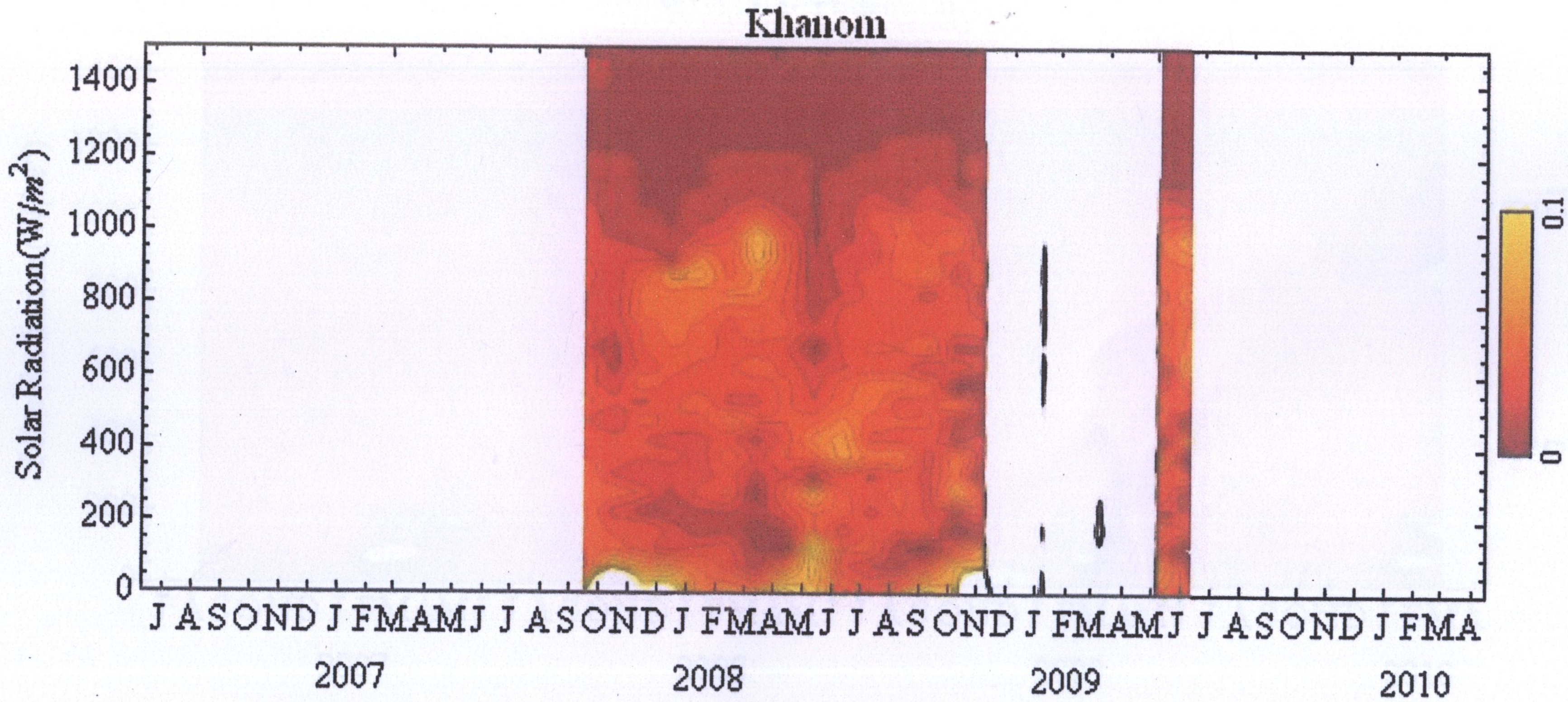

Figure 54 The relative frequency of solar radiation distribution of Khanom study site.

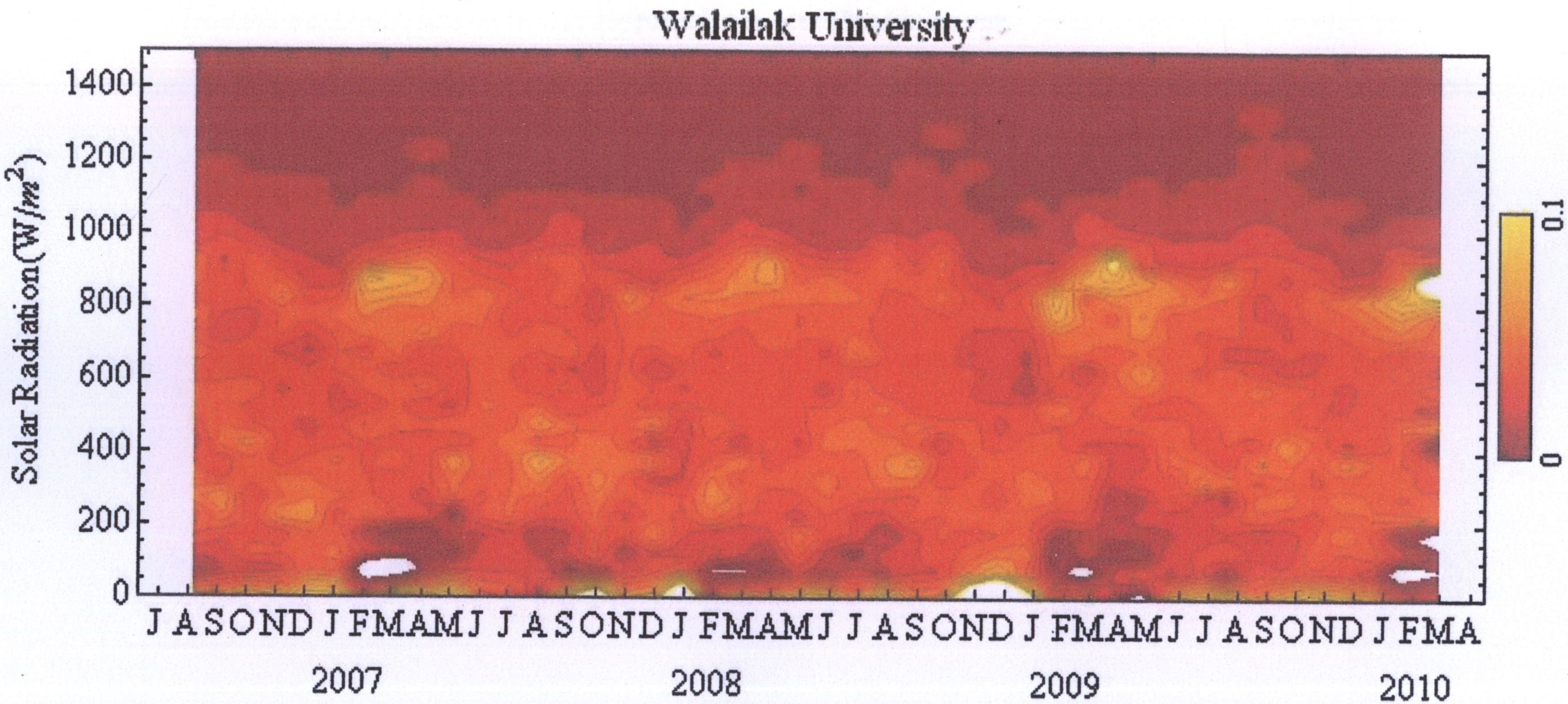

Figure 55 The relative frequency of solar radiation distribution of Walailak University study site.

