Deriving the highest persisting monthly 24-hour dew points in Malaysia for the estimation of PMP

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Abstract The daily dew point records of 24 meteorological stations in Malaysia, for the 10 years 1994–2003, have been used to provide generalized maps of the highest persisting 24-hour 1000 mb dew points for each month of the year, ranging between 24 and 26ºC. These dew point maps can be used for obtaining the climatologically highest amount of atmospheric moisture that might be expected to occur over any location in Malaysia from tables such as those given in WMO (1986) needed for storm maximization and consequently for estimation of the probable maximum precipitation, PMP.

Key words dew point; probable maximum precipitation; moisture maximization factor, precipitable water

INTRODUCTION

Malaysia (Fig. 1) has an equatorial climate with high temperatures and high humidity of over 80% year round, except in the highlands. The country is greatly influenced by both the southwest (June –September) and the northeast (November–February) monsoons. These monsoons bring heavy rainfall all over the country resulting in severe floods. There are many places in Malaysia which have recorded about 400 to 800 mm of rainfall within a period of 24 hours (Desa *et al*., 2001, 2003; Desa & Rakhecha, 2004). It is of considerable importance in flood hydrology to find out the maximum possible rainfall for a given duration in a given location. Conceptually this value can be seen as the upper bound of rainfall amount, the probable maximum precipitation (PMP) (WMO, 1986, 1994). Estimates of PMP are required for the derivation of probable maximum flood (PMF) for spillways of large dams.

There are two basic methods of PMP estimation, the statistical method and the physical or hydrometeorological method. Most countries often prefer the physical method based on the transposition and moisture maximization of rainfall depths obtained from the major rainstorms. Moisture maximization is the enhancement of storm rainfalls by a numerical factor known as the Moisture Maximization Factor (MMF). The MMF is calculated as the ratio of the highest amount of moisture or precipitable water (W_m) that might be expected in the study area to the amount of moisture estimated in the concerned storm (W_s). The main purpose of moisture maximization is to estimate the upper bound of rainfall. The most important factor in moisture maximization is the estimation of the highest amount of atmospheric moisture in the study area and the amount of moisture in the storm.

The US Weather Bureau (1960) and Reitan (1963) showed that the moisture in an air mass that produces high rainfalls can be estimated from the surface dew point temperatures decreasing with height at the saturated pseudo-adiabatic lapse rate. In such moisture maximization studies, the climatological highest value of atmospheric moisture in the specific area is estimated from the highest persisting 12-h or 24-h dew points ever recorded. On the other hand, the amount of the moisture during the storm is estimated from the highest 12-h or 24-h persisting dew points of the air which produced the rain. Thus, the information on the highest 12-h or 24-h persisting dew points, based on the long period of data for various months of the year at several stations in Malaysia, has potential value in estimating the highest amount of moisture for PMP work. Many countries such as Australia (Bureau of Meteorology, 1994), India (Rakhecha *et al*., 1990), Pakistan (Malik, 1964) and USA (US Weather Bureau, 1960) have published mapped values of the highest 12-h or 24-h persisting dew points, but this information is not published for Malaysia.

This paper presents maps of the highest 24-h persistent dew points generated for Malaysia that can be used to obtain the highest values of moisture that might be expected at any location in Malaysia.

