DETERMINATION OF THE AMOUNT OF WATER VAPOR IN THE TROPOSPHERE OVER THAILAND USING SURFACE DATA

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ABSTRACT

The amount of water vapor 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 1993-2014. The relationship between the precipitable water vapor from the upper air data and the surface data obtained from a mathematical model was investigated in this paper. The result showed that the relationship had a relatively high level of reliability. The precipitable water vapor was nearly equal to the value from the model. The precipitable water vapor from 85 meteorological stations across the country was calculated from the model. The result showed 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 was varied along the latitudes of the stations. For low latitudes, the high value was obtained, but it was low for high latitudes.

KEYWORDS: Water Vapor, Greenhouse Gas, Hydrologic Cycle, Surface Data ,Upper Air Data

1. Introduction

The troposphere, which is the lowest layer of Earth's atmosphere, consists of gas, water vapor and aerosols. It is about 10-12 kilometers from the earth's surface. It has a lot of water vapor that is a major cause of many meteorological phenomena. Climate change and variability are easy. Although, water vapor has a small amount, it has a great impact on the weather and climate [1]. Due to the water in the air can change back and forth in all three states, a mechanism of receiving and emitting energy can drive climate change [2]. Water vapor is a greenhouse gas. Naturally, it is approximately 60 percent of all greenhouse gases in the atmosphere [3-6]. It has the ability to absorb infrared radiation emitted from the Earth. It is one of the most important variables in the reduction of solar radiation through the atmosphere to the surface of the Earth. 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 [7-9]. Water vapor is a part of the water cycle. Not only it is the carrier and heat dissipation for the atmosphere and surface, but also it has the ability to trap heat, keeping the temperature of the Earth warm, suitable for living organisms [10-11]. Normally, the amount of water vapor in the atmosphere is shown in the form of precipitable water vapor in terms of the height of the water column of the atmosphere in centimeters. Therefore we assume that the vapor inserted in the column of the atmosphere is condensed into water [7, 12]. In Thailand, there is no direct measurement. However, it was found that water vapor quantity is closely related to the relative humidity and the ambient temperature. When the required water vapor data are scarce, the use of empirical models is a common practice [5, 7, 13-14]. In this study, the objective was to determine the amount of water vapor in the troposphere over Thailand using surface data. The location, time, and season affecting the data distribution were also investigated.

2. Methodology

The relative humidity and air temperature from the upper air data are used. In Thailand, there are 4 meteorological stations: Chiangmai (18.78 °N, 98.89 °E), Ubon Ratchathani (15.25 °N, 104.86 °E), Songkhla (7.2 °N, 100.6 °E) and Bangkok Meteorological Department (13.73 °N, 100.56 °E). The upper air data was used at various pressure levels, which was the daily data during the years 1993 to 2014. Theoretical calculation of water vapor from upper air data is derived from the following equation.

$$w = \sum_{i=1}^{n} \frac{M_i}{\rho g} |\Delta P|_i \tag{1}$$

where w is precipitable water vapor (cm), M_i is a mixing ratio at any pressure level, g is the acceleration due to gravity of the Earth (986.665 cm/s^2), ρ is the density of water (g/cm^3), and P_o is the atmospheric pressure at the surface level (mbar).

A relationship between air temperature and relative humidity was investigated, which was the surface data at the same station and the same time period in a mathematical model. The model was tested using data from 2015, which was an independent data not used to generate. Model performance was determined in terms of root mean square error (RMSE) and correlation coefficient (R^2).

3. Result and Discussion

Precipitable water vapor was consistent at all stations. It was very high at a pressure of 850 mbar or at an altitude of about 1.48 km. At an altitude of less than 2 km, there was a low cloud that consisted of a water vapor that was covered by a wide area. It accounted for 41.95 percent of the water vapor in the atmosphere. The precipitable water vapor at Songkhla station was the highest, followed by Bangkok station, Ubon Ratchathani and Chiang Mai stations, respectively. It decreased when the altitude increases for all stations. It rapidly dropped to near zero at an altitude of more than 10 kilometers [5-6,13]. The result is shown in the Figure 1. The performance of the humidity sensor of the meter does not work at low temperatures, as shown in Figure 2.