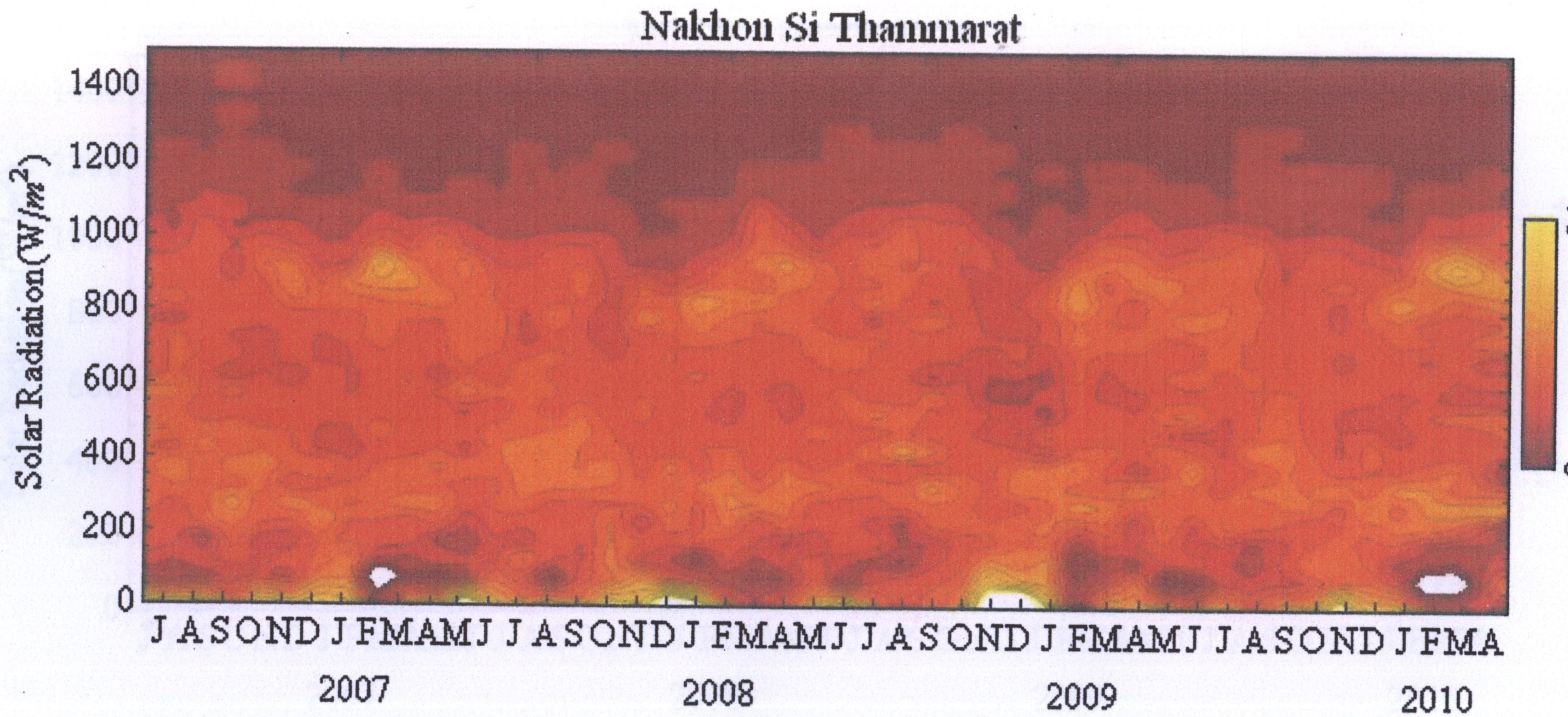

Figure 56 The relative frequency of solar radiation distribution of Nakhon Si Thammarat study site.

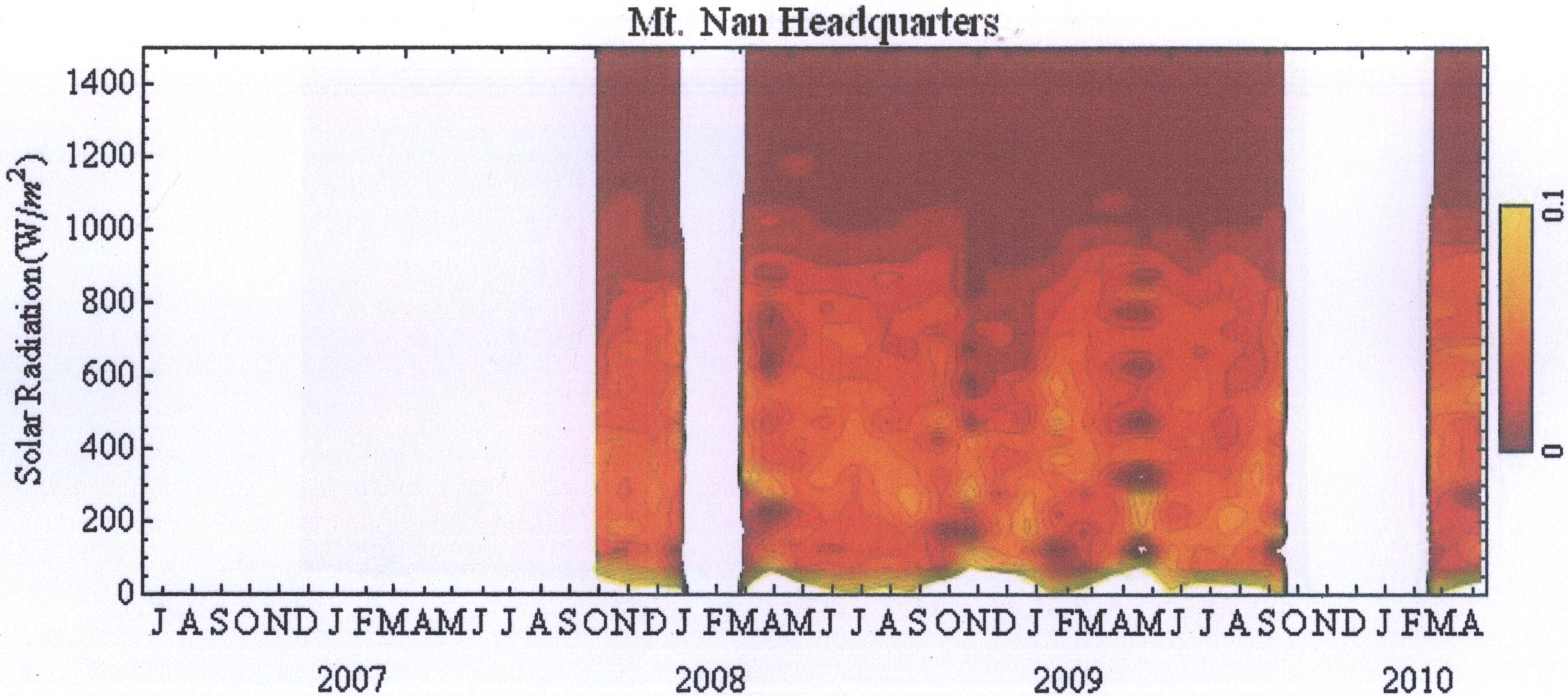

Figure 57 The relative frequency of solar radiation distribution of Mt. Nan Headquaters study site.

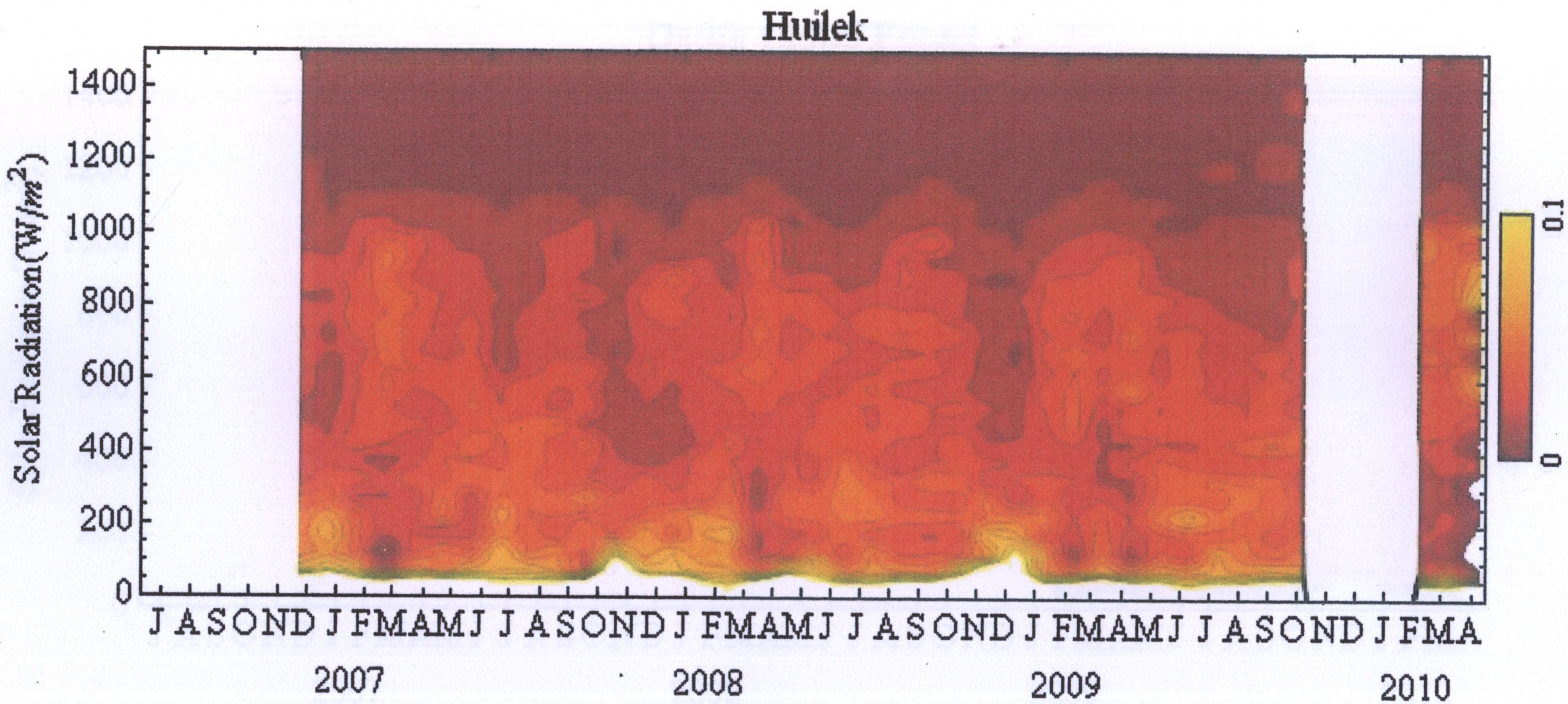

Figure 58 The relative frequency of solar radiation distribution of Huilek study site.