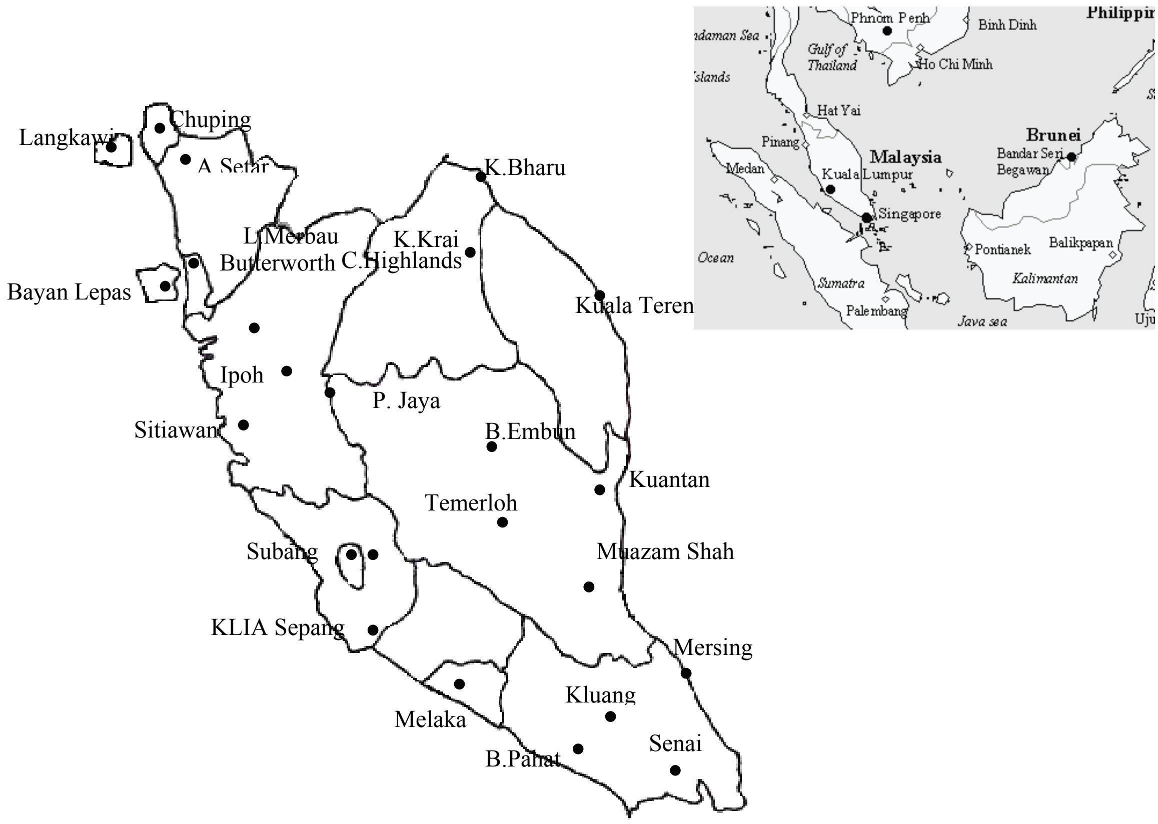

Fig. 1 Locations of meteorological stations in Peninsular Malaysia used for the study (not to scale).

DEFINITIONS OF PERSISTING AND HIGHEST PERSISTING DEW POINTS

The amount of moisture in an air mass can be calculated from the single observation of the highest dew point temperature, but the method has synoptic limitations and such measurements are susceptible to observational error (WMO, 1986). The moisture itself must persist for a period of several hours rather than minutes. The dew point value used to estimate the storm and the highest moisture over an area should be based on all dew point observations during period of 12 or 24 hours. The lowest temperature of all observations during the 12- or 24-h period is called the 12-h or 24-h persisting dew point temperature. For example, Table 1 shows a series of dew points observed at 12 hourly intervals on four days, varying from 20 to 24°C. It shows that the 24-h persisting dew points are 22°C, 23°C, 23°C, 24°C, 20°C and 20°C. Hence, the highest persisting 24-h dew point from the series is 24°C.

Table 1 Dew points observed at 12 hourly intervals.

	Day 1		Day 2		Day 3		Day 4	
Time(GMT)	00	12	00	12	00	12	00	12
Dew point °C	22°	23°	23°	24°	26°	24°	20°	21°
24-hr persisting dew point °C	22		23	23	24	20	20	

DATA USED

The daily dew point temperatures at meteorological stations are continuously observed by the Malaysian Meteorological Service (MMS). For this study, the daily dew point temperatures and the daily minimum temperatures for 24 stations for a period of 10 years, from 1994–2003, and for all 12 months, January to December, were used (Fig. 1 and Table 2).

Table 2 Geographical characteristics of stations used.

