Atmospheric water vapor: Distribution and Empirical estimation in the atmosphere of Thailand

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Abstract. Atmospheric water vapor is a crucial component of the Earth's atmosphere, which is shown by precipitable water vapor. It is calculated from the upper air data. In Thailand, the data were collected from four measuring stations located in Chiang Mai, Ubon Ratchathani, Bangkok, and Songkhla during the years 1998-2013. The precipitable water vapor obtained from this investigation were used to define an empirical model associated with the vapor pressure, which is a surface data at the same stations. The result shows that the relationship has a relatively high level of reliability. The precipitable water vapor obtained from the upper air data is nearly equal to the value from the model. The model was used to calculate the precipitable water vapor from the surface data 85 stations across the country. The result shows that seasonal change of the precipitable water vapor was low in the dry season (November-April) and high in the rainy season (May-October). In addition, precipitable water vapor varies along the latitudes of the stations. The high value obtains for low latitudes, but it is low for high latitudes.

1. Introduction
Water vapor is a critical component of Earth’s climate systems. It is the Earth’s primary greenhouse gas, trapping more heat than carbon dioxide [1,2]. Knowledge of accurate water vapor quantification and interpretation of their physical characters are crucial in understanding how the global climate system such as global warming changing over time [3]. In addition, the water vapor in the atmosphere is an important influence in the solar radiation depletion that comes through the atmosphere to the Earth [4]. The water vapor can absorb more than 10% of solar radiation traveling through the atmosphere, while the amount of absorption depends on the water vapor in the atmosphere [5-7]. Generally, the quantity of water vapor in the atmosphere is shown by precipitable water vapor. Precipitable water vapor represented by the height of the water column of the atmosphere from the surface of Earth to the top of the atmosphere. Assuming that the water vapor insert in the column of the atmosphere condensation becomes water. The height of the water in the vertical is precipitable water vapor [7-9]. In Thailand, there is no direct measurement. However, it was found that water vapor quantity is closely related to the relative humidity and the temperature.

In this study, our aim is to find a mathematical model for calculating the precipitable water vapor in the atmosphere of Thailand. The findings will help to lower the cost of measure the value of water vapor for the stations which has no upper air data. The use of empirical model is a common practice. It is used as basic data in the study about incoming solar radiation in the Earth's surface. In addition,
detailed data of the water content are important input data for hydrological, energetic and radiation models [2,5,10-11].

2. Materials and methods
The precipitable water vapor is calculated from the relation between the relative humidity and temperature of the upper air data at four meteorological stations, namely Chiang Mai (18.78 °N, 98.98 °E), Ubon Ratchathani (15.25 °N, 104.87 °E), Bangkok (13.73 °N, 100.57 °E) and Songkhla (7.20 °N, 100.60 °E) during the years 1993-2013. The precipitable water vapor from upper air data which are the observe values. It is determined using the following equation [3,8,12]:

$$w = -\frac{1}{\rho g} \int_{p_1}^{p_2} M_p dp$$

where $w$ is precipitable water vapor (cm), $g$ is the acceleration due to the earth’s gravity (986.665 cm s$^{-2}$), $\rho$ is the density of liquid water (g cm$^{-3}$), $p$ is the atmospheric pressure along altitude (mbar), $p_1$ and $p_2$ are the atmospheric pressure at the Earth’s surface and top of the atmosphere respectively. $M_p$ is mixing ratio at the pressure level, p. The integration is from the surface at $p_1$ up to the pressure designated by $p_2$ which depends on the final altitude reached by the radiosonde observation. $M_p$ can be calculated by [1,7].

$$M_p = \frac{0.622e}{p-e}$$

where $e$ is the actual vapor pressure (mbar). The actual vapor pressure is obtained as the product of the saturated vapor pressure ($e_s$) and the relative humidity ($RH$) at pressure $p$ [4,7].

$$e = \frac{RH e_s}{100}$$

The saturated vapor pressure value depends only on the air temperature ($T$) in degree Celsius. The saturated vapor pressure (in mbar) is calculated according to [13-14]:

$$e_s = 6.112 \exp \left( \frac{17.67 T}{T + 243.5} \right)$$

The precipitable water vapor from upper air data was analyzed to find the relation between temperature and relative humidity which is surface data from the same stations. The researcher test the performance of the proposed model with independent data from the year 2014 in order to confirm the accuracy of the model. The performance of model was assessed based on some commonly used statistical indicators. Three statistical estimators of mean bias error (MBE), mean percentage error (MPE) and root mean square error (RMSE) are used to evaluate the accuracy of the model [1,7,12].

