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# The Distribution of Precipitable Water Vapor in the Atmosphere of Thailand

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## Abstract

This research aims to calculate the amount of precipitable water vapor in the atmosphere of Thailand and to map the distribution of water vapor in the atmosphere. The precipitable water vapor in the atmosphere was calculated from upper air checking data, relative humidity, and temperature. The data were collected at four meteorological monitoring stations located in Chiang Mai, Ubon Ratchathani, Bangkok, and Songkhla during the years 1991-2010. The figures for precipitable water vapor obtained from this investigation were used to formulate a mathematical model relating to the precipitable water from four stations with surface climatological data, relative humidity, and temperature at the same stations. The results showed that the relationship has a relatively high level of reliability. The precipitable water vapor obtained from upper air is nearly equal to the value from the model. The difference in the Root Mean Square Error (RMSE) is equal to 0.223 cm. Then, the researcher used a model to calculate the amount of precipitable water vapor at 85 meteorology stations nationwide. The results showed that the precipitable water vapor was low in the dry season (November to March) and relative high in the rainy season (April-October). The average per year was found to be 4.52 ± 0.149 cm.

*Keywords:* Solar radiation, Precipitable water vapor, Relative humidity, Temperature

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## 1. Introduction

In solar energy, education for applying for designing energy technology system has to know quantity solar radiation value divide by area at station. Usually, solar radiation that changes the atmosphere still comes in the Earth's surface when compared with location of solar radiation outside the atmosphere because the worldly atmosphere absorbs solar radiation. Moreover, the amount of vapor in the atmosphere is an important influence in the solar radiation depletion that comes through the atmosphere to the earth. The water vapor can absorb more than 10% of solar radiation traveling through the atmosphere [2,5,7]. The amount of water vapor in the atmosphere indicates the change of weather and cloud formation, which build up rain, fog, snow, hail, etc. In

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addition, water vapor in the atmosphere can absorb solar radiation in broad band (0.25-4.0 μm) at 15% [8], which the amount of absorption depends on the water vapor in the atmosphere [5]. Generally, the quantity of water vapor in the atmosphere is shown by perceptible water vapor. This water vapor is amount in zenith direction assuming that water vapor in zenith direction will then be condensed. Water vapor quantity in the atmosphere generally often gets difficult and Thailand still has no quantity water vapor measurement in the atmosphere. From the investigation, it was found that water vapor quantity has the relation to the relative humidity and the temperature of the air from checking upper air data. Furthermore, water vapor has temporal and geographical variation [2].

Usually, we are able to show the amount of the perceptible water vapor, which will be in a form of the total amount of water vapor in the zenith direction assuming that the vapor is somewhere between the atmosphere that turns into water. The amount of the vapor is too much for the four meteorological stations in Thailand to collect all of its data, in covering other area as well by other station which has no upper air checking data. This research uses the data that were measured consecutively during the years 1991-2009. The research result showed that it can reduce the expenses in seeking the value of water vapor for the station which has no checking upper air data and uses based data in the education about incoming solar radiation in the Earth's surface, including the ability to absorb solar radiation of water vapor [1,8]. This research will therefore create the perceptible water vapor meter that is able to collect the data in each and every area in Thailand, which will be useful to the model of forecasting the weather and designing the solar power instruments.

## 2. Methodology

This study calculated the perceptible water vapor from the relation between the relative humidity and temperature of the weather from upper air checking data at four meteorological monitoring stations, namely Chiang Mai, Ubonratchathani, Bangkok and Songkla during the years 1991-2009. Then the amount of water from upper checking data was analyzed to find the relation between temperature and relative humidity which is surface data from the same stations. Then, result was used to formulate the water vapor model, which was used for calculating water vapor in other stations. The researcher tested the model by using free data from the year 2010.

