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An Optical Spectro Pluviometer for the measurement of raindrop properties

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Abstract: The intensity of physical soil degradation, detachment and transport of soil particles by raindrop splash and interrill erosion is largely controlled by rainfall characteristics. There is still a lot of debate as to which parameter expresses the best rainfall erosivity. Due to the limited data on drop-size distribution of natural rainfall and the time consuming nature of methods to obtain these data, rain erosivity parameters are commonly obtained from empirical relationships. This paper describes an improved Optical Spectro Pluviometer (OSP) which is based on measuring the optical shadow. It enables one to measure drop size and drop velocity in real time and thus any parameter linked to rainfall erosivity. The OSP has been largely tested under natural rain conditions. A description of the device, the results obtained and its limitations are presented. Laboratory experiments using a nozzle type rainfall simulator have been conducted. Drop-size characteristics of simulated rain (obtained by OSP) are compared with the most widely used (but time consuming) method of the filter paper technique. The drop-size distribution measured by both methods are in agreement.

INTRODUCTION

An Optical Spectro Pluviometer (OSP) designed to perform real-time measurements of the drop size and the terminal drop velocity is presented. The easiness and the speed of the measurements made with the apparatus allow one to estimate in real-time rainfall characteristics such as kinetic energy, momentum and rainfall intensity. Description of the OSP is given in the next section. Calibration and limitation of the OSP are discussed in another section.

DESCRIPTION OF THE OPTICAL SPECTRO PLUVIOMETER

The Optical Spectro-Pluviometer (OSP) was designed in order to measure automatically the size and fall velocity distributions of raindrops at ground level. Introduced by Picca & Trouilhet (1964) the principle of this shadowgraph instrument is simple (see Figs 1 and. 2). The infrared light (0.9 μm wavelength) transmitted by a light emitting diode is shaped into a 60 cm^3 cuboid beam of parallel light by a pair of converging lenses and rectangular masks. The total light intensity transmitted through the beam is monitored by a single receiving photo-diode that delivers an electric signal proportional to the received light intensity. When a drop falls across the beam, the light intensity received by the photo-diode decreases. The amplitude

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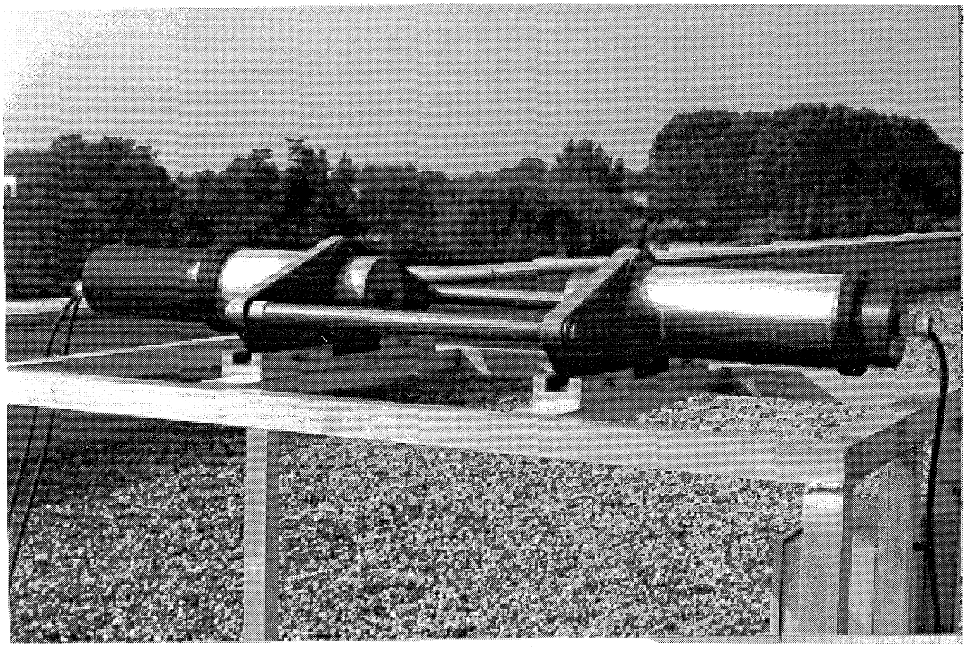

Fig. 1 View of the Optical Spectro Pluviometer.

and the duration of the signal variation are proportional to the cross-section of the drop and to its residence time in the beam respectively. The residence time can be converted to a fall speed assuming the drop crosses the two horizontal faces of the beam (separated by a known height of 1 cm).