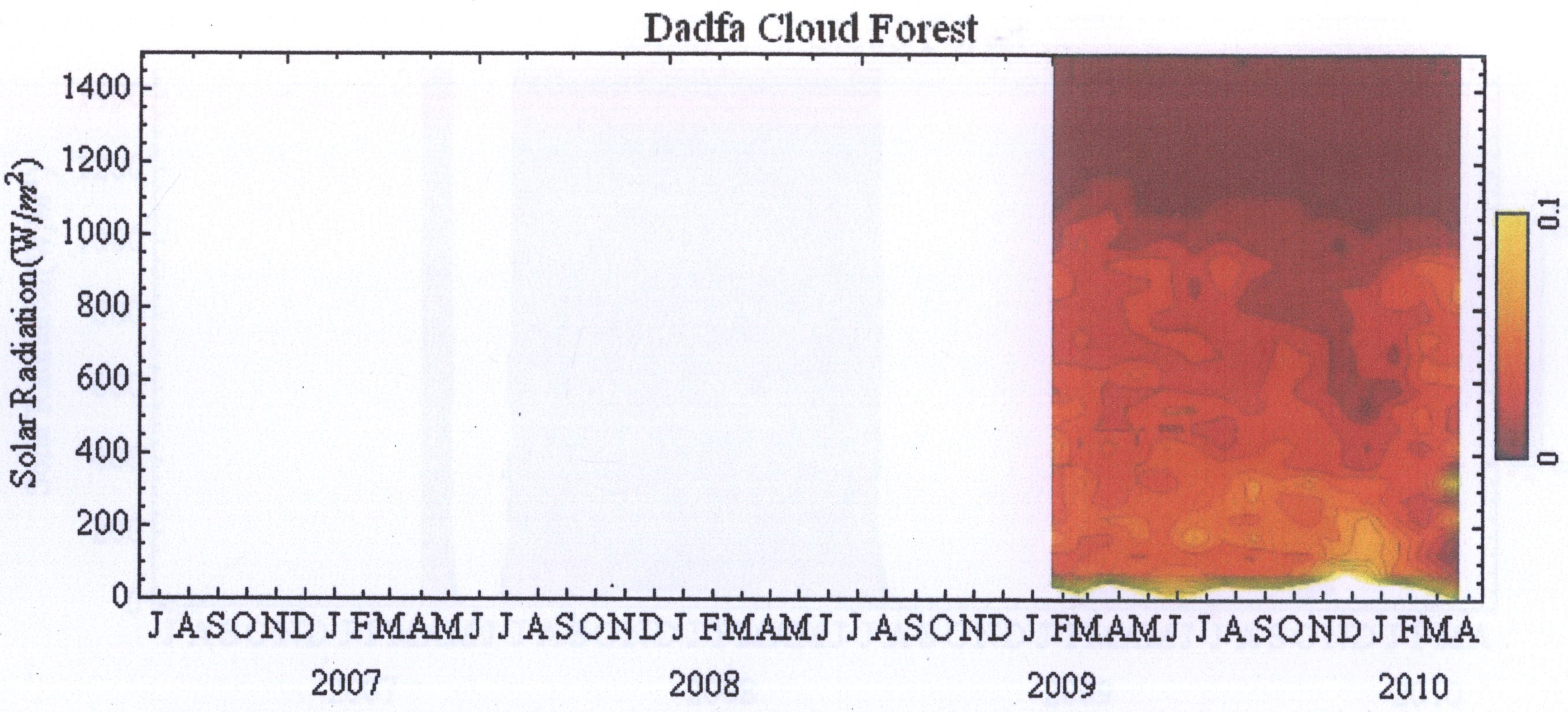

Figure 59 The relative frequency of solar radiation distribution of Dadfa cloud forest study site.

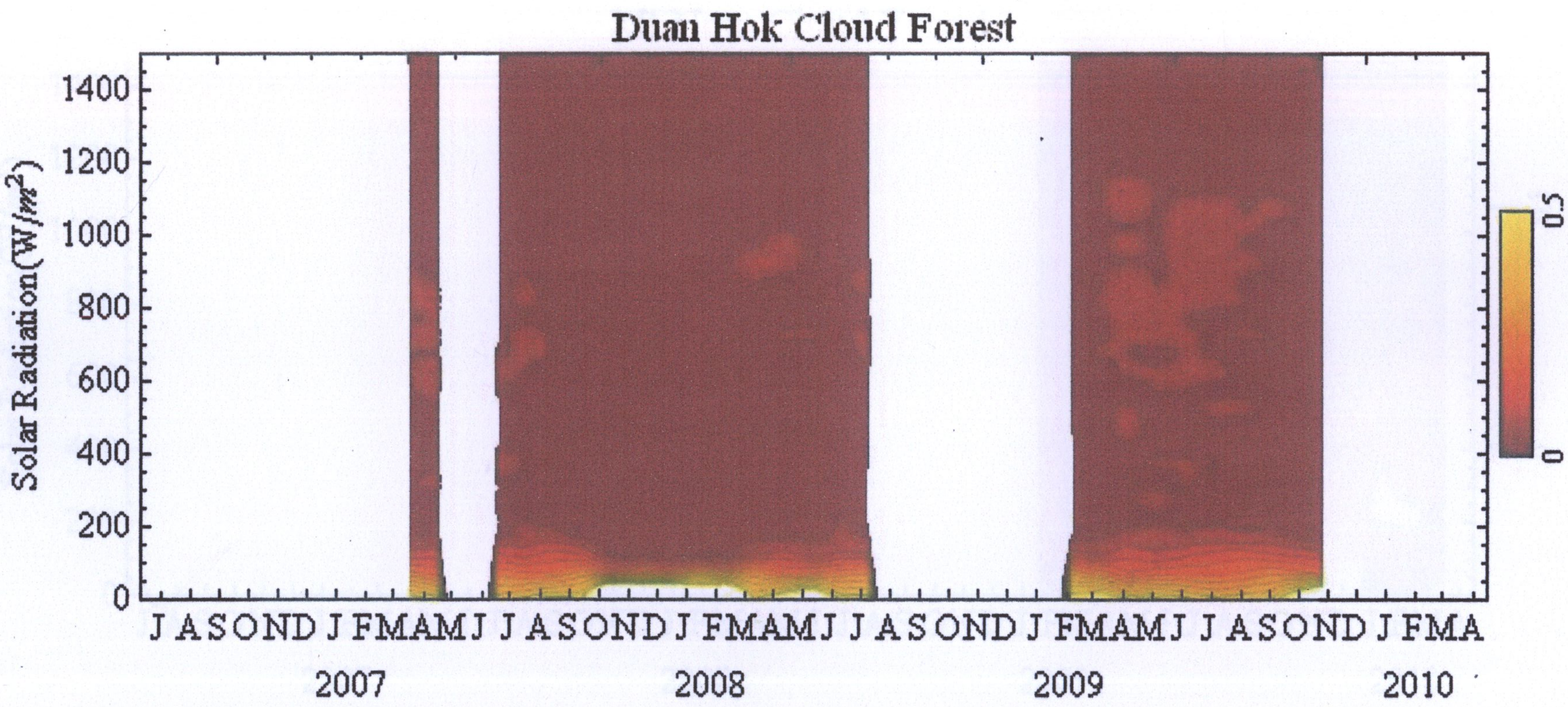

Figure 60 The relative frequency of solar radiation distribution of Duan Hok cloud forest study site.

