An experimental study on drying-up paved surfaces

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1 On the representativeness of road condition measurements

The quality of automatical road condition measurements depends i. a. on the road condition's spatial inhomogeneity. The state of dampness on a road, for instance, is usually quantified from routine observations involving water film thickness measured at a point of the road surface (Norrman, 2000). However, due to the spatially varying water film thickness on a road the representativeness of such measurements for a larger road section may be questionable.

When measuring evaporation rates at a moist road surface the eddy correlation technique might provide an advantage. It implicitely integrates over a large surface area (Schmid, 2002) and thus over spatially inhomogeneous road conditions, i. e. dry patches. On the other hand the representativeness of such measurements is problematic if used in connection with areas of limited extent (Foken and Wichura, 1996). Wojcik and Fitzjarrald (2001), for example, used an eddy correlation technique in oder to obtain evaporation rates from a concrete bridge. The measurements turned out to be strongly influenced by the bridge's surrounding area.

This study adresses the use of a water film sensor and an eddy correlation system for a better quantification of the drying-up process on paved surfaces. A field campaign is undertaken. The resulting data are assessed concerning the water film sensor's performance, and the representativeness of both, water film thickness and evaporation rate measurements.

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2 Methods

2.1 The water film sensor FP2000

Texture and colour of the MicKS FP2000 water film sensor are designed to imitate a true road surface. The device is reported to measure calculational water film thickness in a range from 0 mm to 3 mm at a resolution of 0.01 mm and a relative accuracy of 20%. A sensor calibration was undertaken at the Bundesanstalt für das Verkehrswesen, Bergisch-Gladbach / Germany. The applied calibration procedure is standardised and described in Badelt et al. (2002). With the tested sensor, however, reproducibility was weak for reasons which remain unclear (see Figure 1). Therefore, a composite calibration curve was taken and used during all further calculations. The temporal change of calculational water film thickness can be determined more accurately since among the individual calibration curves the slope differs not as greatly as the value.

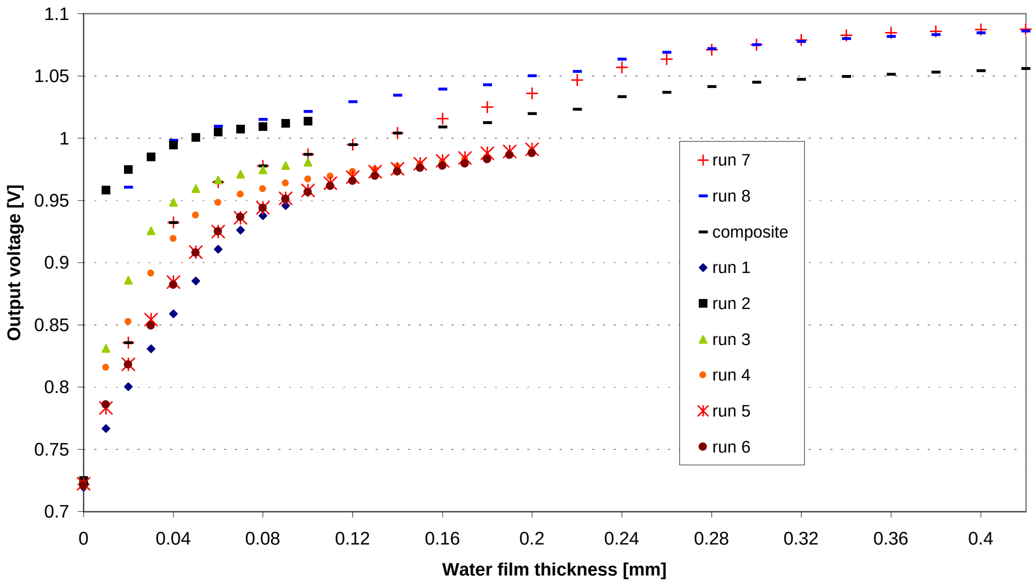


Figure 1: Calibration curves for the water film sensor.

2.2 Eddy correlation technique

The eddy correlation technique can be used for obtaining evaporation rates from a simultaneous high-frequency measurement of vertical wind velocity w, and water vapour density ρ_v. Evaporation rates are calculated from $\overline{w'\rho_v'}$, where $w' = w - \overline{w}$

