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On the errors associated with the use of hourly data in wind-driven rain calculations on building facades

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Abstract

Wind-driven rain (WDR) is the one of the main moisture sources for building facades. It is an important factor in the dry and wet deposition of pollutants, facade surface soiling and facade erosion. WDR calculations require data records of wind speed, wind direction and horizontal rainfall intensity as input. Most meteorological datasets contain at best arithmetically averaged hourly wind and rain data. Their use is common practice in WDR calculations. As an example, existing WDR standards request at best hourly data. This paper however demonstrates that the use of such data can yield (very) large errors in the calculated WDR amounts and intensities. The reason is that arithmetic averaging on an hourly basis generally causes an important loss of information about the co-occurrence of wind and rain. An improved data averaging technique for wind and rain data is proposed that respects this co-occurrence by applying appropriate weighting factors in the averaging procedure. The performance of this technique is evaluated by WDR calculations on buildings in three cities with different climates. While arithmetically averaged hourly data yield large underestimation errors (Eindhoven, The Netherlands: 11%, Bloomington, USA: 45%, Grahamstown, South Africa: 31%), the improved averaging technique provides very good results (errors: 0%, 4%, 3%, respectively). In conclusion, WDR calculations should not be performed with arithmetically averaged hourly data. Instead, either high-resolution data (e.g. 10-minute data) or hourly data that have been obtained with the proposed weighted averaging technique should be used.

Keywords: Driving rain; Building; Error; Time resolution; Climatic data; Data averaging

1. Introduction

Wind-driven rain (WDR) is an important factor in the dry and wet deposition of atmospheric pollutants on building facades. The water layer on the facade enhances the surface collection efficiency for pollutants brought to the facade by wind (dry deposition). Wet deposition occurs either directly – by rain impingement – or indirectly – by the relocation of earlier dry and/or wet depositions by rainwater that runs down along the facade. Rainwater is also an agent for most physico-chemical deterioration processes. As such, it is an important boundary condition for facade surface soiling and facade erosion (Camuffo et al., 1982; Camuffo, 1992; Etyemezian et al., 2000; Tang et al., 2004; Tang and Davidson, 2004). To study these problems and to provide remedial measures, accurate methods for WDR calculations on building facades are required.

WDR calculations on buildings can be performed using either analytical models or numerical models based on Computational Fluid Dynamics (CFD). Both types of models use data records of the wind speed U_{10}, wind direction φ_{10} and horizontal rainfall intensity R_h as input. U_{10} and φ_{10} refer to values measured at a reference height of 10 m and R_h is the intensity of rainfall through a horizontal plane (i.e. the rainfall measured by a rain gauge with a horizontal orifice). An important question concerns the required time resolution of these data. The natural fluctuations in wind and rain characteristics suggest that the measurement samples of U_{10}, φ_{10} and R_h should be gathered at a sufficiently high resolution in order to be "time-representative", i.e. to yield accurate WDR calculation results. Indeed, meteorological measurements of wind and rain are generally made at high time resolutions (smaller than or equal to 1 minute or 10 minutes; called short-term data). However, these data are generally converted to data at a lower time resolution (i.e. averaged over a certain averaging interval, typically one hour) before they are stored and made available by meteorological and research institutes. This conversion is typically performed using the arithmetic averaging technique, see Eq. (1) for the wind speed and the horizontal rainfall intensity:

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$$U_j = \frac{\sum_i U_i}{n} \quad ; \quad R_{hj} = \frac{\sum_i R_{hi}}{n} \tag{1}$$

where the index j refers to the averaging interval, the index i refers to the short-term data in the averaging interval and the summation extends over all data samples (n) in this interval. The use of arithmetically averaged hourly wind and rain data in WDR research is generally accepted and current practice. For example the existing standards for WDR calculations (BSI 1992, CEN 2002) request at best hourly averaged data.

As wind speed and rainfall intensity are highly variable in time (Van der Hoven, 1957; Sumner, 1988), data averaging inevitably leads to smoothing of the data, where a specific rain intensity is no longer associated with the corresponding specific wind speed, thus leading to a loss of information of the co-occurrence of the two main variables required to calculate WDR. The importance of the co-occurrence of wind and rain for the resulting WDR intensity has been recognised and studied by (Choi, 1994a), but this study used hourly wind and rain data and did not focus on different time resolutions and on the errors involved. In this paper, the reason for the errors in WDR calculations using hourly data is explained, the importance of these errors is illustrated and a more appropriate data averaging technique is proposed and evaluated. Because the analysis is performed based on CFD-generated WDR results, in section 2, the methodology for CFD WDR calculations is briefly described. Section 3 focuses on the error associated with arithmetic data averaging. The improved weighted averaging technique is derived in section 4. In section 5, its performance is demonstrated by WDR calculations on identical buildings in three cities with different climates. Section 6 (discussion) and Section 7 (conclusions) conclude the paper.