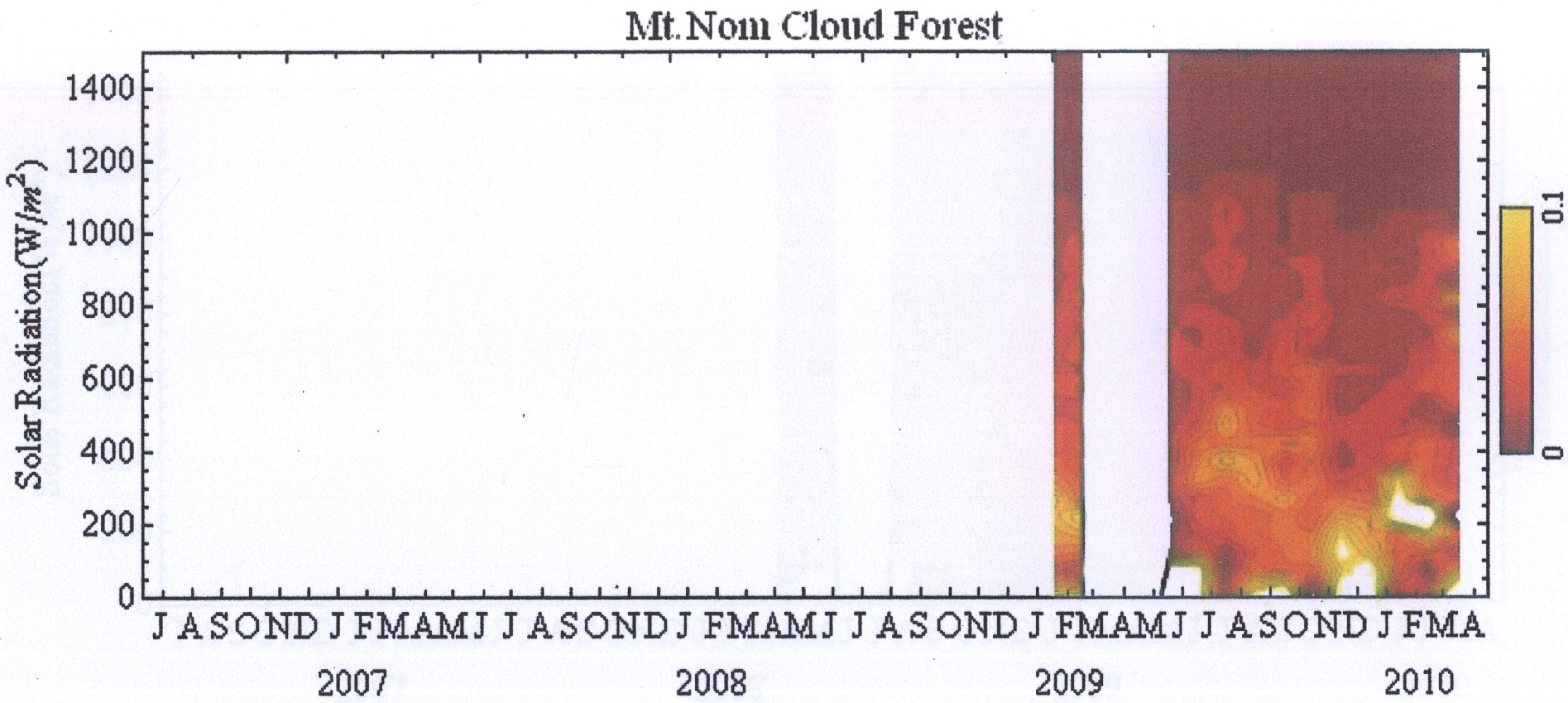

Figure 61 The relative frequency of solar radiation distribution of Mt. Nom cloud forest study site.

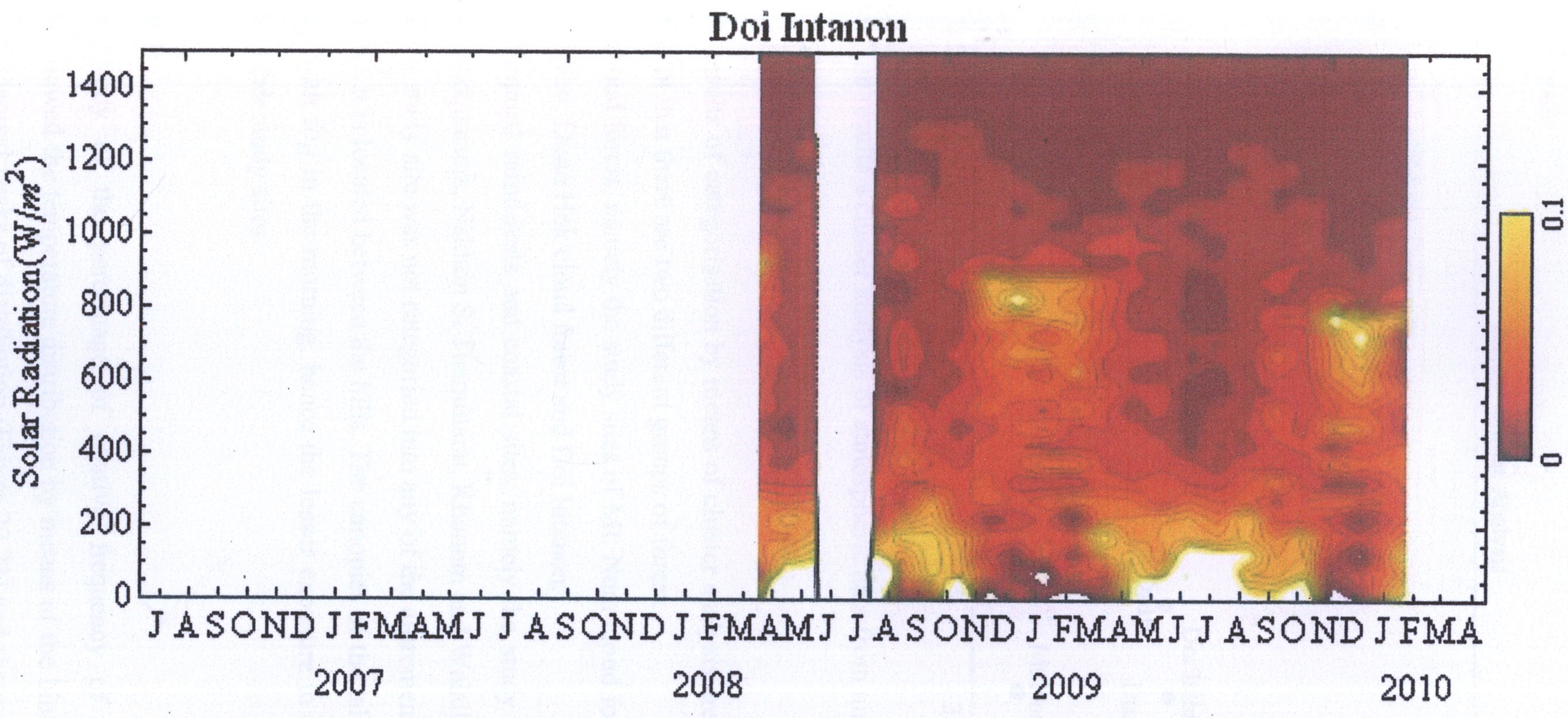

Figure 62 The relative frequency of solar radiation distribution of Doi Intanon study site.

Cluster Analysis

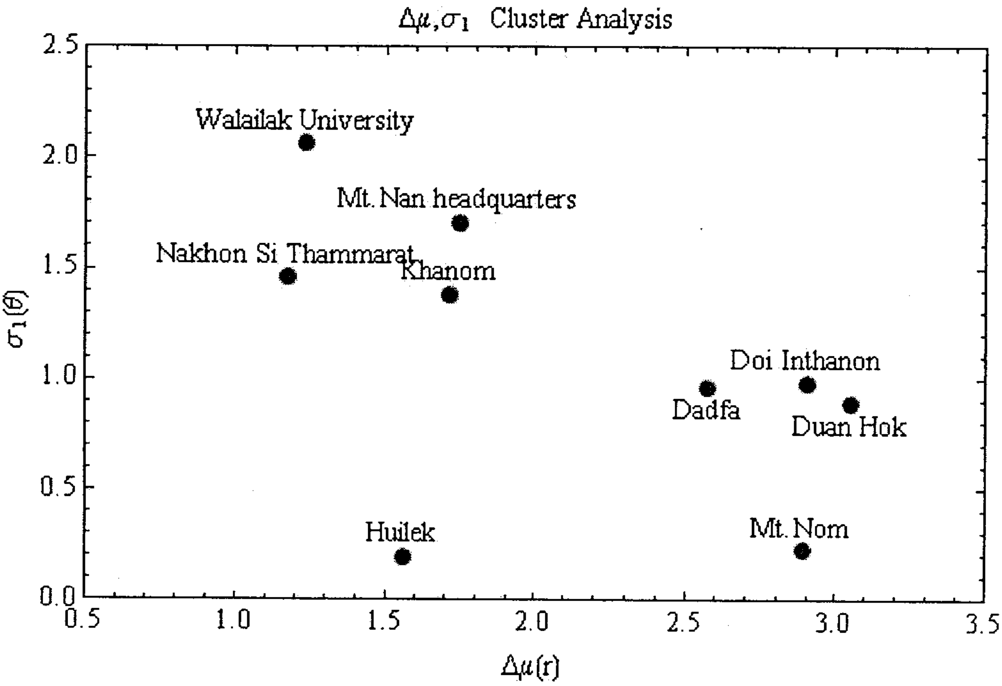

Figure 63 The results a cluster analysis of atmospheric data from nine automatic weather station.

The results of categorisation by means of cluster analysis are shown in Figure 55. It is evident that there are two different groups of forest:

1. Cloud forest, namely the study sites of Mt. Nom cloud forest, Dadfa cloud forest, Duan Hok cloud forest and Doi Intanon.
2. Tropical rainforests and coastal sites, namely the study sites of Mt. Nan headquarters, Nakhon Si Thammarat, Khanom and Walailak University.

Huilek study site was not categoried into any of the aforementioned groups for the reason that it is located between the hills. The canopies of the tall trees in this site are covered with fog in the morning, hence the lesser exposure to the sunlight than those in the other study sites.

Discussion

The study of the percentage of relative frequency of the temperature distribution showed the temperature distribution by means of the bimodal distribution made two overlapped peaks of distribution (Figure 22,23) and that was real and more accurate than the use of normal distribution that was aimed at studying the temperature distribution.

When the atmospheric data were plotted on a three-dimensional graph, the relative frequency of the temperature distribution are shown in Figure 25, which indicated that the temperature distribution varied with the season. The low temperature distribution normally is from November to February in each study site. This is congruent with Doi Intanon study site, of which the relative frequency of the temperature distribution is 8 °C in winter (Figure 22). By comparison with the relative frequency of the temperature distribution at Doi Intanon study site, that of the southern part of Thailand is not very different.

Base on the graphs (Figure 25a,b,c), the study sites of Khanom, Walailak University and Nakhon Si Thammarat have a wider range of the temperature distribution than the others when compared with μ_1, and μ_2 (Figure 25a,25b,25c). This resulted from the coastal study sites. Since the study sites of Mt. Nan and Huilek are located in the tropical forest, the range of the temperature distribution is limited. The study sites of Mt. Nom, Dadfa and Doi Intanon have the leaset range of the temperature distribution because they are cloud forests (Figure 22i-f, 25i-f). As for Doi Intanon, it is located on the high mountain far from the equater and is affected by North-Eastern monsoon, hence there are these peaks of the temperature distribution of which the relative frequency is 0.04 and μ is 8.0 (Figure 22i, 25i).