Station	Height (m)	(ºN)	(ºE)	Station	Height (m)	(ºN)	(ºE)
P. Langkawi	6.4	6º 20′	99º 44′	Batu Embun	59.5	3º 58′	100º 21′
Bayan Lepas	–	5º 18′	100º 16′	Subang	16.5	3º 07′	101º 33′
Butterworth	2.8	5º 28′	100º 23′	Petaling Jaya	45.7	3º 08′	101º 39′
Alor Setar	3.9	6º 12′	100º 24′	Muadzam Shah	33.3	3º 03′	103º 05′
Chuping	21.7	6º 29′	100º 16′	KLIA Sepang	–	2º 43′	100º 42′
Kota Bahru	4.6	6º 10′	102º 19′	Temerloh	39.1	3º 28′	100º 23′
Kuala Krai	68.3	5º 32′	100º 12′	Kuantan	15.3	3º 47′	103º 13′
K. Terengganu	35.1	5º 23′	103º 0′	Melaka	8.5	2º 16′	102º 15′
Setiawan	7	4º 13′	100º 42′	Batu Pahat	–	1º 52′	102º 59′
Lubuk Merbau	–	4º 48′	100º 34′	Kluang	88.1	2º 01′	103º 19′
Ipoh	40.1	4º 34′	101º 08′	Mersing	43.6	2º 17′	103º 50′
Cameron Highlands	1545	4º 28′	101º 22′	Senai	–	1º 30′	103º 40′

DETERMINATION OF THE HIGHEST 24-h PERSISTING DEW POINTS

In determining the 24-h persisting dew point, the daily dew point values of all observation times during the 24-h period were examined for their reliability, and then the lowest of these values was selected as the 24-h persisting dew point. Daily minimum temperatures were also used to ensure that the dew point persisting for any period had not exceeded the minimum temperature observed during the period.

A series of 24-h persisting dew points for each month, January to December, for each of the 10 years were determined for each station. Thus, the maximum persisting dew points for each month and for all years were determined and the highest, out of these was taken as the highest persisting 24-h dew point for that month. The monthly highest persisting dew point values for each station were reduced pseudo-adiabatically to the 1000 mb level so that the estimates at stations at different elevations would be comparable (WMO, 1986).

GENERALIZED MAPS OF THE HIGHEST 24-HR PERSISTING DEW POINTS

The monthly highest persisting 24-h dew point values of 24 stations were plotted on the maps of Malaysia and isotherms were drawn. The resulting generalized maps for January to December are shown in Figs 2 and 3 The spatial pattern of the highest persisting dew points, which is a measure of the climatologically highest moisture over an area, depends upon the direction of moisture flow, topographic barriers and other geographic factors. The isotherms of the highest dew points range from about 24ºC to 25ºC in January–March and in July–December, and from 24ºC to 26ºC in April–June. The coastal areas receive heavy rainfalls from the southwest and northeast monsoons consistent with the high degree of moisture and highest dew points observed around the coasts. The low values of dew points are observed in the interior parts of the country extending from north to south, reflecting the decreasing effect of the inflowing moist currents of the southwest and northeast monsoons.

These dew point maps can be used to determine the highest persisting 24-h dew point for any location during January–December in Malaysia. Moreover, these maps will help in maintaining consistency and uniformity between estimates of dew points in various parts of the country.

MOISTURE AND PRECIPITABLE WATER

The estimation of moisture in the air is extremely useful for storm maximisation. The moisture content of air is the amount of water vapour present in the air. It is highly variable in space and time. The concentration can be as high as about four per cent by volume in hot humid air to more than a hundred times less in very cold air and as such is related to the temperature of the air (WMO, 1986). The temperature at which the unsaturated air becomes saturated when cooled at a constant pressure is the dew point temperature.