2. Wind-driven rain calculations based on CFD

CFD simulation has been proven to be an accurate tool as part of a methodology for WDR calculations on building facades (Blocken and Carmeliet, 2004). This statement is confirmed by several full-scale validation studies (Blocken and Carmeliet, 2002, 2005, 2006; van Mook, 2002; Tang et al., 2004; Tang and Davidson, 2004). The methodology for CFD WDR simulations with wind and rain input data is based on the extension of Choi's steady-state simulation technique (Choi, 1994b) into the time domain by Blocken and Carmeliet (2002). The steady-state simulation technique comprises solving the wind-flow pattern around the building(s) and calculating raindrop trajectories in this flow pattern. The extension consists of adequately combining the results of these simulations with meteorological data records. The extended methodology is used as the basis for the analysis in this paper. Note however that the statements and the conclusions that will be made are not limited to calculations of WDR using CFD, but that they are equally applicable to WDR calculations with analytical models.

The dimensionless quantity that is used to describe the WDR amount or intensity in CFD-based simulations is the catch ratio η. It is defined as the ratio of the WDR amount (S_{wdr}) impinging on a certain facade location in a certain time interval to the corresponding horizontal rainfall amount (S_h). The extended methodology consists of generating η-charts based on CFD simulations that were conducted for a discrete set of wind speed (U_{10}) and horizontal rainfall intensity (R_h) values. An η-chart displays the catch ratio η as a function of these discrete values, for a given facade position and a given wind direction (e.g. Fig. 1, for wind direction perpendicular to the facade). These charts are then combined with meteorological data records of U_{10}, φ_{10} and R_h. For each time step or interval in these records, the meteorological data in this time step are used to extract the corresponding catch ratio η from the charts. The procedure is as follows. Let us focus on a data record (rain event) in which the wind direction is constant. Let us consider a time step i in this rain event and let the corresponding data couple (U_i, R_{hi}) be situated in a segment (k, l) as shown in Fig. 1:

$$U_k \le U_i < U_{k+1} \quad , \quad R_{hl} \le R_{hi} < R_{h(l+1)} \tag{2}$$

Within this segment, the catch ratio for the time step i, η_i, can be approximated by linear interpolation as follows:

$$\eta_i = \alpha_{kl}\left(U_i - U_k\right) + \beta_{kl}\left(R_{hi} - R_{hl}\right) + \gamma_{kl} \tag{3}$$

where the coefficients α_{kl} and β_{kl} are the slopes of the segment surface $\eta(U_{10},R_h)$ in point $\eta(U_k, R_{hl})$ in the direction of the U_{10} and R_h-axis respectively, and γ_{kl} is equal to $\eta(U_k, R_{hl})$. This way, the catch ratio η_i for each time step i can be obtained. The corresponding WDR amount S_{wdri} is obtained by multiplying η_i with the horizontal rainfall amount S_{hi}. This procedure is then repeated for every time step in the data record. Summing all S_{wdri} values yields the cumulative amount of WDR at that specific facade position.