The temperature distribution varying differently with the season indicates the fluctuating nature of weather. For example, at Walailak University study site, there was the high rate of weather variation with the high temperature between February and May 2009 (Figure 27).

Similarly, it is evident that the weather variation at Walailak University and Nakhon Si Thammarat study sites has been fluctuating since January 2010 (Figure 27,28).

Our results show that Dadfa cloud forest had slightly higher temperature than Mt. Nom and Duan Hok cloud forests. This could be due to the fact that Dadfa cloud forest was located near coastal area at low elevation (i.e. 700 m a.s.l). On small tropical islands, TMCFs can be found at lower altitudes. TMCFs obtain more moisture from deposited fog water in addition to precipitation (Bruijnzeel and Proctor, 1995; Still et al., 1999; Weathers, 1999).

Our study showed that Mt. Nom, Duan Hok and Dadfa cloud forest had σ_1 less than 1. This indicates the spike curve on the modal 1 and can be used as an indicator of cloud forest located near the equator. On the other hand, this could not be applied to high latitude cloud forest like Doi Intanon because in Winter (November to February) the temperature was lower than the other month (Figure 25i). The first peak of relative frequency in figure 22i was 8 degree Celsius and the second peak was 12.7 degree Celsius that was the mean temperature in rainy season and the third peak was showed the mean temperature in summer (Figure 25i).

Our results indicate that the temperature distribution of Kanom, Walailak University and Muang Nakhon Si Thammarat weather stations were similarly because they were located near coastal areas with the elevation of 8 m a.s.l.. The temperature distribution of Mt. Nan Headquarters and Hui Lek weather stations were similarly because they were located at tropical rain forest with the elevation of 200 m a.s.l. The temperature distribution of Mt. Nom, Duan Hok, and Dadfa weather stations were similarly because they were located at cloud forest with the elevation above 700 m a.s.l. The temperature distribution of Doi Intanon weather station was different from the rest because it was located at high latitude cloud forest with the elevation above 1300 m a.s.l.

Our results show that the relative frequency of the first peak at Doi Intanon was approximately 0.04 and the second peak of 0.23. This low first peak at Doi Intanon could be due to the fact that Doi Intanon had the winter period which had lower temperature than the rest. However, the relative frequency at the second peak was higher than 0.20. This indicates that cloud forest temperature distribution should exhibit the relative frequency of a shape peak more than 0.20.

Our results show that the distributions of cloud forest sites had two marked. This bimodalilty might be due to the interference of the annual cycle: summer and rainy seasons. The summer peak is shorter than the rainy season peak because rainy season peak is less variable than summer weather. Cloud forest with saturated fog and lower temperature occurs during rainy season peak.

Conclusion

Bimodal distribution of temperature can be used as to separate forest types. From nine study sites, the mean and variance of the bimodal distribution can group them into two classes: (1) four cloud forest sites (Duan Hok, Dadfa, Mt. Nom, and Doi Intanon stations), (2) two tropical forests (Huilek and Khao Nan headquarters stations) and three coastal sites (Walailak University, Khanom and Muang Nakhonsithammarat stations). We can use the data from field sensors to analyse the weather variation and climate change. In this study, we use the relative frequency of temperature, relative humidity and solar radiation distribution to better understand the fluctuating nature of weather.

Acknowledgements

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Chapter VI

Cloud Forest Climatic Characteristics of Tropical Montane Cloud Forest at Mt. Nan, Thailand

Abstract

This study investigated the climatic characteristics of the tropical montane cloud forest in Southern Thailand that located at the elevation 700 to 1300 m.a.s.l. We compared the climatic characteristics of cloud forest and rain forest at Mt. Nan National Park in Nakhon Si Thammarat province with Doi Intanon cloud forest as the elevation 2200 m.a.s.l.in Northern Thailand. We installed automatic weather stations at four study sites: Mt. Nom cloud forest the elevation 1300 m.a.s.l., Dadfa cloud forest the elevation 700 m.a.s.l., Mt. Nan Headquarters the elevation 180 m.a.s.l. and Doi Intanon cloud forest. The results showed that Doi Intanon cloud forest had the lowest temperature, relative humidity, dew point, heat index, solar radiation, solar energy, UV index than Mt. Nom cloud Forest that was the cloud forest in Southern Thailand. Mt. Nom cloud forest and Doi Intanon cloud forest had highest wind speed and lowest daily rainfall than Dadfa cloud forest and Mt. Nan headquarters.

Keywords: Cloud forest, Climate, Weather station, Thailand

Introduction

Tropical montane cloud forests (TMCFs) are one of the world's most threatened ecosystems due to their high deforestation rate which are greater than all other tropical forests and climatic warming (Doumenge et al., 1995; Hamilton et al., 1995; Bruijnzeel and Hamilton, 2000; Bubb et al., 2004; Cayuela et al., 2006; Téllez-Valdés et al., 2006). These TMCFs typically have high levels of endemism, low rates of net primary production and play an essential role in the hydrologic cycles of tropical mountains (Stadtmüller, 1987; Tanner et al., 1990; Bruijnzeel and Proctor, 1995; Grubb, 1995; Foster, 2001). Deforested TMCFs takes centuries to recover due to its slow grow rate. These ecosystems are complex, relatively rare, extremely vulnerable to climate changes and very long-term human impacts (Byer and Weaver, 1977; Scatena, 1995; Foster).

TMCFs occur in mountainous altitudinal band frequently enveloped by orographic clouds (Bruijnzeel and Proctor, 1995; Still et al., 1999). This forest obtains moisture from deposited fog water in addition to bulk precipitation (Foster, 2001; Weathers, 1999; Chang et al., 2002). The main climatic characteristics of cloud forests include frequent cloud presence, usually high relative humidity and low irradiance (Foster). TMCFs typically occur at elevations between 1,500 to 3,300 m a.s.l., occupying an altitudinal belt of approximately 800 to 1,000 m at each site. The lowermost occurrence of low-statured cloud forest (300–600 m a.s.l.) is reported from specific locations like small islands, were the cloud base may be very low and the coastal slopes are exposed to both, high rainfall and persistent wind-driven clouds (Bruijnzeel and Proctor). On small tropical islands, such as Puerto Rico, TMCFs can be found at lower altitudes. On average, rainfall in tropical montane cloud forest ecosystems ranges from 500 to 10,000 mm/yr (Wård, 2007).

TMCFs are important in their effects on hydrological balances at regional scales and the biodiversity that they support; tree species richness may be low on tropical mountains but epiphytic abundance and diversity are higher than in other types of forest (Richards, 1984). In montane tropical forests, fog represents an increasingly important water source as rainfall and temperature decrease and relative humidity increases with increasing elevation (Sugden and Robins, 1979; Cavelier and Goldstein, 1989).

Little has been done on climatic factors and their effects on TMCFs in Thailand or south-east Asia in general. The lack of understanding of the cloud forest characteristics make it difficult to predict what the impacts of climate change will be on the cloud forest and its endemic species. This study is the first to investigate the climatic characteristics of TMCFs at Mt. Nam cloud forest, Mt. Nan National Park, Thailand.

Materials and Methods

Mt. Nan National Park is located at latitude 8.76908 °N, longitude 99.80352 °E, and situated at Noppitam sub-district, Thasala district, and Sichon district in Nakon Si Thammarat province, Thailand with an area of 406 km^2. Geographical characteristics of Mt. Nan National Park is a high mountainous range in the North-South direction which is a part of Nakhon Si Thammarat mountain range. The forest at Mt. Nan National Park is a tropical mountain forest which is an important watershed source of Nakhon Si Thammarat province. More than 90% of Mt. Nan National Park still is a primary tropical evergreen forest that is a main watershed source and a home for various species of endangered species.