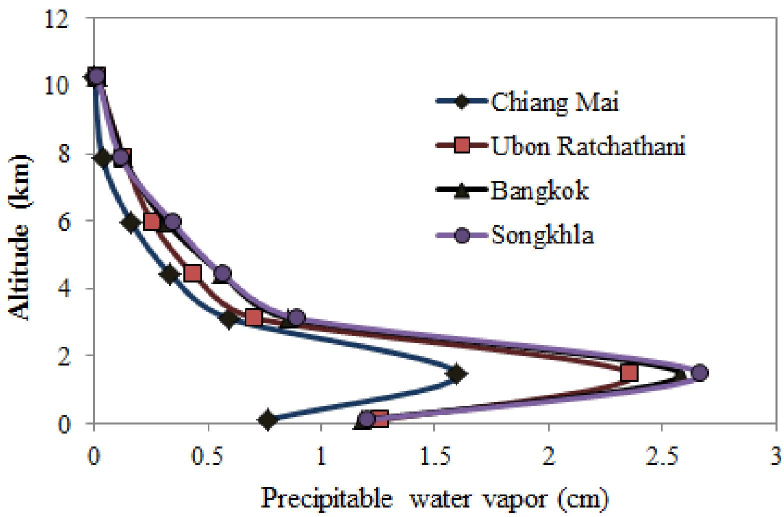

Figure 1 Average precipitable water vapor during the year 1993-2014 from the upper air data of 4meteorological stations at various altitudes above the ground

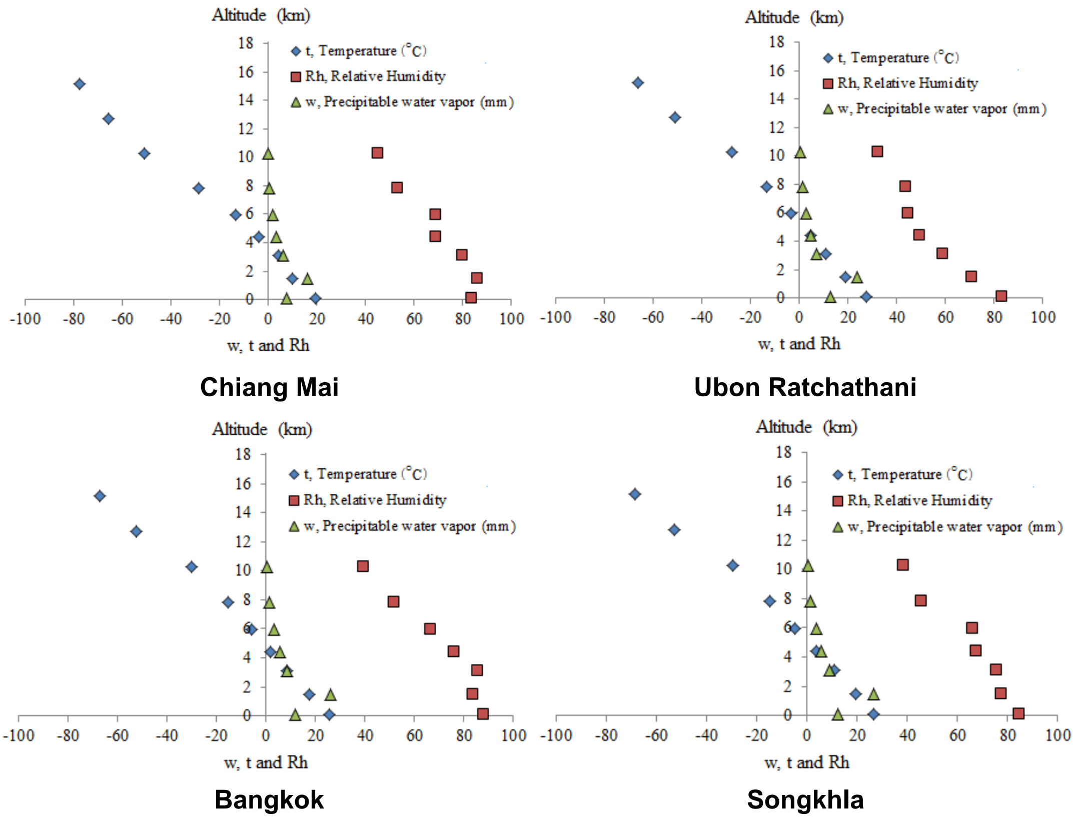

Figure 2 Precipitable water vapor, temperature and relative humidity from upper air data which is the average during the years 1993 to 2014.

