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An attempt to measure evaporation from a Class-A pan using naphthalene sublimation

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Abstract

Determination of water losses via evaporation from a natural and man-made reservoir is of crucial importance for water budget calculations. However, the problem of evaporation measurement from free water surfaces has not been solved completely. In many applications, Class-A pans are generally used for measuring evaporation from free water surfaces. However, it is impossible to measure the evaporation by a Class-A pan when the air temperature is below freezing point. Therefore, Class-A pans must be removed from measurement stations during winter months. Under these considerations, we aimed to develop a new measurement method in order to overcome the disadvantages arising from measurements using a Class-A pan. For this reason, a relationship between mass losses due to naphthalene sublimation and evaporation from the free water surface has been investigated experimentally. In the experiment, evaporation from the Class-A pan and the sublimation from naphthalene block were measured using a hook-gauge and a precision balance, respectively. The Pearson correlation coefficient between these 2 mass losses is found to be 0.86, which is fairly encouraging for this first attempt.

Key Words: Class-A pan, Evaporation, Naphthalene, Sublimation.

Introduction

In spite of the fact that there are several methods used in applications, the issue of determination of evaporation losses from free water surfaces is not resolved completely. The methods used in the application can be listed as water budget, energy budget, mass transfer, empirical formulas, and direct measurements. The water budget method does not give reliable results, especially for a short period of time. Moreover, the energy budget methods include many terms that require precise measurements. The mass transfer methods, which are based on Dalton's law, give reasonably good results in many cases. Empirical formulas require careful application because of (a) difficulties in the measurement of variables at other places, (b) their limited range of accuracy in the model structure, and (c) difficulties in comparing one method with another due to method-specific model

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variables (Ali et al., 2008). Direct measurement of evaporation from free water surfaces also has some problems, which will be discussed later on.

Determination of evaporation losses from land surfaces is also an important task, especially for agricultural purposes. There are several instruments such as the evapotron (Dyer and Maher, 1965), fluxatron (Dyer et al., 1967), and hydra (Shuttleworth et al., 1988) for measurement of evaporation losses from land surfaces. It should be kept in mind that these instruments give reliable results, especially in fine weather conditions (McNeil, 1997).

Measurement of evaporation from large water surfaces can be made directly or indirectly by using a Class-A pan. In order to conduct direct measurements, a Class-A pan is placed as if it floats freely on a lake surface. However, this way of measurement causes some serious measurement errors due to wave motion on the water surface. In such measurement conditions, it is always possible that waves cause some water masses to enter the pan. In the indirect measurement approach, the Class-A pan is placed somewhere out of the water body. After the measurements have been obtained, they are multiplied by a coefficient, known as the pan coefficient. This process converts the pan measurements into the evaporation amount from the water body, which is close to the measurement site (Viessman and Lewis, 2003).

Today, Class-A pans are widely used all over the world. However, before the frost season begins, measurements with Class-A pans must be terminated. This is one of the main disadvantages of these instruments. Due to quick heat losses, water mass in the pan freezes more quickly than that in a lake or a reservoir. In the cold season, however, evaporation from a lake surface continues at a decreased rate. Then the following question arises: is it possible to find a more practical way of measuring the evaporation losses from a free water surface than the conventional methods? A possible answer to this question can be found in the study conducted by Bernier (1987). In his study, he used the sublimation property of naphthalene under normal atmospheric conditions and determined the average wind speed with great accuracy.

The purpose of this study is to investigate the relationship between the mass loses of naphthalene and water substances without considering the effects of other meteorological variables. In the organization of this paper, the measurement set is introduced in detail in the following section, and the results and discussion are set out in the last section of the paper.