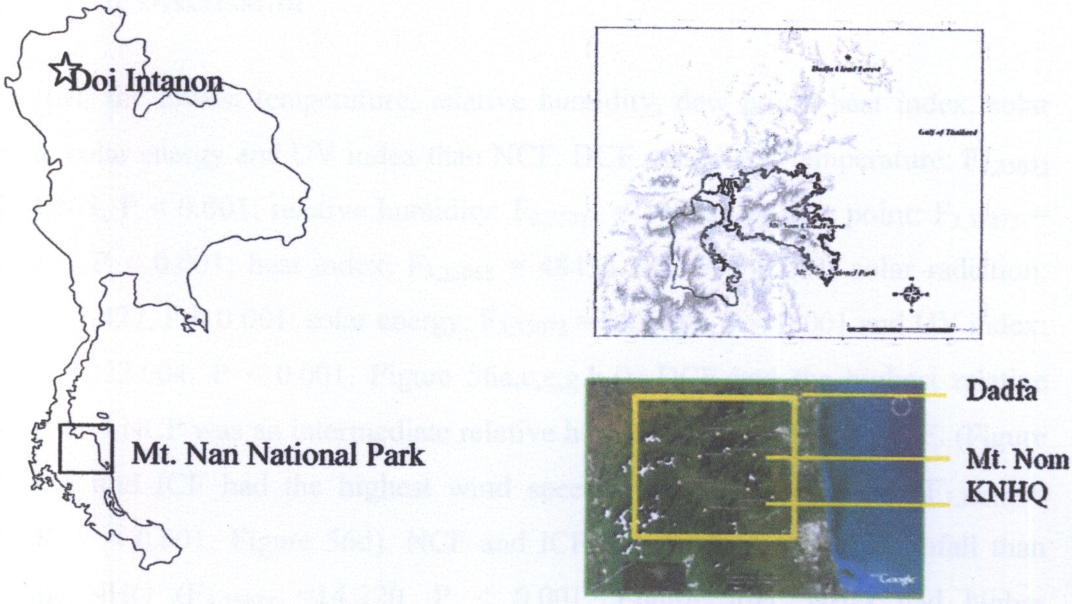

Figure 64 Study sites: Mt. Nom cloud forest, Dadfa cloud forest, Mt. Nan Headquarters and Doi Intanon cloud forest where the automatic weather stations were installed. Black line represents Mt. Nan National

We installed Davis weather stations model Vantage Pro II Plus to collect climatic data every 30 min at three locations: Mt. Nom cloud forest (NCF), Dadfa cloud forest (DCF), Mt. Nan Head Quarter (NHQ) and Doi Intanon cloud forest (ICF). NCF was located at latitude 8.48698 °N longitude 99.45000 °E, and elevation 1,274 m a.s.l. (Figure 16). NHQ was located at latitude 8.76908 °N longitude 99.80352 °E, and elevation 182 m a.s.l. (Figure 56). DCF was located at latitude 9.125360 °N, longitude 99.825531 °E, and elevation 680 m a.s.l. (Figure 56). Davis weather stations were collected nine climatic data: air temperature, relative humidity, dew point, wind speed, heat index, daily rainfall, solar radiation, solar energy and UV index. Climatic data at these three sites were collected during 16 January to 23 September 2009.

Parametric statistics tests were used when underlying assumptions were met. One-way ANOVA and Bonferroni post-hoc tests were used to test climate factor differences among NCF, DCF NHQ and ICF. Linear regressions were used to test the association between temperature and relative humidity at NCF, DCF,NHQ and ICF. All significant tests were two-tailed.

Results and Discussion

ICF had the lowest temperature, relative humidity, dew point, heat index, solar radiation, solar energy and UV index than NCF, DCF and NHQ (temperature: $F_{3,35073} = 56713.408$, $P < 0.001$; relative humidity: $F_{3,35073} = 1120.220$, dew point: $F_{3,35073} = 76093.803$, $P < 0.001$; heat index: $F_{3,35065} = 48432.288$, $P < 0.001$; solar radiation: $F_{3,35073} = 37.427$, $P < 0.001$; solar energy: $F_{3,35073} = 683.184$, $P < 0.001$ and UV index: $F_{3,35072} = 1022.004$, $P < 0.001$, Figure 56a,c,e,g,h,i). DCF had the highest relative humidity, and NCF was an intermediate relative humidity than NHQ and ICF. (Figure 56b). NCF and ICF had the highest wind speed than DCF and NHQ ($F_{3,35073} = 5898.768$, $P < 0.001$, Figure 56d). NCF and ICF had the lowest daily rainfall than DCF and NHQ ($F_{3,35073} = 14.220$, $P < 0.001$, Figure 56f). NHQ had higher evapotranspiration than DCF, NHQ and ICF ($F_{3,35001} = 65.388$, $P < 0.001$, Figure 56j).

NCF fog free day

$$RH_{ncf} = 3.92(44.14 - T_{ncf}) \quad ; (T_{ncf} > 18.63) \qquad (4)$$
$$RH_{ncf} = 100 \quad ; (T_{ncf} \leq 18.63)$$

NCF fog bound day

$$RH_{ncf} = 43.52(20.01 - T_{ncf}) \quad ; (T_{ncf} > 17.71) \qquad (5)$$
$$RH_{ncf} = 100 \quad ; (T_{ncf} \leq 17.71)$$

DCF fog free day

$$RH_{dcf} = 3.78(48.31 - T_{dcf}) \quad ; (T_{dcf} > 21.85) \qquad (6)$$
$$RH_{dcf} = 100 \quad ; (T_{dcf} \leq 21.85)$$

DCF fog bound day

$$RH_{dcf} = 22.58(25.76 - T_{dcf}) \quad ; (T_{dcf} > 21.33) \qquad (7)$$
$$RH_{dcf} = 100 \quad ; (T_{dcf} \leq 21.33)$$

Nan Head Quarter

$$RHnhq = 4.23(47.63 - Tnhq) \quad ; (Tnhq > 23.97) \qquad (8)$$

$$RHnhq = 100 \quad ; (Tnhq \leq 23.97)$$

ICF fog free day

$$RHicf = 15.45(19.62 - Ticf) \quad ; (Ticf > 13.14) \qquad (9)$$

$$RHicf = 100 \quad ; (Ticf \leq 13.14)$$

ICF fog bound day

$$RHicf = 159.47(10.62 - Ticf) \quad ; (Ticf > 9.99) \qquad (10)$$

$$RHicf = 100 \quad ; (Ticf \leq 9.99)$$

Where RHncf, RHnhq, RHdcf and RHicf were relative humidity at four study sites and Tncf, Tnhq, Tncf and Ticf were air temperature data at Mt. Nom cloud forest, Mt. Nan Head Quarter and Dadfa cloud forest, respectively.

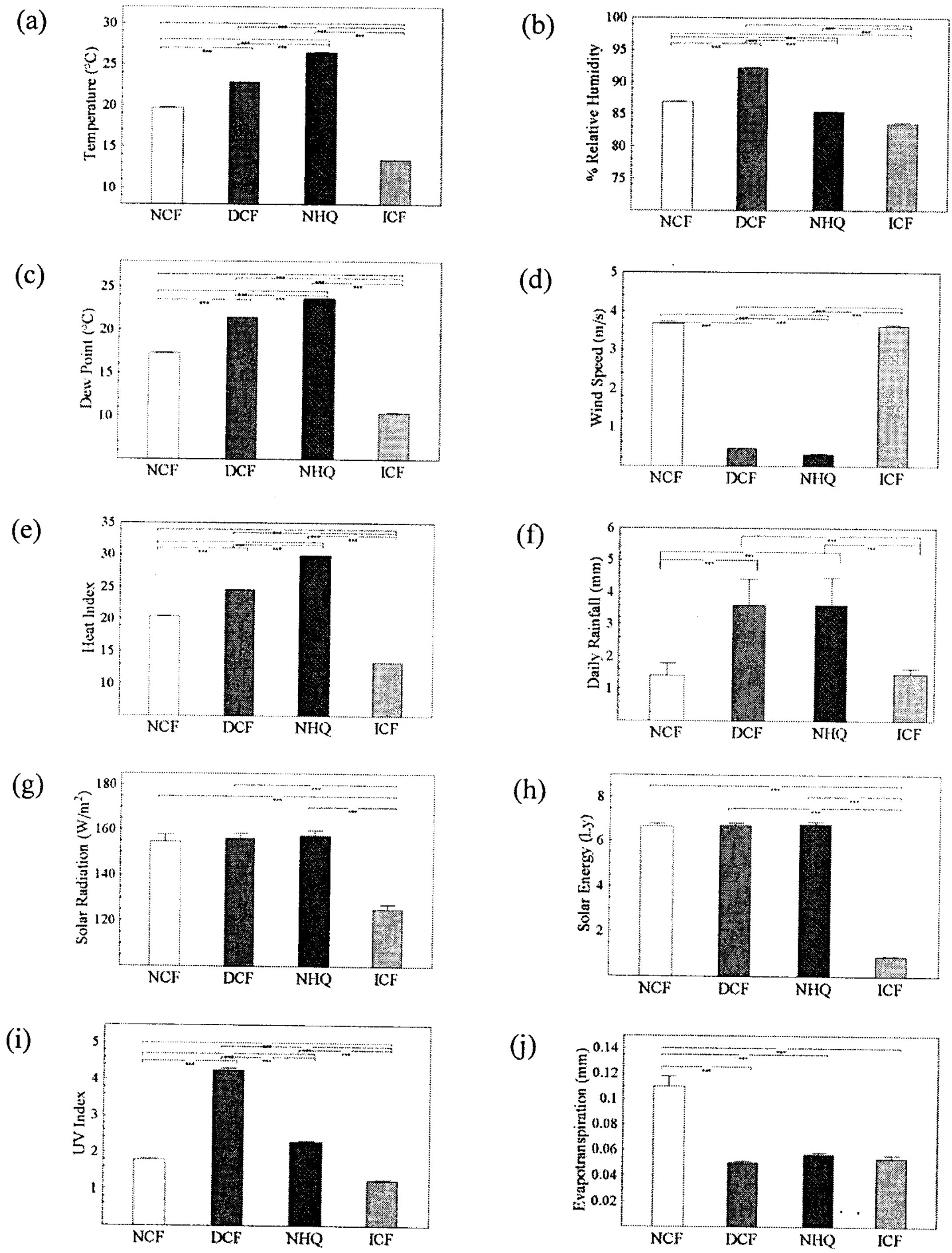

Figure 65 Mean (±SE) of climatic factors at Mt. Nom Cloud Forest (NCF), Dadfa Cloud Forest (DCF), Mt. Nan Head Quarter (NHQ) and Doi Intanon Cloud Forest (ICF). (a) temperature (°C), (b) relative humidity, (c) dew point (°C), (d) wind speed (m/s), (e) heat index, (f) daily rainfall (mm), (g) solar radiation (W/m^2), (h) solar energy (Ly), (i) UV index and (j) evapotranspiration (mm). *P<0.05, **P<0.01, ***P<0.001.