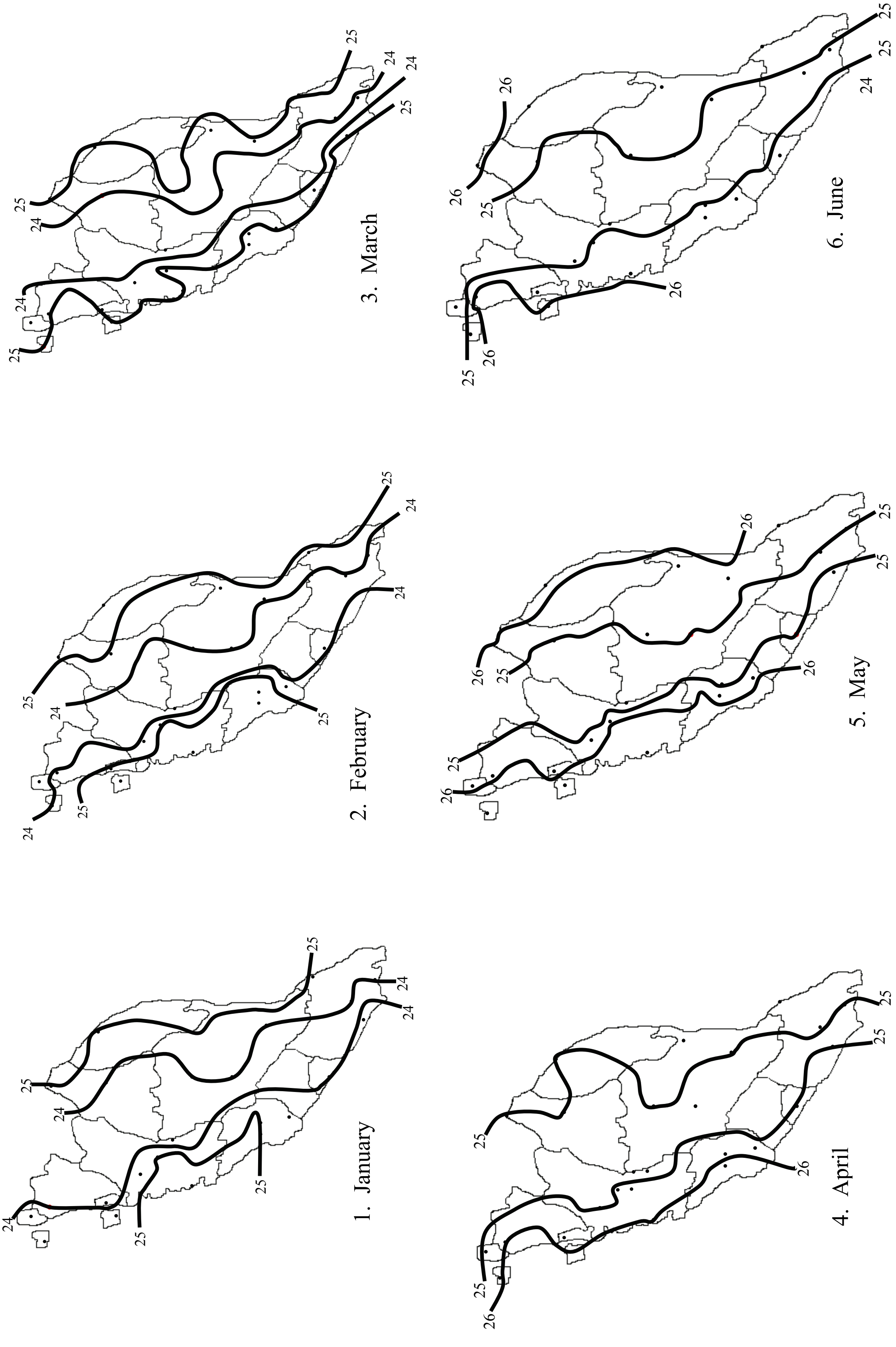

Fig. 2 Highest persisting dew points (°C) for 24-hours 1000 mb for January to June (not to scale).

