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Mathematical model on the effects of global climate change and decreasing forest cover on seasonal rainfall in Northern Thailand

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ABSTRACT

This research involves the study of the long-term behaviors of Northern Thailand rainfall as affected by changes to its forest area and the rise in global temperature. Global temperature and forest data are considered annually while rainfall data are considered seasonally to best capture the effects of severe weather hazards such as draught and flood. A differential equation model was developed and verified using the mean global temperature data collected annually during 1880–2010, Northern Thailand forest area data collecting during 1973–2008, and data on the daily amounts of rainfall in Northern Thailand during 1971–2011. The rise in global temperature as well as the decline in Northern Thailand's forest area can be, as shown in the paper, represented by logistic equations. Northern Thailand rainfall is, however, represented as a periodic function; hence, second order differential equation, of which the solution is periodic, is used to represent the rate of change in the amount of rainfall. In addition, by correlation analysis, the predator-prey terms of forest, global temperature and rainfall are presented in the models. All parameters in the models are validated by minimizing sum squared error.

1. Introduction

Climate change is a major concern affecting all organisms. Over the past 30 years, global surface temperature has been rising approximately 0.2 °C per decade (Hansen et al., 2006; Meinshausen et al., 2009). Severe weather conditions such as draught and flood have been known to result from high global temperature (Vellinga and van Verseveld, 2000; Maarten and van Aalst, 2006). The amount of greenhouse gases (especially carbon dioxide) in the atmosphere depends inversely on the amount of forest area (Upton et al., 2007; Miner, 2010). Today, forest cover has decreased from the past due to timber demands for building and manufacturing (Walker, 1987) and to land usage for agriculture (Foley et al., 2005). The El Niño phenomenon has played an important role on the behavior of rainfall in different areas of the world; it is also a major cause of extreme weathers in many regions of the world (Sura, 2011). Changes in global temperature, therefore, lead to variations in the amount of rainfall in different areas of the world, an amount which depends on the level of forest transpiration (Street and Cockburn, 1972).

Many mathematical models in ecology have been developed to describe the relationship between carbon dioxide and global warming (Manabe and Stouffer, 1980; Alexiadis, 2007; Caetano et al., 2008; Islam and Salam, 2011), between forest and carbon dioxide or greenhouse gases (Norby et al., 2005; Olchev et al., 2008), between climate change and extreme weathers (Dubey et al., 2009; Tramblay et al., 2012), between species (or population) survival and pollution, i.e., industrialization (Dubey and Das, 1999), between species (or population) survival and forestry or biomass resources (Kiehl and Trenberth, 1997; Dubey et al., 2009) and between industrialization, population, and pollution (Dubey and Narayanan, 2010). There is also a study to control the amount of pollution in the environment in order to restrain the global carrying capacity of population (Thomas et al., 1996). In another study, the dynamic of the relationship between biomass (which can be viewed as forestry resources), industrialization, population, pollution, and pollution released by the biomass resources (which obviously includes carbon dioxide) was written in the form of a system of differential equations (Dubey and Narayanan, 2010). Furthermore, there is a mathematical model related to the competition among rain forest species using the Lotka-Volterra predator-prey model (Bampfylde et al., 2005). However, a mathematical model that simultaneously represents the relationship between global temperature, amount of forest area and amount of rainfall has never been presented.

According to statistical data from Thailand Forest Management Bureau (http://www.forestinfo.forest.go.th), Thailand forest area

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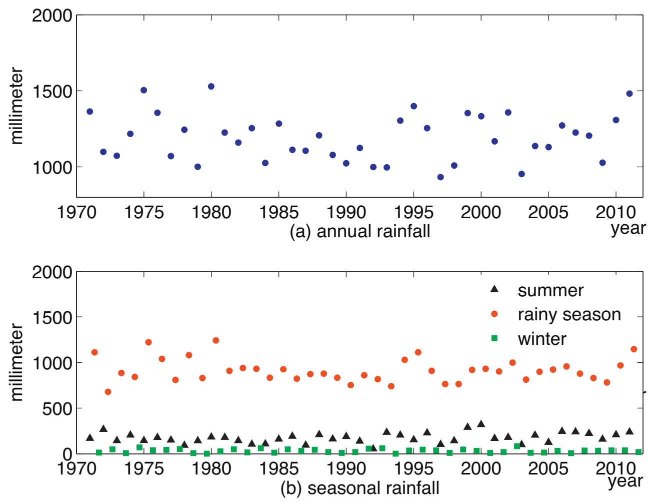

Fig. 1. The amount of rainfall in Northern Thailand during 1971–2011 collected on (a) annual and (b) seasonal basis.

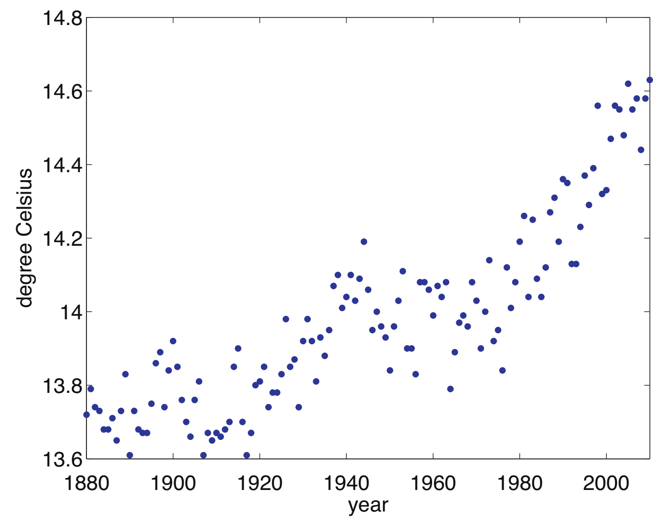

Fig. 2. Annual global temperature during 1880–2010.