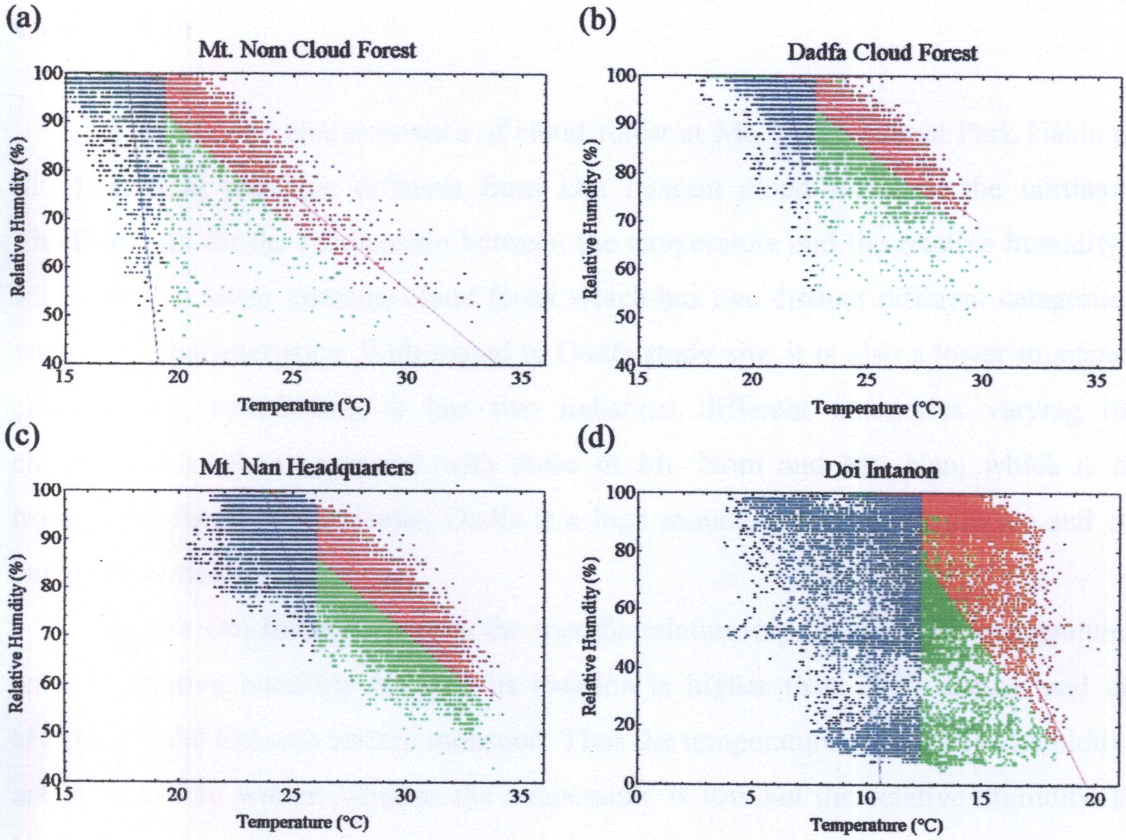

Figure 66 Temperature (°C) and relative humidity at (a) NCF, (b) DCF, (c) NHQ and (d) ICF

Grubb and Whitmore (1966) categorised TMCFs based on temperature and relative humidity data into three day types: fog-bound, fog-free and intermediate days. They defined fog-bound day as having no bright sunshine for at least half the daylight hours and fog-free day as having no fog in the daylight hours and at least 4 hr bright sunshine. Our results support Grubb and Whitmore's (Grubb and Whitmore, 1966) study that TMCFs at NCF and DCF also can be categorised into three day types: fog-free, fog-bound and intermediate days. On the other hand, NHQ cannot be categorised into three day types. This suggests that having fog-bound and intermediate days were one of the main climatic characteristics of TMCFs.

Conclusion

The climatic characteristics of cloud forest at Mt. Nan National Park Nakhon Si Thammarat province different from Doi Intanon cloud forest in the northern Thailand. As for the relationship between the temperature and the relative humidity, Mt. Nom is a lower montane cloud forest which has two distinct different categories varying in characteristics. With regard to Dadfa study site, it is also a lower montane cloud forest; nonetheless, it has two indistinct different categories varying in characteristics when compared with those of Mt. Nom and Mt. Nan, which is a tropical rainforest. In particular, Dadfa is a high mountain located by the sea and is being deforested for agriculture.

As for Doi Intanon, there is the specific relationship between the temperature and the relative humidity because its location is higher than 2000 m.a.s.l. and is affected by the Chinese eastern monsoon. Thus the temperature and relative humidity are quite low in winter, whereas the temperature is low but the relative humidity is high in the rainy season.

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World Congress *Soil Science., Moscow. Genesis, Classification and Geography.*

Appendix

Mathematica Code

Mathematica Code

Import Data

```
workingDirectory = DirectoryName[ToFileName["FileName" /. NotebookInformation[SelectedNotebook[]]]];
SetDirectory[workingDirectory];
Needs["MultivariateStatistics`"];
Needs["BarCharts`"];
temp = FileNames["*.csv"];
tempImport = Import[temp[[1]]];
tempCurrent = Transpose[tempImport];
tempCurrent[[3]];
date = tempImport[[All]] // TableForm;
dateDrop = Drop[date[[1]], {1, 2}];
ac = dateDrop[[All, {1, 2, 3, 4, 5}]];
acc = Select[ac, (#[[3]] =!= "---" && #[[4]] =!= "---" && #[[5]] =!= "---") &];
timeList[fws_] :=
  Flatten[
     {Flatten[{Flatten[StringSplit[#[[{1, 2}]], {"/", ":"}]][[{3}]],
         Flatten[StringSplit[#[[{1, 2}]], {"/", ":"}]][[{2, 1, 4, 5}]], 00}], Drop[#[[All]], {1, 2}]}] & /@ fws;
ac1 = timeList[acc];
```

Data Preparation

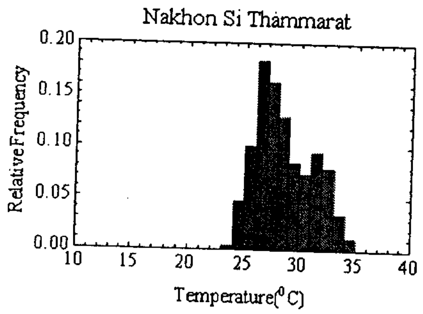
```
FromDate[ToExpression[{#[[1]], #[[2]], #[[3]], 0 * #[[4]], 0 * #[[5]], 0}]] & [ac1[[1]]];
DayStart = ToExpression[{#[[1]], #[[2]], #[[3]], 0 * #[[4]], 0 * #[[5]], 0}] & [ac1[[1]]];
DayEnd = ToExpression[{#[[1]], #[[2]], #[[3]], 0 * #[[4]], 0 * #[[5]], 0}] & [ac1[[-1]]];

FirstPtPlot = {2006, 6, 10, 0, 0, 0};
EndPtPlot = {2010, 4, 15, 0, 0, 0};
PreEmpty = (FromDate[DayStart] - FromDate[FirstPtPlot]) / (24 * 60 * 60);
PostEmpty = (FromDate[EndPtPlot] - FromDate[DayEnd]) / (24 * 60 * 60);

totalDays = (FromDate[DayEnd] - FromDate[DayStart]) / (24 * 60 * 60);

fromDate[x_] := FromDate[ToExpression[{x[[1]], x[[2]], x[[3]], x[[4]], x[[5]], 0}]]
sel30DayData[i_] := Select[ac1, (0.0 ≤ (fromDate[#] - FromDate[DayStart + {0, 0, i, 0, 0, 0}]) ≤ 30 * 24 * 60 * 60) &]

sel30DayData[0];
```

2D Histogram

```
genVis[data_, bW_] := Module[{hData},
  DataPlot = Transpose[data];
  temp = DataPlot[[7]];
  freqto = BinCounts[temp, {10, 40, bW}];
  locationB = Drop[bW / 2 + Table[x, {x, 10, 40, bW}], -1];
  freqdivnto = freqto / Length[temp] // N;
  hData = Thread[List[locationB, freqdivnto, bW]];
  Histo = GeneralizedBarChart[hData, Frame → True, Axes → False, PlotRange → {{10, 40}, {0, 0.2}}]
 ]
```

```
g = genVis[sel30DayData[24], 1];
```

```
HisNKSTTemp = Show[g, FrameLabel → {"Temperature(°C)", "Relative Frequency"}, BaseStyle → {"Times", 14},
  PlotLabel -> " Nakhon Si Thammarat ", ImageSize → 300]
```