Measurement set

Naphthalene can be found in any markets in various forms such as powder, fine plates, and moth balls. Naphthalene in the form of powder and fine plates is not suitable for our purpose because wind induced turbulence will cause some naphthalene particles to be scattered into the environment. In addition, moth balls are also not suitable because sublimation will cause their surface area to be gradually reduced over time, but the evaporating surface area remains unchanged during evaporation measurements with a Class-A pan. Thus, in order to keep the sublimating surface of naphthalene constant during the observation period, cylindrical cartons 4 cm in height and 7.9 cm in diameter were prepared. After this step, 100% pure melted naphthalene was poured into the cylindrical carton to ensure that the surface area of the naphthalene block remained constant during the sublimation process.

It is important for the naphthalene block to be placed at the same level as the Class-A pan. Thus, the naphthalene holder (Figures 1 and 2) was installed so that the naphthalene surface and water surface were at the same level. Although naphthalene is a chemical substance that does not dissolve in water, the naphthalene surface must be free of rain water because rain water will cover the naphthalene surface partially or completely and cause the sublimation process to be affected to a certain extent. In order to protect the naphthalene surface from rain water, as shown in Figures 1 and 2, the naphthalene holder was placed under a transparent cover.

Figure 1. Location of measurement elements in the observation station. A: Naphthalene holder (A1: Transparent shelter, A2: Naphthalene, A3: Carton cup, A4: Holder for shelter and naphthalene block), B: Class-A pan, C: Rain gauge, D: Precision balance (inside the box).

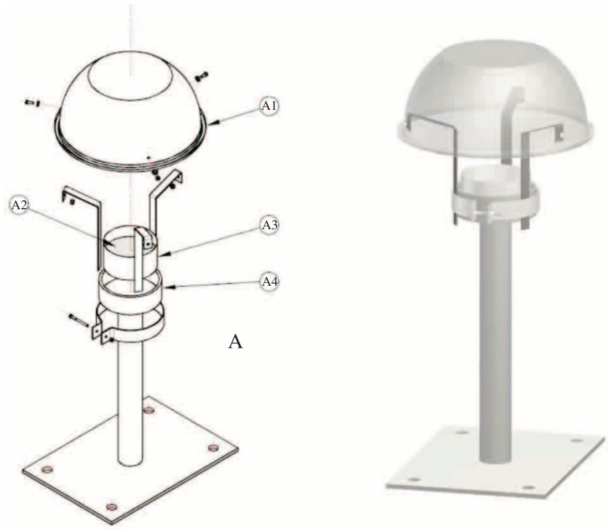

Figure 2. Exploded assembly (left panel) and rendered drawing (right panel) of the naphthalene holder marked with the letter **A** in Figure 1 (A1, A2, A3 and A4 are as explained in Figure 1).

The naphthalene holder was firmly fixed to the ground with the aid of 4 iron rods. The naphthalene holder was installed near the Class-A pan in order to ensure that all parts of the measurement set were subjected to the same meteorological conditions. Besides the naphthalene holder and Class-A pan, in the observation station, there are a rain gauge to measure the rainfall amount and a precision balance to weigh the naphthalene block. Weighing was done using a Precisa XB 220A (Swiss made) electronic balance, which can measure with a precision of 0.0001 g.

It is obvious that one of the most important parts of the measurement set is the Class-A pan. Water level in the pan and the sublimating surface of the naphthalene block are at the same height from the ground. The success of the study depends on obtaining precise measurements of water level changes. For this purpose, a hook-gauge, which is simply a micrometer, was used.

All measurements (rainfall, evaporation, and sublimation) were recorded once a day at the local time 14:00. An amount of water equal to the loss of water due to evaporation was added to the pan after every measurement.

Furthermore, it is generally expected that some problems are encountered in the case of measurements obtained in the open air. Some problems and proposed solutions to these problems are as follows:

1. To protect the precision balance from the wind, rain, and other negative effects, it is placed in a galvanized iron box. Although the balance has its own protection against external effects, the balance does not reach the stable condition necessary to start the weighing operation because on opening the cover of the box the air movement outside the box causes pressure changes that make the balance unstable. To solve this problem, a circular window with a diameter of 2 cm was created in the cover of the box, and after putting the naphthalene block on the scale the weighing results were read without opening the cover of the box.