3. Results and discussion
The relation between precipitable water vapor value from upper air data, air temperature and relative humidity which is surface data from the same station were calculated using the average daily during the years 1993-2013. The data of $w$ from the upper air data and the actual vapor pressure from surface data at the same station. The least square straight line fit to these data yields the relation to be used for an estimate of precipitable water vapor. The empirical model under investigation is as follows.

$$w_p = 1.461407 \exp(0.0451e)$$

where $w_p$ is precipitable water vapor (cm) which is used as a model. The $e$ is the actual vapor pressure (mbar), which depends temperature and relative humidity at surface. The precipitable water vapor obtained from upper air data is nearly equal to the value of the surface data. It was found that predominantly high correlations and relatively high coefficients of variation were obtained for the
linear relationships at all the stations. The MBE was 0.029 cm, the MPE was 8.196%, shows the RMSE was 0.521 cm, and the correlation coefficient (R^2) was 0.875.

The model is retested with independent data, which has never been used in the modeling by using the data of year 2014 of the same stations to verify the accuracy of the model. The findings are presented in the model as shown in table 1. This result was compared to that reported by this research, Okulov et al. [1], Adeyemi [3] and Leckner [9] based on the relationship between surface temperature and relative humidity, which is the same data at the same time. The actual value of the upper air data (\(\bar{X} = 4.278 \pm 0.922\) cm) were compared. Model in this research showed the best performances according to its RMSE, MBE and MPE. Shows the RMSE was 0.525 cm, the MBE was -0.128 cm and the MPB was 10.844% (as shown in table 1), which are in good agreement than other methods.

Table 1. \(\bar{X}\), RMSE, MBE and MPE of the precipitable water vapor difference obtained from the comparison study between this researches with the researches Okulov et al., Adeyemi and Leckner.

| Method          | \(\bar{X}\) (cm) | RMSE (cm) | MBE (cm) | MPE (%) |
|-----------------|------------------|-----------|----------|---------|
| This research   | 4.406\(\pm\)0.785 | 0.525     | -0.128   | 10.844  |
| Ocui et al.[1]  | 3.243\(\pm\)0.431 | 1.198     | 0.431    | 14.108  |
| Adeyemi [3]     | 3.481\(\pm\)0.524 | 0.973     | 0.797    | 23.004  |
| Leckner [9]     | 4.503\(\pm\)0.665 | 0.592     | -0.225   | 12.573  |

The average daily from surface data during the years 1993-2013 of 85 stations across the country were calculated by the model. Found that, precipitable water vapor is quite high in rainy season, and a decrease in the dry season. In addition, water vapor has changed the location and month of the year. Consistent with Okulov et al. [1], Smirnov and Moore [10] and Maghrabi and Clay [12], finds that the amount of water vapor depends on the surface data and the seasonal changes. The experimental result is shown in the following figure 1. The precipitable water vapor is used to study changes along the latitude of each station using the average yearly. That is, precipitable water vapor is inversely proportional to latitude, which is similar to what Okulov et al. [1], Gueymard and Garrison [4] and Maghrabi and Clay [12] reported. There were high values for low latitudes and low values at high latitudes, That is, precipitable water vapor is high in the South and low in the North, as shown in figure 2.

Figure 1. Changing patterns according to the time of year of the precipitable water vapor using the average data from 1993 to 2013.

Figure 2. Changes along the latitude of the precipitable water vapor using the average annual from surface data of 85 stations during the year 1993-2013.
4. Conclusions
From the importance of the amount of water vapor in the atmosphere that affects the weather and climate changes and influencing the intensity of solar radiation. This research has calculated the amount of water vapor from relative humidity and temperature from upper air data of the four stations. The values of the correlation analysis of the temperature, and relative humidity from the surface data, which is measured at the same station. The results of analysis of precipitable water vapor have a relationship with the surface data, which can be written in terms of mathematical models. Test models using independent data, linear regression displayed verify the strong linear relationship between these variables. The study use surface data (temperature and relative humidity) from eighty-five stations across the country, which is applied to the model to calculate the precipitable water vapor. The simulation results showed that the precipitable water vapor changed by the time of the year which is higher in the rainy season from May to October, and less during the dry season from November to April. The precipitable water vapor is high in the South and low in the North.

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