The OSP was first developed and tested by Donnadieu *et al.* (1969). Both the sensor and the processing system of the OSP were re-designed by Klaus (1977) and then by Hauser *et al.* (1984). A complete overhaul of the signal processing and some minor hardware modifications has been performed by Salles *et al.* (in press). The OSP offers several advantages. The electronics and the optics of the sensor are not

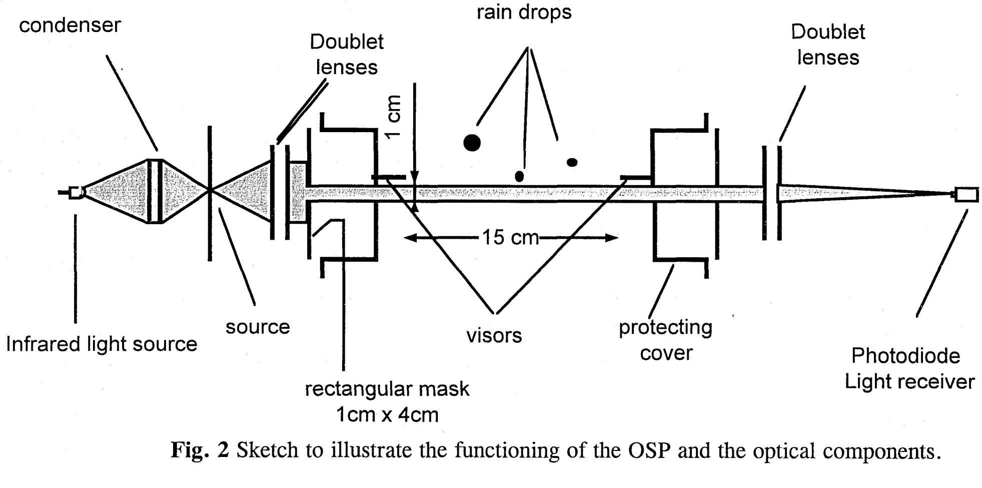

Fig. 2 Sketch to illustrate the functioning of the OSP and the optical components.

sophisticated which makes the instrument easy to calibrate, reliable, movable and robust.

The software implemented on a digital acquisition processor combined with a Personal Computer allows the storage of the drop diameter (corrected for the oblate ellipsoid effect according to Pruppacher & Pitter (1971)), the velocity and the arrival time of each drop. These parameters and the derived parameters (e.g. kinetic energy, D_{50}) are obtained in real time on a basis of one minute. As an example two screen copies of the possible results are given in Fig. 3(a)–(b). In the top left corner of Fig. 3(a), a 25 class histogram of the percentage of the rain volume is plotted. In the top right corner the kinetic energy is plotted *vs* rainfall intensity calculated both on a basis of a 1-min time step. The lower part of Fig. 3(a) gives the hyetogram with a 1-min time step for the last 4 h of record. The bottom left corner is the legend which gives the correspondence between colours used for the histogram and number of drops in the drop-size class. In Fig. 3(b) the other optional screen results are plotted. The difference with Fig. 3(a) resides in the top left corner where the distribution plotted is now the distribution of drops according to their diameter and their speed.

CALIBRATION AND LIMITATIONS

The sensor is designed in order to deliver a voltage of 1 V for a drop diameter equal to 1 mm. Overestimation and underestimation of, respectively, the larger and smaller drop diameters are expected from diffraction effects. The complete measurement range was calibrated by using steel spheres of different sizes and water drops. The effective diameter range is 0.3–4.7 mm. Drops with a diameter greater than 4.7 mm are all classified in one class. The fall velocity is deduced from the residence time of the drop inside the beam. The residence time range is between 1 and 40 ms. Thus the velocity range is 0.3–10 m s^{-1}. From the two drop-characteristics (diameter and velocity) the OSP allows real-time computation of the DSD and parameters related to drop characteristics.

Limitations of the OSP are of two kinds: limitations due to the environmental conditions and instrumental limitations. In the first case we should consider limitations due to the non-sphericity of the raindrops. The deviation, which could involve an underestimation in the diameter of the larger drops up to 5%, is corrected according to the drop shape given by Pruppacher & Pitter (1971). The most important environmental influence is the wind influence. The non-aerodynamic shape of the OSP induces turbulence around the beam, which modifies both the raindrop speed and trajectory. According to Salles *et al.* (in press) the underestimation due to wind could reach a relative value of 10% for a wind velocity equal to 10 m s^{-1} and a rainfall intensity equal to 40 mm h^{-1}.

The instrumental limitations are threefold: (a) the drop or drop fragments resulting from the rebounds over the body of the OSP generates additional drops in the sampling zone; (b) drops falling across the vertical edge of the beam are partially identified, their diameter is underestimated; and (c) the simultaneous presence of drops in the beam. The algorithm of the software is such that when only two drops are simultaneously present in the beam, the identification according to the shape of the signal is realized. The case with more than two drops has been recently

(a)

(b)