2. Dust from the immediate environment causes some adverse effects on the measurement systems. Dust from the atmosphere settles at the bottom of the Class-A pan, producing a thin layer of mud. This muddy layer causes the reflection of radiation from the pan bottom to vary to a certain degree. In order to decrease this adverse effect, the Class-A pan was cleaned periodically once a week.

3. The dust problem mentioned above is valid not only for the Class-A pan, but also for the naphthalene block. Absorption of incoming solar radiation by dust particles affects the sublimation rate of naphthalene. To eliminate this negative effect, the dust particles were removed from the naphthalene surface with a smooth brush once a week. A possible mass loss of naphthalene during the removal of dust particles was taken into consideration by weighing afterwards.

4. The cover of the naphthalene holder is made of hard and transparent plastic. Over the course of time, the properties of this cover change and so it was renewed once a month. In addition, the cover will cause the incoming solar radiation to change to some degree. This adverse effect will show up as a systematic error in the measurements. It is expected that the differences between sublimation and evaporation will be slightly greater without the cover.

Results and Discussion

Measurements were conducted every day between 11 June and 30 September 2007 during which 112 data points were collected. It is assumed that this period of time will be sufficient to determine properly the relationship between the mass losses for the summer months. During the observation period, evaporation, precipitation, and naphthalene were measured and recorded regularly. Time series of daily evaporation and sublimation rates are given in Figures 3 and 4. In addition, some statistical indicators of the variables and the observations made during September 2007 are given in Tables 1 and 2, respectively.

Table 1. Some statistical indicators of the whole data set.

	Sublimation	Evaporation
Mean	2.157	5.344
Standard Deviation	0.736	1.645
Skewness	0.107	-0.431
Minimum	0.5989	1.0800
Maximum	4.1604	9.0400

Table 2. A sample of observation values measured during September 2007.

Days	Sublimation (g)	Evaporation (mm)	Rainfall (mm)
1	2.9040	5.0325	0
2	2.9041	7.0350	0
3	1.9246	4.0750	0
4	1.2530	3.1200	0
5	0.9512	2.5000	0
6	1.5420	3.5200	0
7	1.3500	3.3200	3.75
8	0.8110	2.9650	13.25
9	1.0183	3.2450	0
10	0.9027	2.3400	0
11	1.3158	3.9000	0
12	1.3915	3.8000	0
13	0.9772	3.0800	1.625
14	0.9792	3.9250	0
15	1.4437	4.1440	0
16	1.2836	4.0000	0
17	1.2915	4.1150	0
18	1.3575	4.1750	0
19	1.2818	3.1700	0
20	1.7668	4.6350	0
21	1.0933	2.6600	2.75
22	0.8013	1.0800	1.5
23	1.0148	1.6650	4
24	0.5989	1.6550	1.75
25	0.9959	1.2050	0.25
26	1.2120	3.4150	0
27	1.4869	3.3000	0
28	1.3503	3.1950	0
29	1.4285	3.7850	0
30	1.7222	4.8600	0

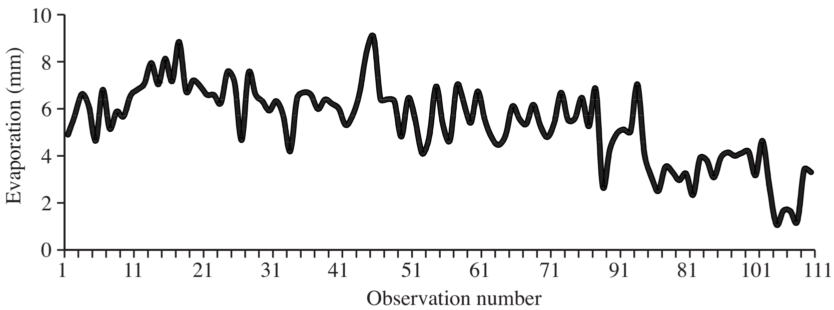

Figure 3. Time series of daily evaporation amount.