The perceptible water vapor from upper air data were determined using the following equation[3].

$$w = \frac{1}{g}\int_{p_o}^{0}\left(\frac{M_p}{\rho}\right)dp \qquad (1)$$

Where $w$ is precipitable water vapor (cm)
$M_p$ is mixing ratio (decimal)
$g$ is the acceleration due to the earth’s gravity (986.665 $cm/s^2$)
$p$ is the atmospheric pressure (mbar)
$p_o$ is the atmospheric pressure at the Earth’s surface (mbar)
$\rho$ is the density of water ($g/cm^3$)

The data are calculated water vapor for 18 years (1991-2009) to determine the long-term daily average per month of January to December and the results were averaged across the year. The results are displayed as monthly perceptible water vapor maps and yearly map of the color map display.

## 3. Results, Conclusions and Discussion

Results constructed a water vapor calculating model for stations that do not have upper checking data. The relation between water vapor values from upper checking data (w), ambient temperature, surface data, and relative humidity, which are surface data from the same station, were calculated. The correlation is shown in Fig. 1.

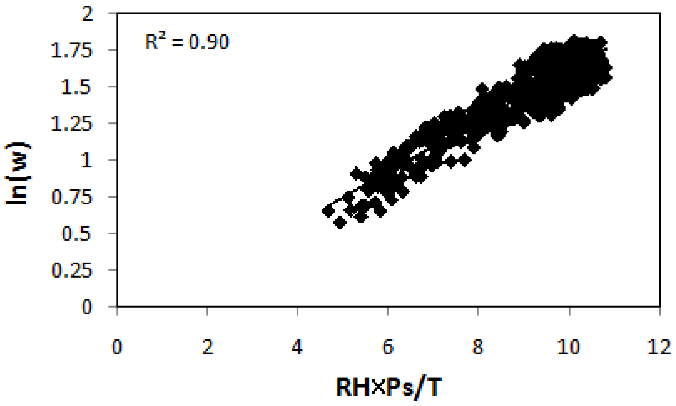


Fig. 1. Correlation between precipitable water vapor with RH, T and $p_s$

The best-fitted equation of the graph is:

$$w = 0.90176\exp\left(\frac{0.1738\,RHp_s}{T}\right) \tag{2}$$

Where RH is relative humidity (decimal)
T is ambient temperature (K)
$p_s$ is the partial pressure of water vapor (mbar)

The partial pressure of water vapor in saturated air is given by the following semiempirical equation.

$$p_s = \exp\left(26.23 - \frac{5416}{T}\right) \tag{3}$$

Then the empirical equation was retested with temperature data and relative humidity, which is free surface data of the year 2010 of the same stations. The perceptible water vapor obtained from upper air is nearly equal to the value of the empirical equation, which is the difference in the Root Mean Square Error (RMSE) is equal to 0.223 cm. The findings were presented in the model shown in Fig. 2.

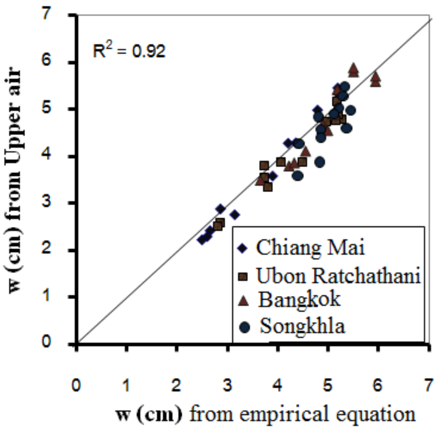


Fig. 2. Comparative data of perceptible water vapor between upper air data and surface data which is free surface data of the year 2010

This result was compared to that reported by Leckner [7] based on the relationship between surface temperature and relative humidity, which is the same data at the same time. The pattern of changes in the corresponding period is shown in Fig. 3.