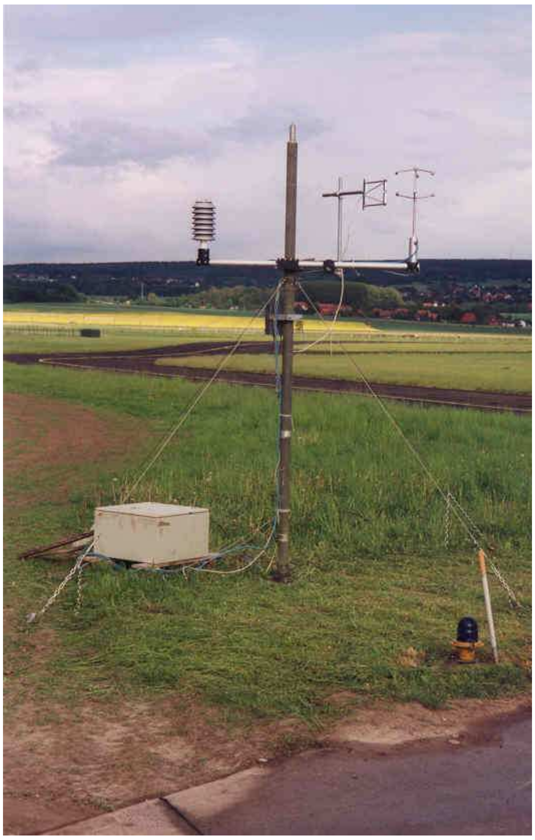


Figure 2: Measuring mast and box. The mast is equipped with a sonic anemometer/thermometer, a Krypton hygrometer, and a sensor for mean temperature/relative humidity (from right to left).

represents fluctuations in vertical wind velocity, $\rho_v' = \rho_v - \overline{\rho_v}$ fluctuations in water vapour density. The overbars represent a temporal mean of 1/2 h. Thus, one single evaporation rate value is based on a half-hour measuring "history".

The measured evaporation rates are associated with a certain area on the ground. That source area can be interpreted in analogy to the "field of view" of a measuring instrument (Schmid, 1997). Only if the source area is located roughly within the surface of interest the measurements will be representative of the latter. The source area's size and location depend on mean wind direction, measuring height, atmospheric stability and roughness of the surface.

The eddy correlation system used in this study (see Figure 2) consists of a METEK USA-1 ultrasonic anemometer/thermometer and a Campbell KH20 Krypton hygrometer. The sampling frequency is 20 Hz. For the given set of measuring devices the measuring height should not be lower than about 2.5 m in order to prevent for large measuring errors. The latter result from line averaging due to the anemometer's path length and from de-correlation due to the anemometer-hygrometer sensor separation. A continuous operation of the eddy correlation system remains limited due to window scaling of the Krypton hygrometer and a large amount of measuring data per hour.

3 Field campaign

3.1 Measuring site

The measurements took place on the air field of a military airport at Bückeburg, Niedersachsen/Germany. The air field is situated on flat terrain, about 70 m above sea level. The measuring devices (red plus signs) are located at the eastern end of a large paved area (see Figure 3). The concrete surface consist of 5m x 5m plates showing a bright-grey colour. The joints between the concrete plates are sealed with black tar. The tarmac surface shows a dark-grey colour and reveals a greater roughness than the concrete plates. The wind field can be expected to be fairly undisturbed by obstacles if the wind comes from WSW.

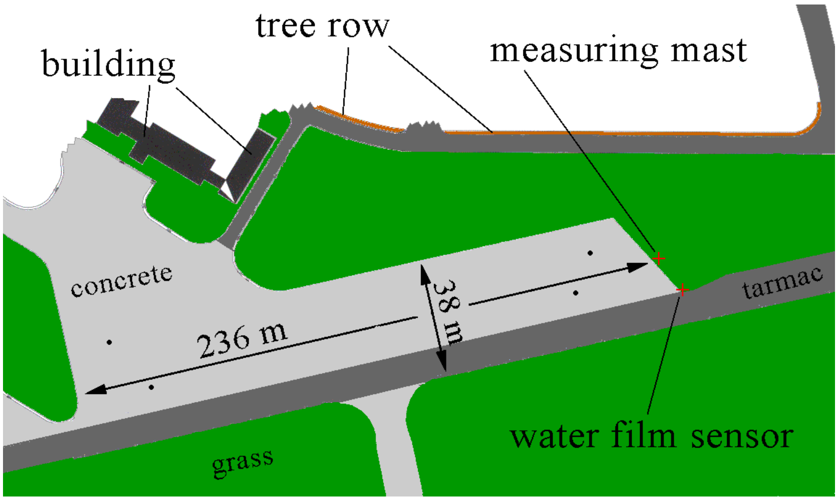


Figure 3: Plan of the measuring site [adapted from Vermessungs- und Kataster-behörde Schaumburg (2003)]. North is up.

3.2 Location of the measuring devices

The water film sensor was placed on bare soil next to the paved surface and the area around the sensor was poured with concrete (see Figure 4). Characteristics of the poured concrete such as heat capacity and heat conductance may be quite different from those of the large paved surface.

Figure 4: Water film sensor (dark round circular area). The sensor is located next to the paved surface. Sections of the grass-grown, concrete (grey) and tarmac (dark-grey) surfaces can be seen as well.

The eddy correlation mast was placed over grass 3 m away from the concrete surface. It was expected that this distance from the paved surface would not influence the flux measurements greatly.

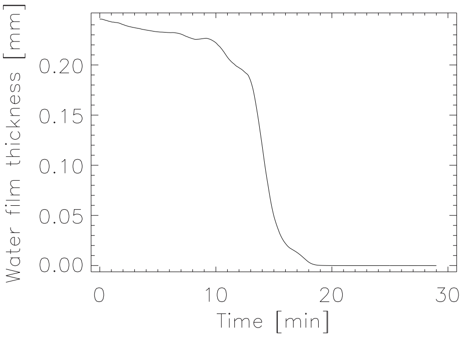
3.3 Measurements

Measurements took place on 13 days between the 6th of March and the 5th of June 2003. Favourable weather conditions were associated with an alternation of sunshine and precipitation events, and a steady WSW wind direction.