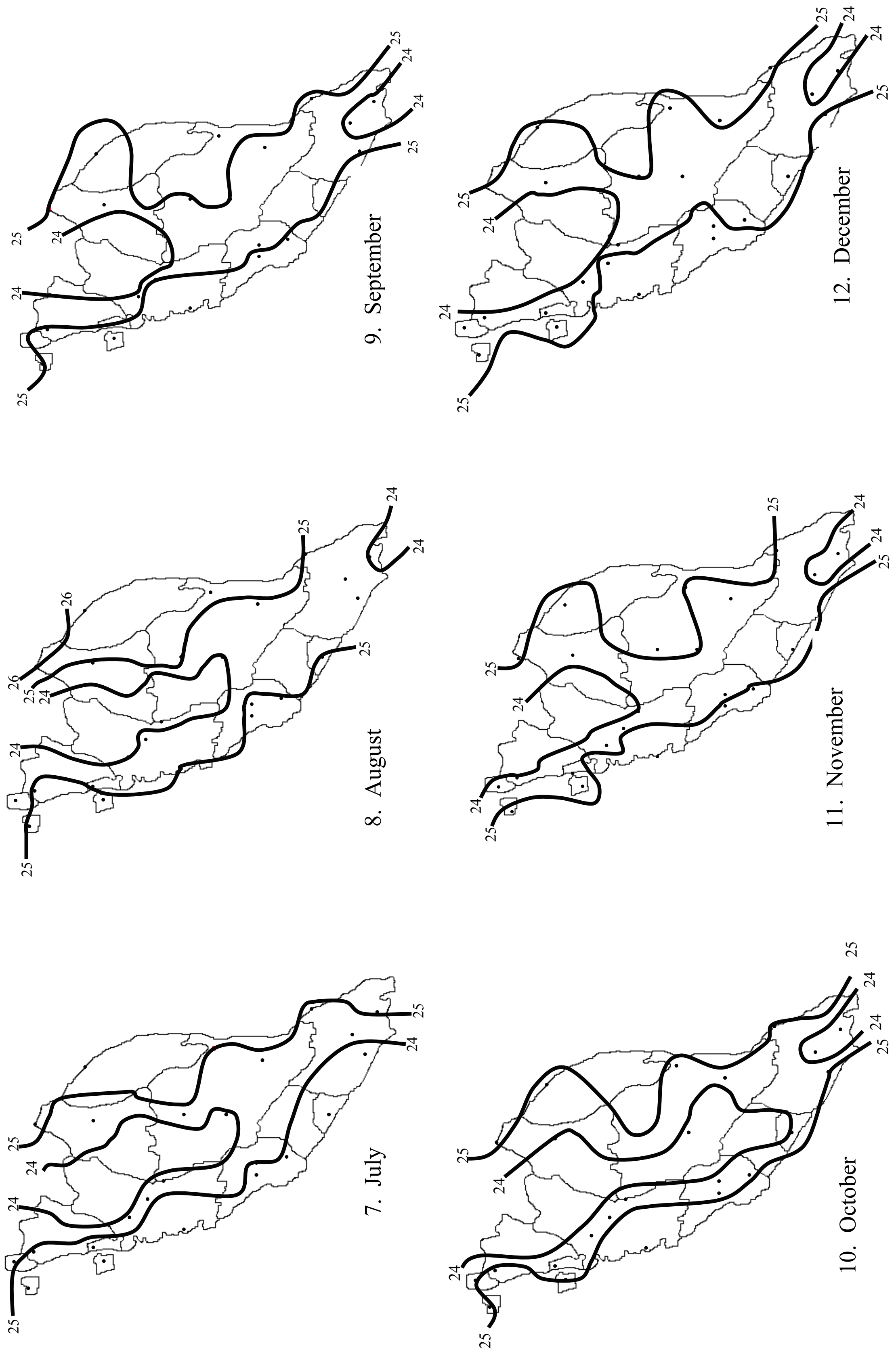

Fig. 3 Highest persisting dew points (°C) for 24-hours 1000 mb for July to December (not to scale).