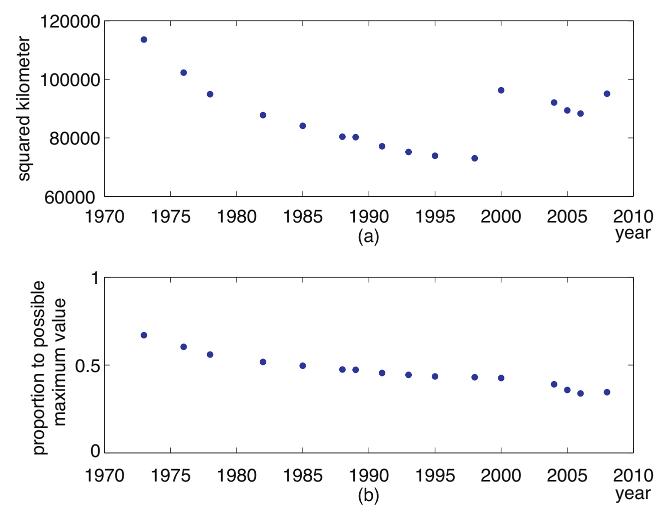

Fig. 3. (a) Raw data and (b) adjusted and normalized data for the amount of forest area in Northern Thailand during 1973–2008.

has decreased continuously. Deforestation is the single largest cause of forest area diminution, even compared to natural disasters such as wildfire. Reforestation campaigns by state agencies have been extensively implemented. However, they can compensate for only 10% of the destroyed region (http://www.dfm.forest.ku.ac.th). Although campaigns to stop deforestation in Thailand date back as far as 1979 and forest concessions were canceled by the government in 1989, deforestation continues apace despite widespread knowledge about the adverse effects of deforestation. Statistical data from Thailand Forest Management Bureau demonstrate that Thailand's forest cover in 2008 made up only 33.44% of the country's total area compared to 43.21% in 1973 (http://www.dnp.go.th). Forest cover in the North, Northeast, South, East and Central regions as a percentage of Thailand's entire forest cover in the year 2008 were 55.41, 16, 12.14, 4.68 and 11.71, respectively. More than half of the country's forest cover is in the North, which is also the origin of major rivers supporting the country's agriculture (Vongted, 1999). Therefore, the focus region in this research is Northern Thailand.

Thailand is an agricultural country located in the tropical zone, with 78% of its agriculture relying on natural rainfall (http://www.hydro-1.com). The amount of rainfall is an important indicator for severe weather conditions such as drought and flood. According to statistical data from Thailand Meteorological Center (http://www.hydro-1.com), the annual rainfalls during 1971–2011 showed a scattered and bound pattern as seen in Fig. 1a. However, seasonal rainfall has explicit patterns as shown in Fig. 1b. Rainfall fluctuations in drought and rainy seasons cause water management difficult and eventually affect to drought and flood. In addition, seasonal rainfall affects not only agriculture but also other industries such as river transportation and tourism (Borobia et al., 2001). Seasonal rainfall data are therefore a main focus of this study.

Following a review of literature, models are constructed under 3 main variables related to climate change: global temperature, forest area, and amount of seasonal rainfall in the studied area. The mathematical model of global temperature is verified during 1880–2010, Northern Thailand forest area and seasonal rainfall during 1973–2008 and 1971–2011, respectively.

2. Data collection, normalization and adjustment

The annual global temperature data have been taken from National Aeronautics and Space Administration (NASA) (http://www.earth-policy.org/datacenter/xls/indicator820111.xls). The forest area data for Northern Thailand have been collected by the Forest Management Bureau (North of Thailand), Department of Forestry (http://www.forestinfo.forest.go.th). Amounts of rainfall were taken from Northern Meteorological Center (North of Thailand), Thai Meteorological Department (http://www.hydro-1.com). Data for global temperature for the years 1880–2010, for Northern Thailand's forest area during 1973–2008, and monthly rainfall data for Northern Thailand during 1971–2011 are used to validate the model created for this analysis.

Temperature, forest area, and the amount of rainfall have different units and numerical scales. To unify the units for numerical result benefits, all data sets are transformed to the ratios of their maximum possible values. The global temperature is normalized to the ratio of the maximum body temperature that normal humans can tolerate (45 °C, (Sherwood and Huber, 2010)); Northern Thailand's forest area is normalized to the ratio of the region's total area (169,644.29 km^2) while the region's total rainfall amount is normalized to the ratio of the maximum possible rainfall amount in the area (1250 mm). This analysis uses annual global temperature, annual forest data (Figs. 2 and 3a, respectively) along with seasonal normalized rainfall data (Fig. 4).