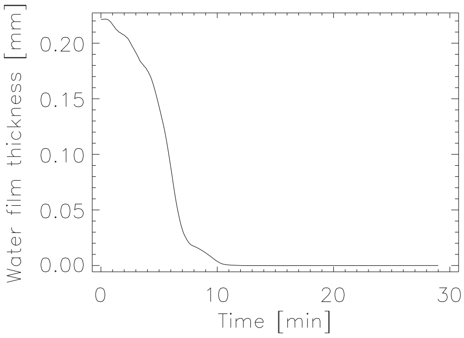
4 Results and discusssion

4.1 Water film sensor

Figure 5 shows time series of calculational water film thickness as determined by the FP2000 water film sensor. The linear decline is followed by a rapid reduction of water film thickness, resulting in a dried-up sensor surface within five minutes. In general, the water film sensor signal can be divided into a roughly linear part and a non-linear part. The linear part continues as long as the sensor surface is covered by a homogeneous water film. This linear decline is expected since the potential evaporation rate is usually not subject to great changes within an interval of a few minutes (Brutsaert, 1984). The non-linear part starts as soon as dry patches appear on the sensor surface, and ends with a completely dried-up sensor surface. During this phase the sensor signal depends mostly on the area of the water film on the sensor surface. In most cases, the phase of rapid reduction replaces the linear decline entirely



(a)



(b)

Figure 5: Calculational water film thickness as a function of time.

4.1.1 Temporal and spatial representativeness with regard to the paved surface

Figure 6: Water film sensor and the surrounding paved area. The sensor has dried-up even though the paved area is still moist.

Figure 6 shows both, the water film sensor and the surrounding paved surface. The sensor has already dried-up even though the paved surface is still covered by a non-disrupted water film. The possibility of additional heating due to voltage supply is unimportant since the sensor surface's drying behaviour was checked while being switched off. Reasons for the short drying-up time of the water film sensor surface might be identified in a small water storage capacity due to small roughness and zero porosity, a greater heat storage capacity, or an enhanced evaporation rate due to a disturbance of the wind field close to the sensor surface.

In addition, any spatial representativeness of the sensor is confined to the time prior to the first appearance of dry patches on the paved surface. The area of an individual dry patch quickly becomes greater than the area of the water film sensor. Furthermore, temporal development and initial location of the patches vary depending on the atmospheric conditions.

4.2 Eddy correlation system

Evaporation rates were obtained from eddy correlation measurements. They turned out to be greater for the paved surface being moist (0.128 mm/h to 0.268 mm/h) than for the surface being dry (0.025 mm/h to 0.111 mm/h). Due to a missing possibility of comparison the rates could not be checked thoroughly. However, it is the spatial representativeness of the measurements which is of main interest here. Non-zero evaporation rates despite of a completely dry surface point towards an upstream source area which is not confined to the paved surface, but extends into the surrounding evapotranspirating grassland.

Here, the term fetch is refered to as the distance along the horizontal mean wind direction, from the edge of the paved surface (see Figure 3) to the measuring mast. Accordingly, the fetch varies with mean wind direction, and can obtain a maximum value of about 236 m (see Figure 3). A conditional sampling technique provides evidence that for a large fetch the paved surface dominates the evaporation rates (source area inside the paved surface), for a small fetch the grassland (source area outside the paved surface).

5 Conclusion

Difficulties occurred during both calibration and operation of the FP2000 water film sensor. Reproducibility during the calibration was weak. During the measuring campaign the sensor surface dried-up much quicker than the paved surface. In general, any spatial representativeness of the sensor is confined to the time prior to the first appearance of dry patches on the paved surface.

Concerning the eddy correlation technique there is evidence that the measured evaporation rates reflect a composite of paved parking area and surrounding grassland, but not the parking area alone. Non-zero evaporation rates despite of a completely dry surface point towards an upstream source area, which extends into the evapotranspirating grassland. Furtermore, a conditional sampling technique provides evidence that for a large fetch the paved surface dominates the evaporation rates, for a small fetch the grassland.

5.1 Recommendations for future work

All measurements were undertaken next to a large paved surface without any influence of traffic. However, according routine measurements at a real road impose additional difficulties:

- The water film thickness measurements should be based on a non-contact principle. This allows a greater sensitive area. The influence of traffic (i.e. shadowing by vehicles) on the non-contact water film measurements has to be taken into account.
- The eddy correlation measurements should be undertaken at a measuring height lower than 10 cm in order to locate the source area within the road surface (Bogren et al., 2001). Thus, a different set of measuring devices is necessary with a smaller path length and smaller sensor separation. The measurements might be affected by the influence of traffic and two or more independent measuring systems are necessary in order to account for all wind directions.

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