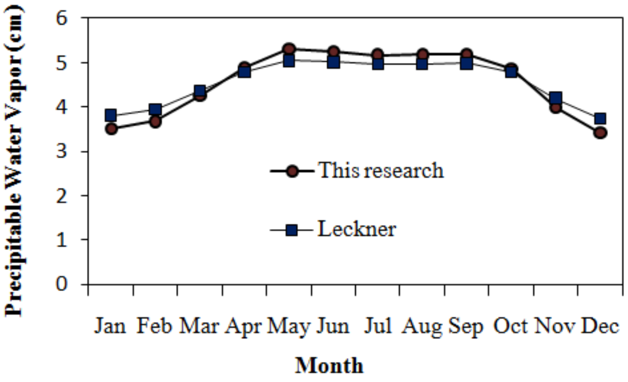
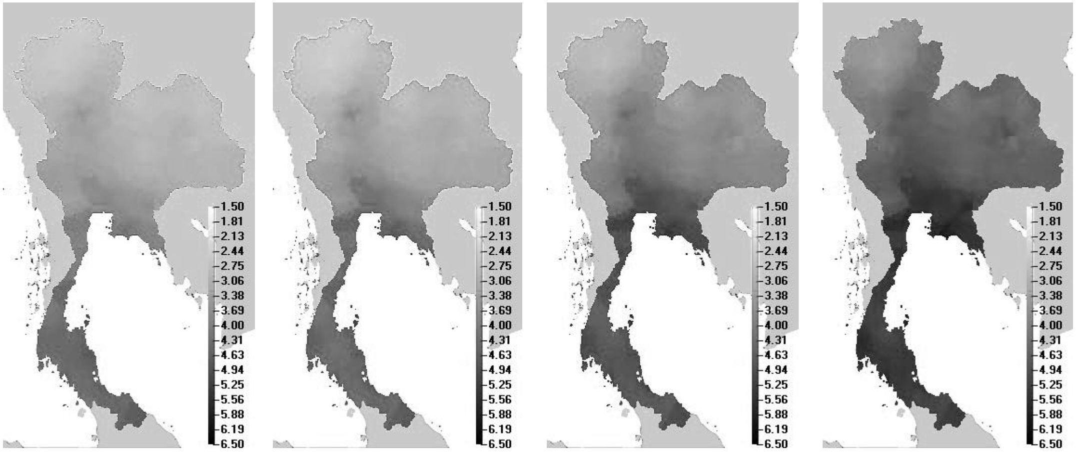
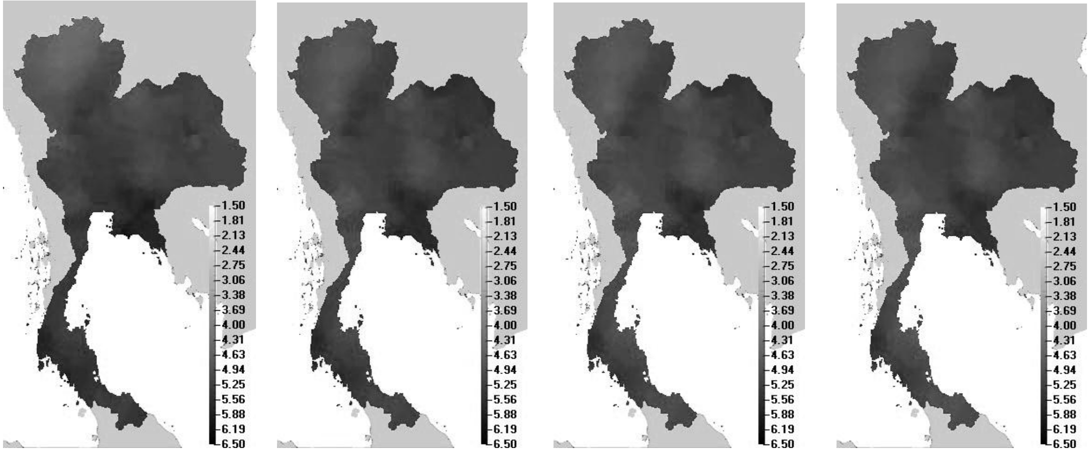


Fig. 3. Comparative data of perceptible water vapor between this research and the research of Leckner [7]