The precipitable water vapor obtained from the upper air data of four station was compared with the temperature and relative humidity, which was the surface data at the same station and the same time. The results showed that data were correlated in mathematical model. The correlation coefficient (R^2) was 0.891. Relationships was fitted as the following equation.

$$w = \exp(0.13546t + 0.018019Rh - 0.000378Ps - 2.1508) \quad (2)$$

where w is the precipitable water vapor (cm), t is the air temperature (°C), Rh is relative humidity (%), and Ps is the pressure of water vapor in saturated air [7].

The model was retested with independent data, which had never been used in the modeling by using the data of year 2015 of the same stations to verify the accuracy of the model. This result was compared to that reported by Okulov et al. [5], Adeyemi [13] and Leckner [14] based on the relationship between surface temperature and relative humidity, which was the same data at the same time. The actual value of the upper air data were compared. The diagonal line represents the reference where the precipitable water vapor from upper air data was corresponding to the precipitable water vapor obtained from the model in this research. It was found that the precipitable water vapor obtained from the upper air data was close to that obtained from the research model. The RMSE was 0.528 cm and the correlation coefficient (R^2) was 0.851, which were in good agreement than other methods (as shown in Figure 3).

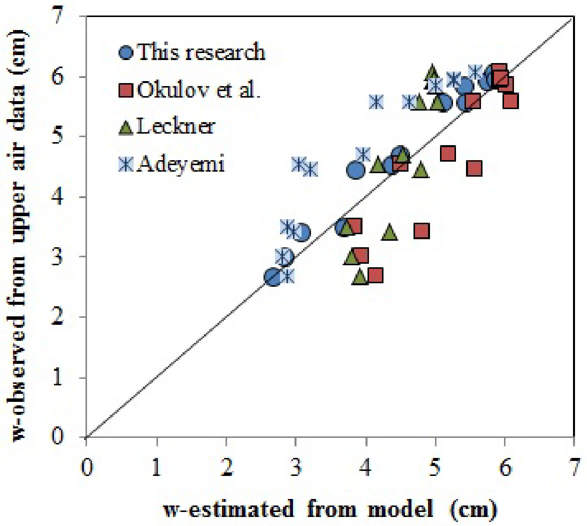

Figure 3 Comparison of observed and estimated precipitable water vapor various models, using average monthly of the year 2015. The 1:1 line is shown in reference.

Equation (2) was used to calculate the precipitable water vapor from monthly average of the surface data (temperature and humidity) in during the years 1993-2014 of eighty-five nationwide stations. The study showed that precipitable water vapor was varied throughout the year from 2.592 to 5.779 centimeters. The yearly average of precipitable water vapor over the country was found to be 4.672±0.731 cm. The precipitable water vapor was quite high in rainy season (May to October), and decreased in the dry season (November to April). The result is shown in the following Figure 4. In addition, water vapor has changed the location and month of the year, consistent with Okulov et al. [5[, Leckner [14] and Zhai and Eskridge [[15, found that the amount of water vapor depended on the surface data and the seasonal changes. When studying changes according to latitude, It was found that precipitable water vapor was inversely proportional to latitude. Precipitable water vapor was high in the South and low in the North, which were similar to what Okulov et al. [5[, Adeyemi [13] and Zhai and Eskridge [[15reported. There were high values for low latitudes and low values at high latitudes, precipitable water vapor slowly increased from the North region to the South region.