3. Arithmetic data averaging and the co-occurrence error

Arithmetic averaging of wind and rain data leads to a loss of information about the co-occurrence of wind and rain. Such loss may result in errors in the calculated WDR intensities and amounts. As an example, Fig. 2 displays two theoretical data records, each consisting of six time intervals with values of U_i and R_{hi} for constant wind direction. In Fig. 2a, high wind speed and high rainfall intensity occur together, as do low wind speed and low rainfall intensity afterwards. In Fig. 2b, high wind speed and low rainfall intensity occur together followed by the opposite combination. Because η increases with increasing U_{10} and R_h (Fig. 1), arithmetic averaging of the data in Fig. 2a will lead to an underestimation of the actual WDR amount, while arithmetic averaging of the data in Fig. 2b will yield an overestimation. To illustrate this, the short-term data in Fig. 2 are arithmetically averaged over the six intervals. If we assume that the short-term data are 10-minute data, the values of the averaged wind speed U_j and horizontal rainfall intensity R_{hj} are 5.33 m/s and 4 mm/h for Fig. 2a, and 5.33 m/s and 6 mm/h for Fig. 2b. WDR calculations are performed for the two data records, with the η-chart in Fig. 1 and with the short-term data (U_i,R_{hi}) as well as with the averaged data (U_j,R_{hj}) using the procedure outlined in the previous section. For the short-term data, Eq. (3) is used six times and the total WDR amount is obtained by summing the six 10-minute WDR amounts. For the averaged data, the couple (U_j,R_{hj}) is directly inserted in Eq. (3) where the index i is to be replaced by the index j. The errors introduced by arithmetic averaging are calculated as:

$$e = 100 \cdot \frac{S_{wdr\_AVG} - S_{wdr\_REF}}{S_{wdr\_REF}} \quad (\%) \tag{4}$$

where S_{wdr_AVG} is the total WDR amount over the hour, calculated with the averaged data and S_{wdr_REF} is the total WDR amount over the hour, calculated with the short-term data (reference solution). Table 1 summarises the results, where η_j is the catch ratio associated with the averaged data (U_j, R_{hj}). The errors caused by arithmetic averaging are -37.7 % and +52.0 % for the rain event in Fig. 2a and 2b respectively. Clearly, disregarding the co-occurrence of wind and rain by arithmetic data averaging can lead to large errors. In the next section, a weighted averaging technique is derived that, by respecting this co-occurrence, reduces the loss of information.

4. Derivation of the weighted averaging technique

In the scope of WDR calculations, time-representative wind and rain data for a time step are defined as values that can be used to obtain a good estimate of the catch ratio η for this time step. Let us assume that 10-minute data are time-representative. This assumption is based on (1) the guidelines for rainfall measurements by Sumner (1988) who recommends 5, 10 or 15-minute intervals and (2) the guidelines for wind speed intervals that result from the existence of the spectral gap in the wind-speed power spectrum (Van der Hoven, 1957), indicating that wind speed data are best provided over a period of 10 minutes to 1 hour. Therefore, for combined wind and rain measurements, a measurement interval of 10 minutes can be considered to be time-representative. This was confirmed by several CFD WDR calculation and validation studies (Blocken and Carmeliet, 2002, 2006; Tang and Davidson, 2004). In the previous section, it was shown that arithmetic averaging over larger averaging intervals does not yield time-representative data. In this section, an averaging technique is derived that, under certain conditions, which are the assumptions stated below, does yield time-representative data for larger averaging intervals. Let us focus on a segment (k,l) of a typical η-chart (Fig. 1). Two assumptions are made:

1. The curved surface $\eta(U_{10},R_h)$ corresponding to the segment (k,l) can be approximated by a linear surface. This implies that Eq. (3) is exact.
2. All data couples (U_i, R_{hi}) in the averaging interval j and therefore also the averaged couple (U_j, R_{hj}) are situated in the segment (k, l).

The validity of the assumptions will be addressed later. With these assumptions, there are two ways to obtain η_j:

1. The first way involves using the 10-minute data (U_i, R_{hi}) as input in Eq. (3) to obtain the corresponding catch ratios η_i. Based on these values, the catch ratio η_j for the larger interval j that comprises a number of time steps i can be obtained by expressing that the WDR amount summed over all the time steps i comprised in interval j must equal the WDR amount for interval j:

$$\sum_i \eta_i \, S_{hi} = \eta_j \sum_i S_{hi} \quad \text{or} \quad \eta_j = \frac{\sum_i \eta_i \, S_{hi}}{\sum_i S_{hi}} \tag{5}$$

where the summation extends over all time steps i in the interval j. Substituting Eq. (3) in Eq. (5) yields:

$$\eta_j = \frac{\sum_i \left[\alpha_{kl} \, (U_i - U_k) S_{hi} + \beta_{kl} \, (R_{hi} - R_{hl}) S_{hi} + \gamma_{kl} \, S_{hi} \right]}{\sum_i S_{hi}} \tag{6}$$