Extreme values of both series coincide well with each other. The minimum of these extreme values also coincide with rainy days (Figure 5) during the measurement period. Moreover, towards the autumn, the expected trend is seen clearly in the evaporation time series. This decreasing trend is also evident in the time series of daily sublimation rates. The scatter diagram of the sublimation and evaporation amounts is given in Figure 6. As seen from this diagram, there is strong linear relationship between the variables. To investigate the linear relationship between the variables, it is necessary to construct a regression equation in the form:

$$Y = a + bX \tag{1}$$

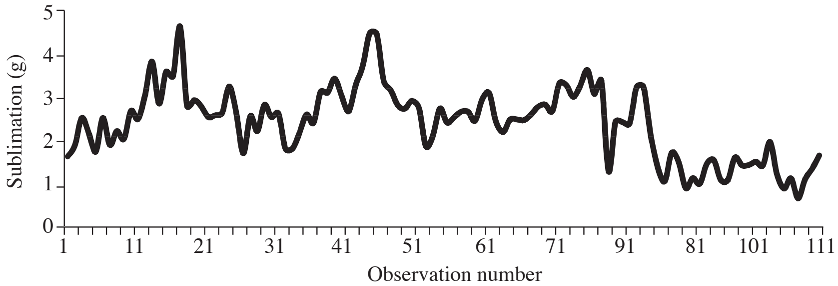

Figure 4. Time series of daily sublimation amount.

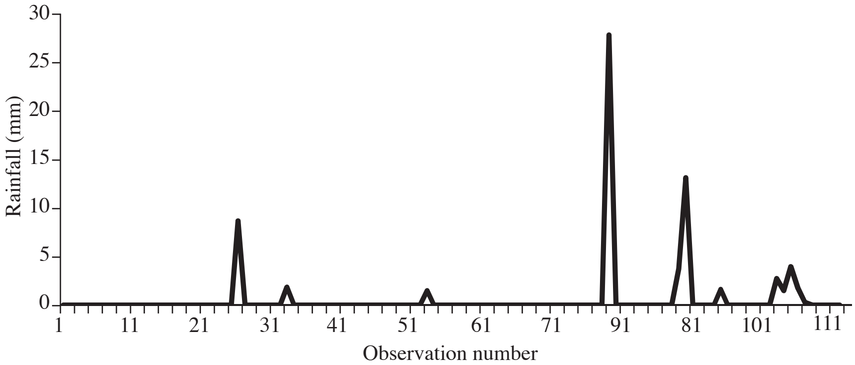

Figure 5. Time series of daily rainfall amount.

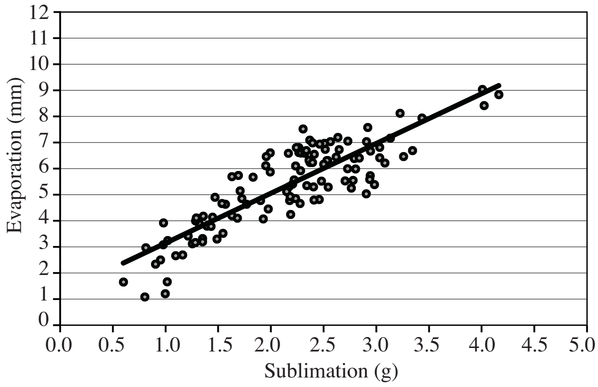

Figure 6. Scatter diagram of evaporation vs. sublimation.