The moisture content in the air is expressed in terms of the precipitable water, which refers to the amount of liquid water that would form in an air column of unit cross section if all the water vapour in it (extending from the surface to the top of the atmosphere) were condensed. It is expressed in height in millimetres or inches. The largest part of the vapour content of the atmosphere is present in the lower layers, close to the ground. If the dew point and the pressure in a given volume of air are known, the amount of water vapour in the volume can be determined by thermo-dynamic considerations. In the case of the atmosphere, however, the dew point is known only at the surface. So when determining the total precipitable water, the assumption is made that the dew point in the atmosphere varies with altitude according to the pseudo-adiabatic lapse rate. This assumption has been used to compute the precipitable water in a column of the air from different values of dew points.

The depth of precipitable water from the 1000 mb surface to various altitudes or pressure levels as a function of the 1000 mb dew point are given in Eihle *et al*. (1968) and WMO (1986). However, in storm maximization, only the depth of precipitable water from the 1000 mb to the 200 mb level is used. The 200 mb level is generally accepted as the top of the storm (WMO, 1986). Table 3 gives the depth of precipitable water in the column of air from 1000 mb to 200 mb in a saturated pseudo-adiabatic atmosphere as a function of the 1000 mb dew point for use in storm maximization. The precipitable water in a column of air above the 1000 mb level corresponding to a dew point of 25ºC at 1000 mb level is 80.8 mm. If continuous soundings are available, the amount of precipitable water (W) in a column of air of height Z can also be calculated as:

$$W = \int_0^z d_w \, dz \qquad (1)$$

$$= \int_0^p \frac{d_w}{d_a * g} dp \qquad (2)$$

$$= \int_0^p \frac{q \; dp}{g} \qquad (3)$$

where d_a and d_w are the densities of air and water vapour respectively, q is the specific humidity, p is the atmospheric pressure at altitude z, and g is the acceleration due to gravity. The above equations can be used to determine the precipitable water between two levels in an air mass knowing the variation of humidity and pressure with height.

Table 3 The depth of precipitable water (mm) between the 1000 mb surface and 200 mb levels in a saturated pseudo-adiabatic atmosphere as a function of the 1000 mb dew points (ºC).

Dew point (ºC)	Precipitable water (mm)	Dew point (ºC)	Precipitable water (mm)	Dew point (ºC)	Precipitable water (mm)
19.0	48.3	23.0	67.9	27.0	95.9
19.5	50.4	23.5	71.0	27.5	100.1
20.0	52.6	24.0	74.3	28.0	104.5
20.5	54.8	24.5	77.5	28.5	109.1
21.0	57.1	25.0	80.8	29.0	113.9
21.5	59.5	25.5	84.3	29.5	118.9
22.0	62.1	26.0	88.0	30.0	124.2
22.5	64.9	26.5	91.9		

MOISTURE MAXIMIZATION

The moisture maximization of an observed storm rainfall aims to determine the rainfall which would result if the moisture available to the storm was the highest (maximized) over the entire project area. The moisture maximization factor (*MMF*) which is applied to the observed rainfall is defined as the ratio of the climatological highest precipitable water (W_m) to the precipitable water estimated for the storm concerned (W_s). Mathematically:

$$MMF = {W_m}/{W_s} \qquad (4)$$

Let us assume a rainstorm occurring in November. The representative persisting 24-h, 1000 mb dew point for the storm is 23ºC and the highest persisting 24-h 1000 mb dew point where the storm is transposed is 25ºC, for example near Temerloh. The MMF is computed as follows:

1. Storm dew point = 23ºC
2. Storm precipitable water between 1000 mb and 200 mb (W_s) = 67.9 mm (Table 3)
3. Highest persisting dew point over the area = 25ºC
4. Precipitable water between 1000 mb and 200 mb (W_m) = 80.8 mm (Table 3)
5. Using equation (4), $MMF = 1.19$

The maximized rainfall is given by the product of MMF and the observed rainfall.

CONCLUSIONS

The paper presents a contribution to the knowledge on the highest persisting dew points for Malaysia. The results are presented in mapped form, and should help in calculating the highest moisture content of the atmosphere for any location within the country for any PMP studies.

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