Given the two assumptions, the parameters α_{kl}, β_{kl} and γ_{kl}, as well as U_k and R_{hl} are constants in the summation. Therefore, Eq. (6) can be rewritten as:

$$\eta_j = \alpha_{kl} \left(\frac{\sum_i U_i S_{hi}}{\sum_i S_{hi}} - U_k \right) + \beta_{kl} \left(\frac{\sum_i R_{hi} S_{hi}}{\sum_i S_{hi}} - R_{hl} \right) + \gamma_{kl} \tag{7}$$

2. The second way involves using the averaged data (U_j, R_{hj}) directly as input in Eq. (3), which yields:

$$\eta_j = \alpha_{kl} \left(U_j - U_k \right) + \beta_{kl} \left(R_{hj} - R_{hl} \right) + \gamma_{kl} \tag{8}$$

Eq. (7) contains the time-representative 10-minute data and hence – by the definition of time-representativeness – yields a good estimate of η_j. In order for the averaged data (U_j, R_{hj}) to be representative, Eq. (8) should provide a similarly good value for η_j. Equating the right-hand side of Eq. (7) to the right-hand side of Eq. (8), the following formulae for representative wind speed and horizontal rainfall intensity are obtained:

$$U_j = \frac{\sum_i U_i \, S_{hi}}{\sum_i S_{hi}} \quad ; \quad R_{hj} = \frac{\sum_i R_{hi} \, S_{hi}}{\sum_i S_{hi}} \tag{9}$$

Representative averaged values can thus be obtained by averaging the short-term data U_i and R_{hi} with the corresponding horizontal rainfall amounts S_{hi} as weighting factors. As could be expected, wind speed values during heavy rain showers are to be given a larger weight than wind speed values during a light-intensity spell as the contribution of the former wind speed values to the total WDR amount is larger. The same holds for horizontal rainfall intensity. Eq. (9) will further be referred to as "the weighted averaging technique". Note that this averaging technique takes into account the co-occurrence of wind speed and horizontal rainfall intensity by applying the appropriate weights, being the horizontal rainfall amounts. Applying this technique to the data in Fig. 2 and calculating the WDR amounts with these weighted averaged data yields errors that are much smaller than those associated with the arithmetic averaging technique: -1.5 % and -3.5 % for Fig. 2a and 2b, respectively (Table 1). The errors resulting from the weighted averaging technique are due to the fact that the two assumptions mentioned above are not completely satisfied. The two assumptions imply that all points (U_i, R_{hi}, η_i) in the averaging interval are situated on the same linear surface, irrespective of the position of the couples (U_i, R_{hi}) in the (U_{10},R_h)-plane (Fig. 1). These assumptions therefore imply that η is a linear function of U_{10} and R_h. This "linearity"-asumption allowed transforming Eq. (6) into Eq. (7). The error made by this assumption will depend on the actual shape (linearity) of the η-chart. When this chart is completely linear, i.e. for the entire (U_{10},R_h)-plane, the weighted averaging technique is exact and no error is introduced by weighted data averaging. In reality, these charts are never completely linear (Fig. 1). CFD simulations of WDR on different buildings however have shown that the linearity condition is generally well satisfied for the larger part of the η-charts (Blocken and Carmeliet, 2002, 2006) and that this condition is only significantly infringed in two situations: (1)

when low rainfall intensities occur in the averaging interval (see curvature of η-R_h curves for low R_h in Fig. 1) and (2) at positions on the facade that are partly sheltered by (horizontal) projections (not shown in Fig. 1). Note that "situation 1" will generally not lead to very large errors since low rainfall intensities only provide a small contribution to the total WDR amount, and that partly sheltered positions (situation 2) are generally of less interest because they receive (much) less WDR than unsheltered positions. The statement on low rainfall intensities will be confirmed in the next section by applying the weighted averaging technique for yearly data records that include to some extent low rainfall intensities.

5. Application for yearly data records of different climates

This section demonstrates the performance of the arithmetic and the weighted averaging technique and the importance of the errors associated with arithmetically averaged hourly data by WDR calculations with real, yearly wind and rain data records for three cities with different climates: (1) Eindhoven, the Netherlands; (2) Bloomington, Indiana, USA; and (3) Grahamstown, South Africa. The data of each city are available at 10-minute intervals. The climate types are Cfb, Dfa and Csb respectively, according to the Köppen Climate Classification System (Strahler and Strahler, 1984). The letters in the classification refer to the main climate type and the two subtypes. "C" refers to a "Humid Middle Latitude Climate" while "D" indicates a "Continental Climate". The second letter "f" refers to a climate that is "moist with adequate precipitation in all months and no dry season", while "s" stands for a "dry summer season". Finally, the third letter – which is of less importance for this study – indicates the type of summer (hot "a" or warm "b").