3D Interpolation

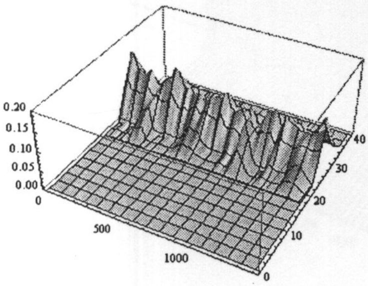
```
genHistI3D[di_, bW_, dW_] := Module[{},
  data = sel30DayData[di];
  locationB = Drop[bW / 2 + Table[x, {x, 0, 40, bW}]];
  If[Length[data] > 0,
   DataPlot = Transpose[data];
   temp = DataPlot[[7]];
   freqto = BinCounts[temp, {0, 40, bW}];
   freqdivnto = freqto / Length[temp] // N;
   l3D = Thread[List[Table[di, {Length[locationB]}], locationB]];
   hData = 1.0 Thread[List[Drop[l3D, -1], freqdivnto, Table[{dW, bW}, {Length[locationB] - 1}]]],
   (* Zero Data Case*)
   locationB = Drop[bW / 2 + Table[x, {x, 0, 40, bW}]];
   freqdivnto = Table[-999, {Length[locationB] - 1}];
   l3D = Thread[List[Table[di, {Length[locationB]}], locationB]];
   hData = 1.0 Thread[List[Drop[l3D, -1], freqdivnto, Table[{dW, bW}, {Length[locationB] - 1}]]]
  ]
 ]
```

```
xT = Table[genHistI3D[i, 1, 1], {i, 1, totalDays, 30}];
xTf = Flatten[xT, 1];
```

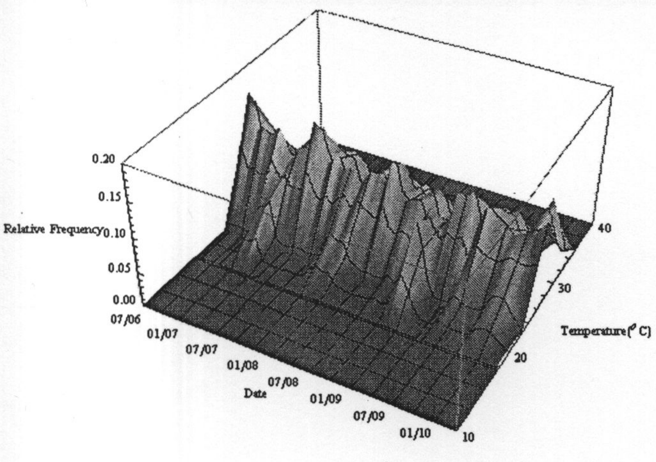
```
GeneralizedBarChart3D[Select[xTf, (#[[2]] ≠ -999) &], BarEdges → True, AxesLabel → {"Date", "Temperature", "Relative Frequency"},
  ImageSize → 300];
```

Interpolation

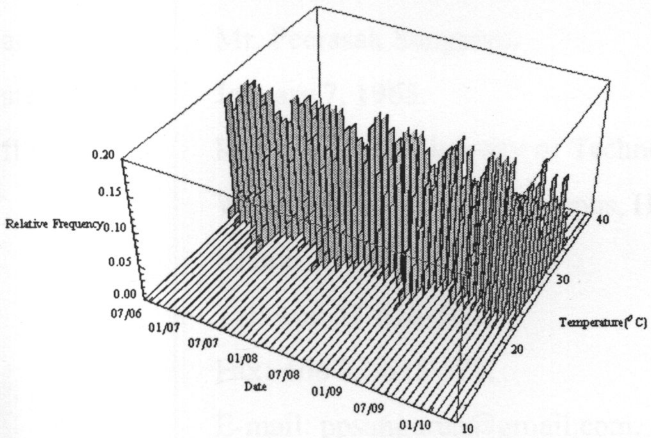
```
hData = Table[genHistI3D[di, 1, 1], {di, 1, totalDays, 30}];
hData1 = (Map[(Drop[#, -1] &), #] & /@ hData);
hData2 = (Map[(If[#[[2]] ≥ 0, #, {#[[1]], -1}] &), #] & /@ hData1);

DatatoPlot = Flatten[hData2, 1];
hFunc = Interpolation[DatatoPlot, InterpolationOrder → 1, Method → "Spline"];

hFunc2 = Interpolation[Flatten[hData1, 1], InterpolationOrder → 1, Method → "Spline"];

g2 = Plot3D[hFunc[d, s], {d, 1, totalDays}, {s, 0, 40}, PlotPoints → {100, 10}, PlotRange → {All, All, {0, 0.2}}, ImageSize → 300]
```



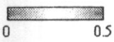

```
beginDate = FromDate[DayStart];
Month0 = {2006, 6, 10, 0, 0, 0.`}; (* Begin Date at Nakhon Si Thammarat study site - begin date at Khanom study site  *)
Month1 = DateList[beginDate];
(* Begin Date at Khanom study site *)

checkPreEmpty = DateDifference[Month0, Month1, "Day"];
m1tom2 = DateDifference[Month0, {2006, 7, 0, 0, 0, 0.`}, "Day"];
m01 = Table[DatePlus[{2006, 6, 1, 0, 0, 0.`}, {i, "Month"}], {i, 1, 48}];
noDate = Table[DateDifference[m01[[i]], m01[[i + 1]], "Day"], {i, 1, 47}];
ntoCal = Table[noDate[[i, 1]], {i, 1, 47}];
Accumulate[ntoCal];
joindate = Join[{m1tom2[[1]] - PreEmpty}, {m1tom2[[1]] - PreEmpty + Accumulate[ntoCal]}];
mtoplot = Flatten[joindate];
mtoplot2 = Table[mtoplot[[i]], {i, 1, 48, 6}];
mplot = Table[Characters[DateString[m01[[i]], {"MonthNameShort"}]][[1]], {i, 1, 48}];
mplot3 = Table[DateString[m01[[i]], {"Month", "/", "YearShort"}], {i, 1, 48, 6}];
mplot2 = Table[DateString[m01[[i]], {"Year"}], {i, 1, 48, 6}];
ftickm = Table[{mtoplot[[i]], mplot[[i]]}, {i, 1, 48}];
ftickm2 = Table[{mtoplot[[i]], mplot[[i]]}, {i, 1, 48, 4}];
ftickm3 = Table[{mtoplot2[[i]], mplot3[[i]]}, {i, 1, 8}];

temp3d2 = Plot3D[hFunc[x, y], {x, 1, totalDays}, {y, 0, 40}, PlotPoints → {100, 10},
  ColorFunction → Function[{x, y, z}, Hue[.65 (1 - z)]], AxesLabel → {"Date", "Temperature(°C)", "Relative Frequency"},
  Ticks → {ftickm3, Automatic, Automatic, Automatic}, BoxRatios → {1, 1, .5},
  PlotRange → {{-PreEmpty, totalDays + PostEmpty}, {10, 40}, {0, 0.2}}, ImageSize → 500]
```



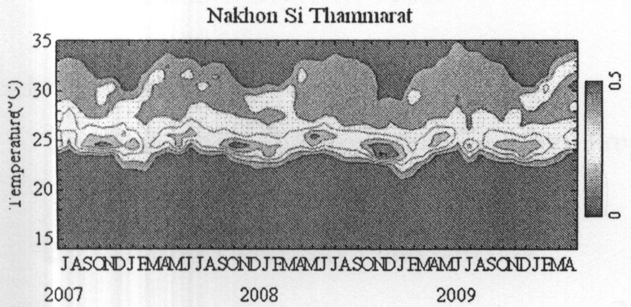
```
temp3d1 = GeneralizedBarChart3D[Select[xTf, (#[[2]] ≠ -999) &], BarEdges → True,
  AxesLabel → {"Date", "Temperature(°C)", "Relative Frequency"}, Ticks → {ftickm3, Automatic, Automatic, Automatic},
  BoxRatios → {1, 1, .5}, PlotRange → {{-PreEmpty, totalDays + PostEmpty}, {10, 40}, {0, .2}}, ImageSize → 500]
```




```
la = Show[ColorData["TemperatureMap", "Image"], ImageSize → 90, Frame → True, BaseStyle → {"Times", 12},
  FrameTicks → {{None, None}, {{{0, "0"}, {1, "0.5"}}, None}}]
```




```
disptemp = ContourPlot[hFunc[d, s], {d, 1, totalDays}, {s, 14, 35}, Contours → 10, PlotPoints → {100, 50},
  AspectRatio → 0.4, ColorFunction → ColorData["TemperatureMap"], FrameTicks → {ftickm, Automatic, Automatic, Automatic},
  BaseStyle → {"Times", 16}, PlotLabel -> "Nakhon Si Thammarat  ",
  FrameLabel → {{"Temperature(°C)", la},
   {"                    2007                                    2008
      2009                                        2010", None}},
  PlotRange → {{-PreEmpty, totalDays + PostEmpty}, {14, 35}, {-0.01, 0.49}}, ImageSize → 500]
```



Curriculum Vitae

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1. Biodiversity Research and Training Program Grant BRT T351131, (2008-2009).
2. Walailak University Fund 05/2009.

List of Publications:

- Sangarun, P., Srisang, W., Jaroensutasinee, K. and Jaroensutasinee, M. (2007). Cloud Forest Characteristics of Khao Nan, Thailand. *International Journal of Mathematical, Physical and Engineering Sciences*, 1, 232-237.
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National Conferences

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