In this equation, the variable X is the predictor (in this study, sublimation amounts) and the variable Y is the predictant (in this study, evaporation amounts). The coefficients a and b are the regression coefficients to be derived from the observations. If we denote the mean values of the variables as $\overline{X}, \overline{Y}$ then the regression coefficients can be given as

$$a = \overline{Y} - b\overline{X} \tag{2}$$

and

$$b = r_{XY} \frac{S_Y}{S_X} \tag{3}$$

In Eq. (3), S_X and S_Y are the standard deviation of the variables and r_{XY} is the Pearson correlation coefficient, which is a measure of the linear relationship between 2 variables. The Pearson correlation coefficient can be calculated from the number of N observations via the following equation:

$$r_{XY} = \frac{\sum_{i=1}^{N} (X_i - \overline{X})(Y_i - \overline{Y})}{(N-1) S_X S_Y} \tag{4}$$

From Eq. (4), r_{XY} was calculated as 0.861. By using this value and the related statistics given in Table 1, the regression coefficients were found to be a= 1.193 and b= 1.924. All of these statistics are statistically significant at the level of 0.05. Considering the above findings the regression equation given in Eq. (1) takes the following form:

$$Y = 1.193 + 1.924X \tag{5}$$

The determination coefficient, which is calculated as $R^2 = r_{XY}^2$, is an important statistic to interpret the results of the regression analysis. The determination coefficient for this analysis was calculated to be R^2= $0.861^2 \cong 0.74$. This states that 74% of the variance of Y can be explained by the variable X. The unexplained part of the variance of Y can result from either measurement errors or an insufficient number of independent variables. The last part of this statement means that the variable X alone is not enough to present properly the variability of Y.

Although evaporation losses are considerable during the summer months, they continue during the winter months as well. As given in Table 1, the minimum value of evaporation is 1.08 mm for the current measurement period, but during the winter months evaporation amounts fall well below this value. Thus, Eq. (5) can be considered valid only for the summer months.

The results of this study aiming to develop a useful and practical evaporation measurement instrument are encouraging. However, there are some sources of errors that have to be eliminated. A high determination coefficient with some improvements and modifications to the experiment set is expected. The problems encountered during the experiment and the proposed solutions mentioned in the section "Measurement set" provide some important clues about the necessary improvements and modifications to the experiment set. In addition, to explain the significant part of the temporal variation in evaporation, air temperature, humidity, wind speed, and other meteorological variables may be considered together with the naphthalene sublimation. As mentioned above, naphthalene does not dissolve in water. This means that the sublimation rate of naphthalene does not depend on the humidity conditions of the atmosphere, in contrast to pan evaporation. Thus, the relative humidity should be considered together with the naphthalene sublimation to represent pan evaporation properly.

In mid-latitudes, it is difficult to obtain continuous evaporation records. Because in cold seasons water in the evaporation pan freezes quickly, which makes measurement impossible. Therefore, in cold seasons, the evaporation measurement set is removed from the observation station during the time when the water might freeze. Therefore, in cold seasons, one cannot know the water losses either by evaporation or by sublimation from free water surfaces. It seems that the proposed method has potential for use in such situations.

Furthermore, snow cover remains on the ground and begins to melt during the warming phase. It is important to estimate the total volume of water due to the melting of snow accumulated on the ground. This information is vital for water engineers to operate reservoirs efficiently. This requires the total mass losses from the snow surface due to sublimation. Depending on the meteorological conditions prevailing on the snow surface, a huge amount of water is lost via sublimation (Fassnacht, 2004; Molotch et al., 2007). The proposed method can be further developed to resolve this problem as well.

In modern meteorological observation stations, automated weather observing systems (AWOS) have begun to be widely used in comparison with the conventional measurement systems. AWOS is a compact collection of many sensors that realize the measurements of temperature, humidity, precipitation, wind speed and direction, solar radiation, etc. Unfortunately, it is not possible to attach a Class-A pan-like evaporation measurement system to AWOS. Thus, the proposed method has potential for use in such a state-of-the-art measurement system.

In the present study, naphthalene was used in order to take advantage of its sublimation property. This does not mean that other chemicals similar to naphthalene cannot be used. It should be kept in mind that this is the first experiment in this field. Thus, the authors think that the experiment set needs further improvements to obtain results more accurate than those obtained in the present study.

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