The WDR calculations are conducted with the η-chart in Fig. 1. Note that η-charts are generally independent of climate, they mainly depend on the building geometry (including environment topography), on the position on the building facade and only to a lesser extent on the raindrop size-distribution (Blocken and Carmeliet 2002, Tang and Davidson 2004). In this study, the size distribution by Best (1950) was adopted to construct the η-charts. This size distribution is based on a large number of measurements in different countries with different climates and its use in CFD calculations has been validated on several occasions (Blocken and Carmeliet 2002, 2006, Tang and Davidson 2004).

The WDR calculations are performed with the 10-minute data and with hourly data obtained by either arithmetic averaging ("arith. avg") or weighted averaging ("weight. avg") of the 10-minute data. To evaluate the averaging techniques for the full set of data, this exercise assumes that the wind direction is perpendicular to the facade at all times. Fig. 3 displays the results in terms of the cumulative WDR amount. It clearly shows that the common way of calculating WDR, i.e. using arithmetically averaged hourly data, leads to large underestimation errors (errors at the end of the year: Eindhoven: 11%; Bloomington: 45%, Grahamstown: 31%). On the other hand, the use of hourly data obtained with the proposed weighted averaging technique provides very accurate results (errors: 0%, 4%, 3%, respectively). For Bloomington, Fig. 4 compares the performance of both techniques on an hourly basis by comparing their results with the results from the 10-minute data. The correlation coefficients for the arithmetic and weighted averaging results are 0.8438 and 0.9963 respectively. For Eindhoven, the coefficients are 0.9892 and 0.9998 and for Grahamstown the values are 0.9456 and 0.9997. Fig. 4 and the correlation coefficients confirm the underestimations by the arithmetic averaging technique for many hours during the year. They also indicate the overall very good performance of the weighted averaging technique for almost every hour during the year.

The main reason for the different errors for each city is the different wind and rain climatology, i.e. the different variability and the corresponding different co-occurrence of the variables wind speed and horizontal rainfall intensity. Especially the type of rainfall is important. Two main types can be distinguished: cumuliform and stratiform rains. The terminology "cumuliform-stratiform" stems from the type of clouds generating the rain. *Cumuliform clouds* or heap clouds develop in an unstable atmosphere as a result of fast and local rising air currents. The type of rainfall from these clouds is referred to as showers. Showers usually start and stop suddenly and are generally of short duration. *Stratiform clouds* or layer clouds develop in a stable atmosphere as a result of widespread cooling and by condensation processes that are slow but persistent. The precipitation from these clouds starts and stops slowly, is quite steady (although it can exhibit breaks), often lasts for many hours and is generally of light to moderate intensity ($R_h < 7.6$ mm/h). The temporal variability of stratiform rain events is less pronounced than that of cumuliform rain events. As a result, cumuliform rain events show larger changes in the co-occurrence of wind and rain, and errors due to data averaging will be more pronounced. An analysis of the meteorological data indicated that rainfall in Eindhoven is dominated by stratiform rains. This is also indicated in Fig. 3a by the gradual increase of the cumulative curves in time, which means that most rainfall series are spread over several hours, which is typical for stratiform rain events. Rainfall in Bloomington on the other hand is dominated by cumuliform rains. This is indicated by the steep increases of the cumulative WDR amount at discrete moments in time, indicating that most rain events only last for one hour at most – this is typical for cumuliform rain events. Finally, the shape of the curves in Fig. 3c indicates that Grahamstown experiences a large number of cumuliform but also some stratiform rain events during the year.

