Estimation water vapor content using the mixing ratio method and validated with the ANFIS PWV model

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Abstract. This study reported the comparison between water vapor content, the surface meteorological data (pressure, temperature, and relative humidity), and precipitable water vapor (PWV) produced by PWV from adaptive neuro fuzzy inference system (ANFIS) for areas in the Universiti Kebangsaan Malaysia Bangi (UKMB) station. The water vapor content value was estimated with mixing ratio method and the surface meteorological data as the parameter inputs. The accuracy of water vapor content was validated with PWV from ANFIS PWV model for the period of 20-23 December 2016. The result showed that the water vapor content has a similar trend with the PWV which produced by ANFIS PWV model (r = 0.975 at the 99% confidence level). This indicates that the water vapor content that obtained with mixing ratio agreed very well with the ANFIS PWV model. In addition, this study also found, the pattern of water vapor content and PWV have more influenced by the relative humidity.

1. Introduction

Our Earth is made liveable by the existence of gases as called greenhouse gases that allowed trap long-wave radiation emitted from the Earth's surface. Greenhouse gasses originated from anthropogenic and their effect on atmospheric temperature have been widely studied (e.g., [1], [2]). Without these gasses, the average of surface temperature in Earth's would be about −18 °C (0 °F) and vice versa with existence these gases the present average temperature of Earth's surface of 15 °C (59 °F). This phenomenon is called as the greenhouse effect. Although water vapor is not come from anthropogenic, it has impact to greenhouse effect about 60% in clear skies compared to the other greenhouse gases such as the carbon dioxide, ozone and trace gases including methane and nitrous di oxide [2].

Atmospheric water vapour is one of the most important components in determining and understanding of global climate change. The content and distribution of water vapour are critical variables for description of the state and evolution of many physical processes in the Earth's atmosphere. A long time ago, Manabe and Wetherald [3] have described the water vapour feedback show an important role in the behaviour of the climate and weather system. For example, water vapour plays important role in dynamic of spread and in radiation exchange within the atmosphere. This process is fundamental to transfer and formation energy in the atmosphere, and propagation of weather [4].

In addition, the water vapour is not only limited role in absorbing and radiating energy from the sun, but also its influence to formation of clouds, aerosols, and chemistry of the lower atmosphere [5]. On the other hand, the distribution of water vapour is closely related to the event of clouds, rainfall, convection and storm, as noted by many authors [6, 7]. Thus, the understanding of amount water vapor concentration is primarily important to monitor weather and climate changes in our Earth.

The purpose of this study is to attempt the calculate of water vapor concentration in our atmosphere using the mixing ratio formula and then validate its value using the total column water vapor in term of precipitable water vapor (PWV) that derived by adaptive neuro fuzzy inference system (ANFIS) PWV model. Observation one-week data from Universiti Kebangsaan Malaysia Bangi (UKMB) station was provided to compare and estimate water vapor concentration and PWV.
Later on, this formula will be used to calculate concentration of water vapor in peatland area, since the water vapor is one of primary component greenhouse gasses that to contribute to greenhouse effect. In the next study, the concentration of water vapor content which calculates with the mixing ratio formula will be compared with the other component greenhouse gasses such as the carbon monoxide (CO₂) and methane (CH₄) to know the relevance of them.

2. Methodology

2.1. The available data
In this study, three parameters of surface meteorological data such as surface pressure, surface temperature and relative humidity were used to determine of water vapor concentration and PWV. The data were taken from the space science centre (ANGKASA), UKMB station (2°55′23″N, 101°46′23″E). All the surface meteorological data were collected directly from the PTU300 meteorological sensor. The PTU300 is a one of meteorology sensor that manufactured by Vaisala. This sensor consists of three parameters measurement which is surface pressure (in mbar), surface temperature (in °C) and relative humidity (in percent). All the surface meteorological data were collected at 1-minute interval.

2.2. ANFIS PWV model
Since, the distribution of water vapor content has primary role in weathers and climate changes such as the determinant success of the weather forecast. Many researchers have developed technique to measure water vapor content in terms of PWV, such as a traditional measurement (radiosonde and water vapor radiometry), and ground-based global positioning system (GPS) [8]. Compared to traditional measurement, the GPS technique has an advantage in the measurement of water vapor content as thought high accuracy, large capacity, and quick variation. However, in the current state, the GPS data have a lacking due to the incomplete data or missing in 24 hour, especially in remote area or area without GPS receiver provider.

To solve this shortcoming, Suparta and Alhasa 2016 [9] was developed the model to estimate the PWV without GPS data, which is only use the surface meteorology data as well as pressure, temperature, and relative humidity. The model have constructed as the multi-layer feedforward neural network. It consists of five layers, where the first layer and fourth layer have four membership functions and rules, respectively, as shown in Figure 1. To achieve the high accuracy, the model has trained with the hybrid learning algorithm. This model was validated with the other techniques such as GPS measurement. The validation result showed that the PWV value that provided by ANFIS PWV model has a strong relationship with the GPS PWV value. For more detail about the physical of this model, please refer this paper [9].
Figure 2 shows the workflow of ANFIS PWV model. Before the model started, the input surface meteorological data such as pressure (P), temperature (T), and relative humidity (RH) that coming to the model should be normalized to scale -1 until 1. After the scaled process, the input value will be entered to first layer and transform their with membership function into fuzzy value. This stage is called as fuzzification process. The membership function that usually used is in the form of a triangular, trapezoid, gauss and generalized bell. For this model the generalized bell membership function was used to transform the input value to fuzzy value. In the next stage, the fuzzy value that have range 0-1, also known as degree membership function will be evaluated by knowledge and rules base in second and third layers. There are four rules that were used in those layers. A linear equation also known as a first-sugeno model in fourth layer was used to calculate PWV value for each rule. This stage is known as the defuzzification process, where the fuzzy values that were evaluated in the previous layer are transforming to crips value (real value). Finally, in the fifth layer, the PWV from ANFIS model were obtained by summation and averaged all PWV value from each rule with use the weight average.