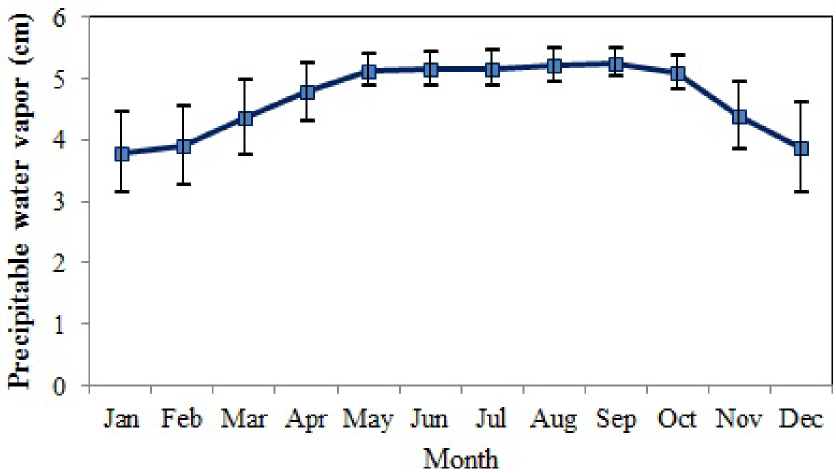

Figure 4 Seasonal variation of the precipitable water vapor using the monthly average of 85 stations during the year 1993-2014, while the error bars on dots denote the standard deviation for each one of mean.

4. Conclusion

From the importance of the amount of water vapor in the atmosphere that affecting weather and climate changes and influencing the intensity of solar radiation found that the water vapor in the atmosphere was inversely proportional to the height above the ground. It was very high at altitudes below 2 kilometer. It then decreased and approached zero when the height increased. 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 were measured at the same station. Analysed results of analysis of precipitable water vapor showed a relationship with the surface data, which can be written in terms of mathematical models. By testing model using independent data and linear regression, demonstration of the strong linear relationship between these variables was displayed. The surface data (temperature and relative humidity) from eighty-five stations across the country were used and applied to the model to calculate the picipitable water vapor. The simulation results showed that the precipitable water vapor was changed by the time of the year which displayed high values in the rainy season from May to October, and low values in the dry season from November to April. It is also found that the precipitable water varied with latitudes of the stations. The precipitable water vapor was high in the South and low in the North.

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References

[1] Follette MB, HudsonRD, Nedoluha GE. Classification of Northern Hemisphere stratospheric ozone and water vapor profiles by meteorological regime. Atmos. Chem. Phys. Discuss 2008;8:13375-411.

[2] Harries JE. Atmospheric radiation and atmospheric humidity. Quart. J. Roy. Meteor. Soc 1997;123:2173-86.

[3] Rind D. Just add water vapor. Science 1998;281:1152-3.

[4] Cohen JL, Salstein DA, Rosen RD. Interannual variability in the meridional transport of water vapour. J. Hydrometeor 2000;1:547-53.

[5] Okulov O, Ohvril H, Kivi R. Atmospheric precipitable water in Estonia, 1990-2001. Boreal Env. Res 2002;7:291-300.

[6] Kassomenos PA, McGregor GR. The interannual variability and trend of precipitable water over Southern Greece. J. Hydrometeor 2006;7:271-84.

[7] Iqbal M. An Introduction to solar radiation. New York: Academic Press; 1983.

[8] Nunez M. The development of a satellite-based insulation model for the Tropical Pacific Ocean. J. Climatology 1993;13:607-27.

[9] Iziomon MG, Mayer H. Assessment of some global solar radiation parameterizations. J. Atmospheric and Solar-Terrestrial Physics 2002;64:1631-43.

[10] Kitoh A, Arakawa O. Precipitation climatology over the Middle East simulated by the high-resolution MRI-AGCM3. Global Environmental Research 2011;15:139-46.

[11] Smirnov VV, Moore GWK. Short-term and seasonal variability of the atmospheric water vapor transport through the Mackenzie River basin. J. Hydrometeor 2001;2:441-52.

[12] Bevis M, Businger S, Herring TA, Rocken C, Anthes RA, Ware RH. GPS meteorology: Remote sensing of atmospheric water vapor using the Global Positioning System. J. Geophys. Res 1992;97:15787-801

[13] Adeyemi B. Empirical formulations for inter-layer precipitable water vapor in Nigeria. Pacific J. Sci. Technol 2009;10:35-45.

[14] Leckner B. The spectral distribution of solar radiation at the earth's surface elements of a model. Solar Energy 1978;20:143-50.

[15] Zhai P, Eskridge RE. Atmospheric water vapor over China. J. Climate 1997;10:2643-52.

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