6. Discussion

Rainfall intensity is characterised by an extreme variability in time (Sumner, 1988). Wind data (wind speed and wind direction) are also highly variable in time. The shortest interval for wind and rain data used in this study was 10 minutes. In theory, the shorter the measurement time interval, the more accurate the registration of parameters will be and the more accurate the resulting WDR calculations. However, data gathered at a higher time resolution (e.g. 1-minute data) have not been used because such resolution can compromise the representativeness of the data and the accuracy of the resulting WDR calculations. As such they cannot be used to provide a reliable reference solution of calculated WDR that can be used to reliably estimate the errors caused by the use of hourly data. The reasons are the following: (1) Wind speed measurements are usually conducted at quite a high time resolution (≤ 1 minute or even ≤ 1 second, depending on the type of measurement equipment that is available). These "raw" measurement data are often averaged over larger time intervals (e.g. 1, 5 or 10 minutes) by the measurement equipment itself (e.g. in an ultrasonic anemometer) and/or by the datalogger (e.g. for a cup anemometer). The usual averaging intervals for wind speed and wind direction are 10 minutes or one hour. The reason is the existence of the spectral gap in the wind-speed power spectrum (Van der Hoven, 1957) which indicates that stationary averages are obtained for these averaging intervals. (2) For rainfall, Sumner (1988) correctly states that even the most sophisticated rain gauges are incapable of measuring instantaneous rainfall. Jones and Sims (1978) mention that the nature of instrumentation forces a compromise whereby instantaneous precipitation is considered to be that which occurs over a duration of one minute. Sumner (1981, 1988) states that due to errors in timing, local turbulence and so on, it is probably more reasonable to settle for sampling intervals of 5, 10 or 15 minutes. As a result, for combined wind and rain measurements, such as needed for WDR calculations, an averaging interval of 10 minutes seems to be a reasonable choice. This is confirmed by recent validation studies of CFD WDR simulations on buildings facades (Blocken and Carmeliet 2002, 2006; Tang and Davidson, 2004) which used 10-minute data and showed a systematically good agreement with full-scale WDR measurements.

This study indicates that new datasets for WDR studies should either comprise 10-minute data or hourly data that have been obtained from 10-minute data by applying the weighted averaging technique. The proposed averaging technique allows the use of hourly data for WDR studies. Therefore these wind and rain data can be included in future standard "hourly" datasets without the need to store future data on a 10-minute basis.

7. Conclusions

The use of arithmetically averaged hourly data is common practice in wind-driven rain (WDR) calculations on buildings. This paper has shown that such data can yield very large errors in the calculated WDR amounts. The reason is that arithmetic averaging can lead to the loss of important information about the co-occurrence of wind and rain, which is essential for accurate WDR calculations. A weighted averaging technique has been derived that adequately takes into account the co-occurrence of wind speed and horizontal rainfall intensity by applying the horizontal rainfall amounts as weights in the averaging procedure. Application of both averaging techniques for WDR calculations on buildings in three cities with different climates has shown that arithmetic averaging can yield very large errors, but that the weighted averaging technique provides accurate results. The size of the errors depends on the wind and rain climatology, which determines the co-occurrence of wind and rain. The conclusion is that arithmetically averaged hourly data sets (i.e. most current climatic data sets) should not be used for WDR studies. Instead, one should use either 10-minute data or hourly data that have been obtained from 10-minute data by applying the weighted averaging technique. New datasets for WDR studies should be obtained accordingly.

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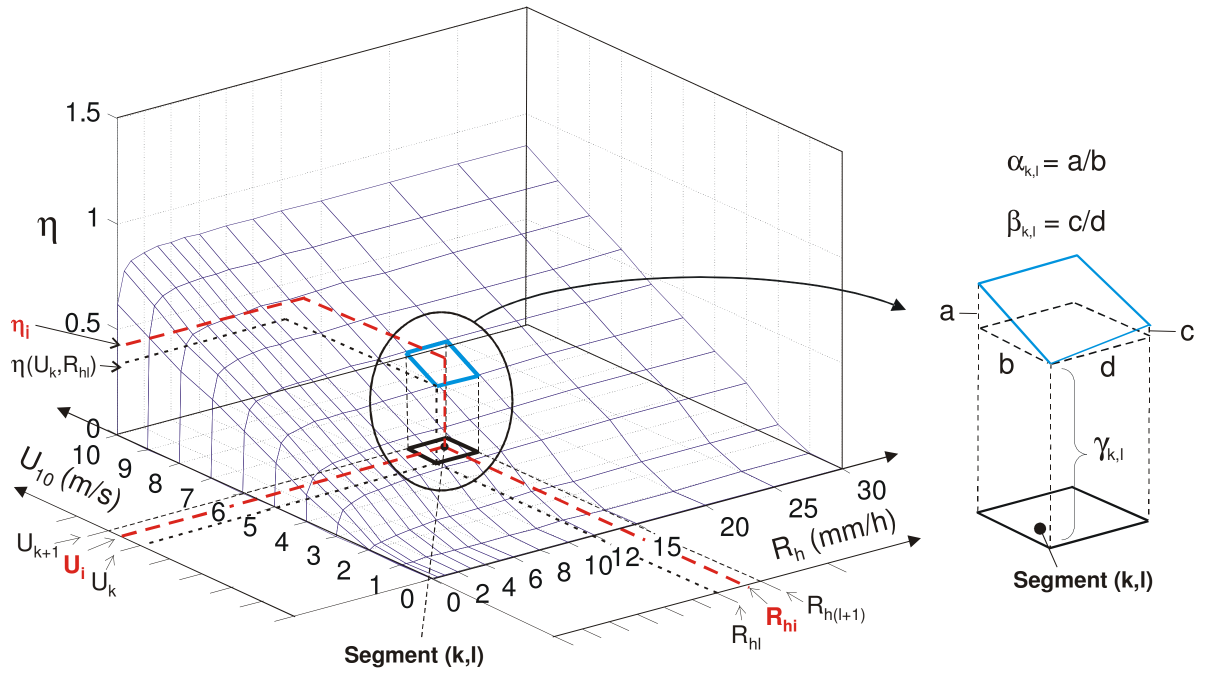