\[ w = \varepsilon \frac{P_w}{P-P_w} \]  

where \( \varepsilon \) is the molecular weight ratio of water to dry air (= 0.622), and \( P_w \) is the partial pressure of water vapor that is obtained In the above equation, \( P_w \) is obtained from the relative humidity (RH) and saturation vapor pressure \( (e_w) \) as recommended from World Meteorological Organization (WMO), Guide to Meteorological Instruments and Methods of Observation (CIMO Guide) and given by

\[ P_w = \frac{RH}{100} e_w \]  

\[ e_w = 6.112 e^{(17.62 T/(243.12+T))} \]  

2.3. Water vapor mixing ratio
In the atmospheric science, the mixing ratio is designed as the ratio of amount mass in a constituent that in a given volume to the total amount of mass from all elements of air in that volume [10]. In this case both of air and water vapor show gaseous constituents, but they are not in condensed phase water or particulate matter. The mixing ratio has advantage in the atmospheric chemical applications which it unchanged by the differences of altitude associated in pressure and temperature or with meteorological variance. In addition, according to equation of state, their concentration is more influence on pressure and temperature.

Related to water vapor, it can be measured with the mixing ratio as called water vapor mixing ratio. It has a definition as the mass of water vapor per mass of dry air, typically expressed in kilogram per kilogram. The equation (1) is describing how to calculate the water vapor mixing ratio \( (w) \) [11].
Since the unit of water vapor content is kilogram per kilogram and mixing ratio of trace gases are commonly given in units of part per million (ppm), then its unit should be converted to ppm unit. In term of mass per mass, 1 ppm is equal to 1 milligram (mg) per kg. From this conversion, it will obtain 1 kg/kg is equal to 1000000 ppm.

3. Result and Discussion

Figure 3 shows the trend all the parameters which measured by the system from 20 to 23 December 2016. The alphabetic letter in this figure presents the sub figure for each parameter. The a, b, c, d, e is represented for pressure (P) in mbar, temperature (T) in degree Celsius, relative humidity (RH) in percent, precipitable water vapor (PWV) in millimeter, and water vapor content (wp) in part per million (ppm), respectively. All parameter that shows in this figure has interval of one-minute measurement. In addition, the empty value was shown in this figure due to the system have loss of the power supply as of the data is not available at that time.

![Figure 3. Variation (a) Surface pressure, (b) temperature, (c) relative humidity, (d) water vapor content, and (e) precipitable water vapor variations for the period of 20 – 23 December 2016 at UKMB station](image)

Look into the pattern of P, T, RH, PWV and wp, they have an interrelationship to each other. According to Figure 3, the temperature have trend at a mid-day will be higher as compared during the night time. In addition, during the four days measurement, the temperature has a reached maximum value in the second day at about 36.55 °C. Opposite trend was showed by relative humidity, where it will be lower at a mid-day and rise in the night. Since the moisture will decrease in conjunction with the rising of temperature, and vice versa. On the other hand, the pattern of pressure is more influence on the height of site position. The higher of sensors installed, the air pressure in the air will be higher since the air layer stretched and thinned. From the measurement, the pattern of pressure at a mid-day time will be decreasing and rising at night time. It will be happened due to the Coriolis Effect.

Related to the other result as thought the PWV and water vapor content, it can be shown in Figures 3d and 3e. Both of the PWV and wp have a trend is closely correlated to each other. As can be seen, the trend of PWV showed a similar pattern to the wp. It can identify that the distribution of wp varies from time-to-time follows the PWV variations, only difference in varying of both ranges. During the four days measurement the range of PWV for this area is varied about 40.54 mm to 55.13. At the same time, the water vapor content has varying from 15240 ppm to 2240 ppm. From the result, it also able to indicate the PWV and wp variation during the last day measurement have a close variation between night time and day time. It could be happen due to light precipitation occurred in this area which was caused a slightly increase in the water vapor during nighttime. Moreover, both of
wp and PWV have more influenced by relative humidity parameter compared to the other surface meteorological parameters. By comparing Figures 3c, 3d, and 3e, it can be noticed from their pattern that either wp or PWV is closely correlated with the relative humidity. It can be seen at the trend of relative humidity rise, either pattern of PWV or water vapor content also rise and vice versa. To clarify the measurement of water vapor content, the relationship between water vapor content and PWV is plotted in Figure 4. The result demonstrated that either water vapor content or PWV have a good relationship, where all data points from them are roughly fall into the line trend. In addition, both water vapor content and PWV have a strong linear correlation with $r = 0.976$ at the 99% confidence level.

![Figure 4. Relationship between water vapor content and PWV in UKMB station for the period of 20 – 23 December 2016](image)

### 4. Conclusion

For the first time, this study reports the successful of estimation of water vapor content with the mixing ratio method in the area of UKMB station. The water vapor content data was compared with PWV ANFIS and found that the water vapor content was a good relationship with the GPS PWV. In addition, either of water vapor content or PWV was found their values are influenced by the surface relative humidity. The patterns of them are following the surface relative humidity. During the four days measurement, the reading of PWV and water vapor content values in the normal air is 46.22 mm and 18263 ppm on average, respectively. By this result, the water vapor mixing ratio will be implemented in the microcontroller to monitor greenhouse gasses variation in Pekan, Pahang peatland.

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