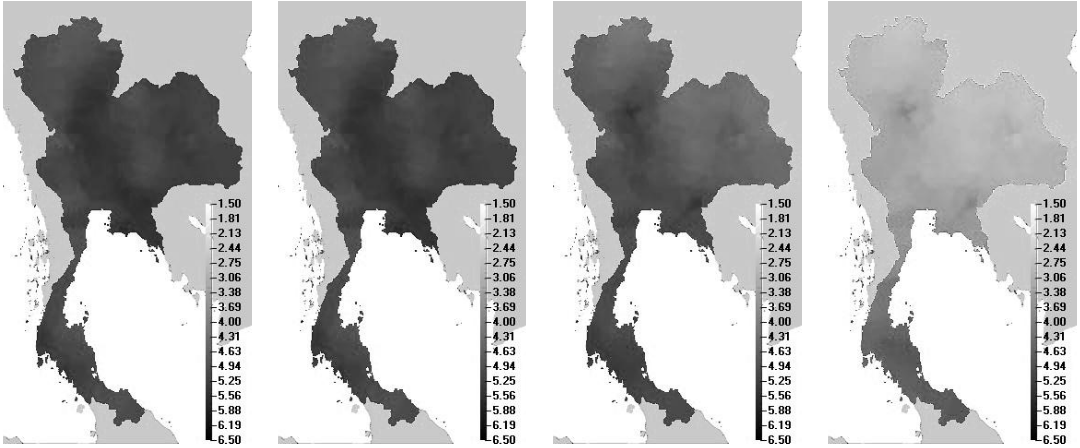
We used the algebraic Eqs.(2) to calculate the perceptible water vapor from the average in during the years 1991-2009 of 85 nationwide stations. It was found that perceptible water vapor associates systematically with surface data. Thus, empirical equation can be formulated from upper checking data. Moreover, the study showed that water vapor varies throughout the year from 2.43 to 6.14 centimetres, which is quite high. The average per year is equal to 4.52 ± 0.149 centimetres. The standard error of the mean is equal to 0.0564. It was also found that perceptible water vapor varies with latitudes of the stations systematically. In other words, water vapor in rainy seasons, i.e., April to October, was the same in every station around Thailand. However, perceptible water vapor slowly increases from the North to the South from November to March. The monthly perceptible water vapor maps and yearly map obtained from the above-mentioned process are shown in Fig 4-5, respectively.



January February March April



May June July August



September October November December

Fig. 4. The monthly precipitable water vapor maps

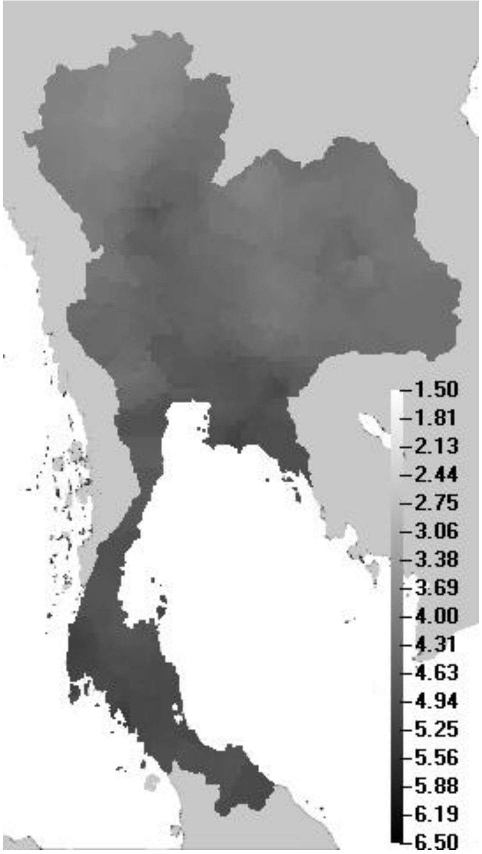


Fig. 5. Yearly precipitable water vapor map

Since the result of this study was indirectly obtained from upper checking data and theoretical calculation. In the future, it is advisable that the modern measuring instrument should be employed and distributed to meteorological stations around Thailand to achieve that accurate data. Data obtained will be useful for the study of weather change, temperature, and solar radiation depletion. The information will be useful for weather forecast, remote sensing using satellite, and other related areas.

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