Figure 1. Typical catch-ratio chart that provides η as a discrete function of U_{10} and R_h, for a given facade position and a given wind direction (in this case perpendicular to the facade). Intermediate values are obtained by linear interpolation in segments indicated by the numbers k and l. Such a segment is indicated with a bold square in the figure.

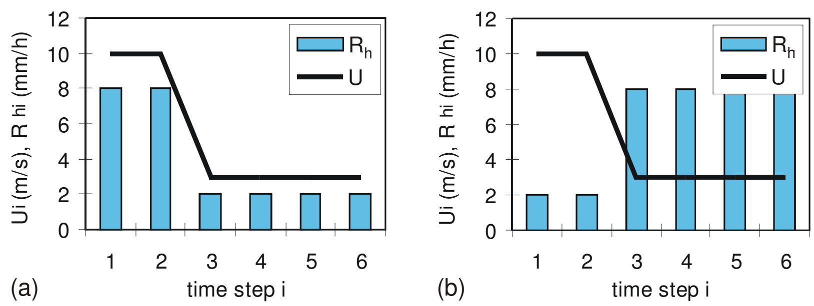

Figure 2. Two theoretical data records (rain events) with data of wind speed U_{10} and horizontal rainfall intensity R_h.

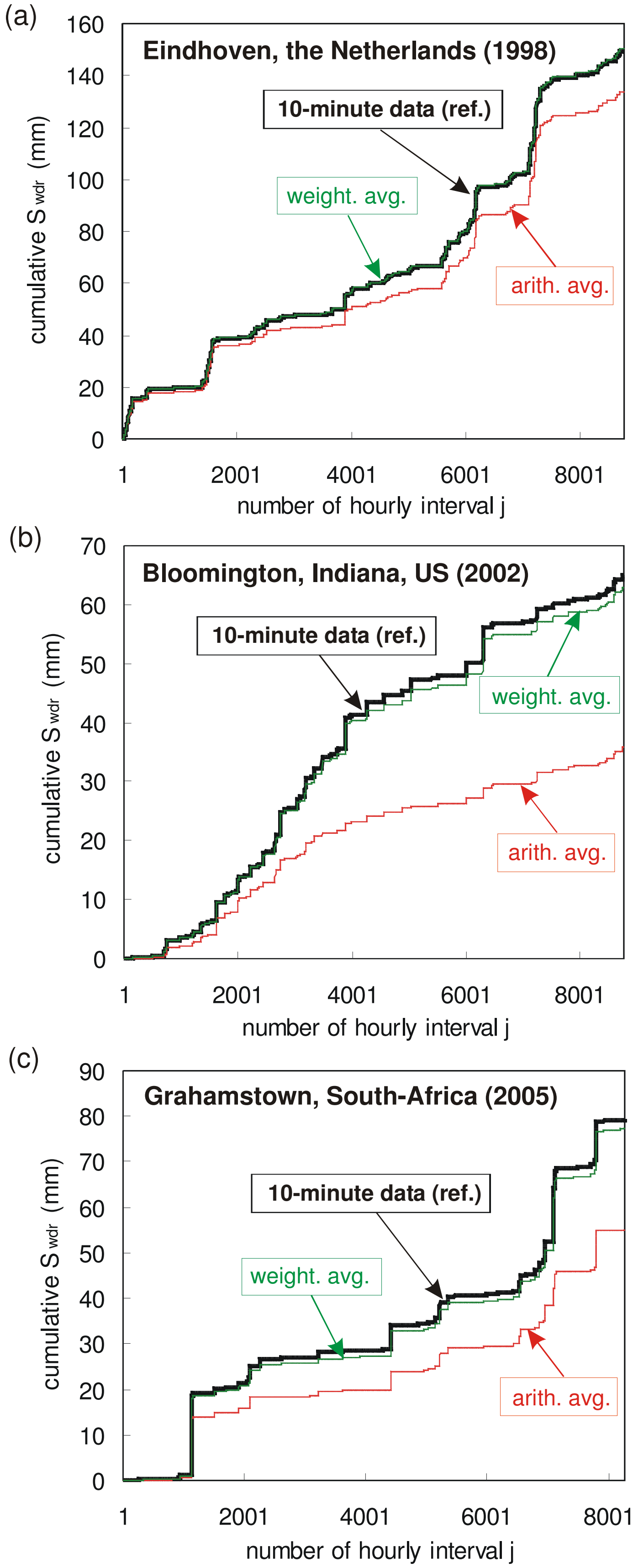

Figure 3. Comparison of cumulative hourly wind-driven rain results obtained with 10-minute data (reference solution) and with arithmetically averaged and weighted averaged hourly data.

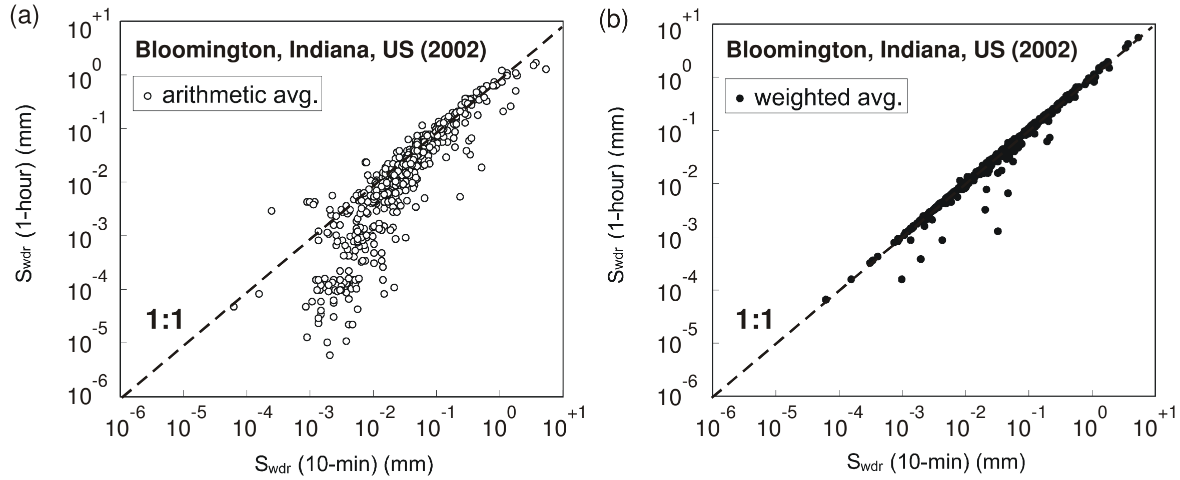

Figure 4. (a) Deviation of the results obtained with arithmetically averaged hourly data from the results obtained with the 10-minute data, for every hour of the year. (b) Idem, but for weighted averaged hourly data.

Table 1. Results and errors in wind-driven rain calculations for the example rain events in Figs. 2a and b with 10-minute data and with arithmetically averaged and weighted averaged hourly data.

Rain event	time resolution	U_j (m/s)	R_{hj} (mm/h)	η_j (-)	S_{wdrj} (mm)	e (%)
(a)	10-min.	-	-	0.619	2.476	
	hourly (ar. avg)	5.333	4	0.386	1.542	-37.7
	hourly (w. avg)	7.667	6	0.610	2.438	-1.5
(b)	10-min.	-	-	0.257	1.544	
	hourly (ar. avg)	5.333	6	0.391	2.347	52.0
	hourly (w. avg)	3.778	7.333	0.248	1.490	-3.5