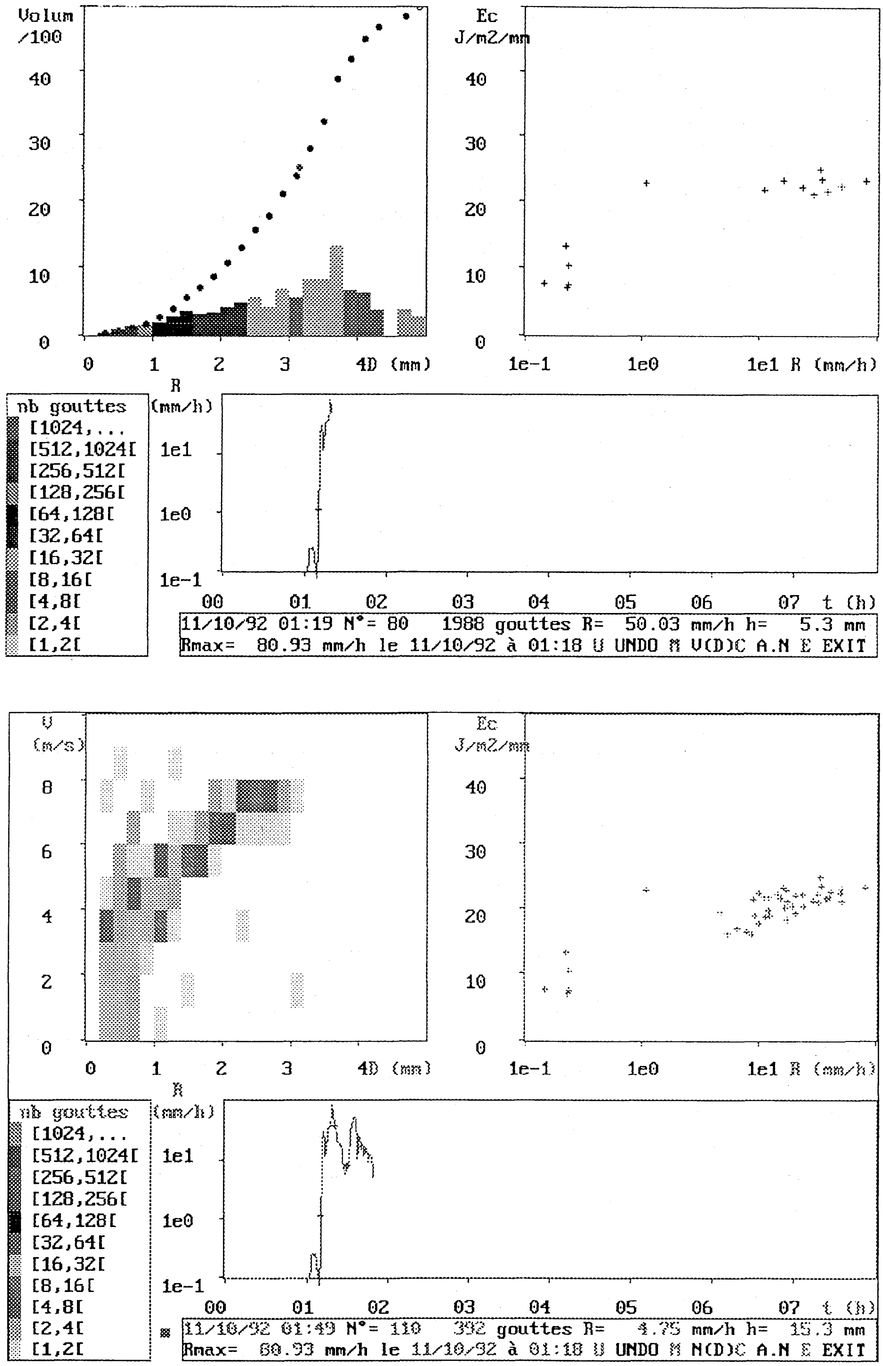

Fig. 3 (a) Screen copy of the available data during a recording session: drop-size distribution (*D*) expressed in volume percent of water (*Volum*), kinetic energy (*Ec*) *vs* rainfall intensity (*R*) and hyetogram. (b) Screen copy of the other possible available results during a recording session: drop diameter (*D*) distribution according to their fall velocity (*V*), kinetic energy *vs* rainfall intensity (*R*) and hyetogram.

implemented in the software analysis. Some uncertainties still remain, values are only indicative of the diameter.

Salles *et al.* (in press) have made a comparison in the rainfall intensity measurement which shows a tendency toward an underestimation for the OSP. After different modifications the rainfall estimation by the OSP is still 10% less than the rainfall measured with a tipping bucket raingauge. Most of the underestimation is due to the environmental conditions.

The OSP has been tested under simulated rain conditions. Two nozzles have been used during laboratory experiments with a rainfall simulator. A first set of data obtained with the first nozzle also used by Poesen *et al.* (1990) (a Lechler full cone nozzle numbered 460.788) with an operating pressure of 0.21 bar was recorded. The second set of data have been obtained by using a Lechler full cone nozzle numbered 461.008. The operating pressure was equal to 0.36 bar. Experimental conditions and DSD characteristics measured with the OSP are reported in Table 1. The same rainfall simulator has already been calibrated by Poesen *et al.* (1990) and by Borselli (personal communication). DSD have been measured both with the filter paper method (Hall, 1970). Numerical values of D_{50} obtained by these authors are also reported on Table 1. Considering the different methods used, the approximate equal conditions and mainly the sample size effect, D_{50} values obtained by Poesen *et al.* and Borselli with the filter paper method are in agreement with the values measured with the OSP.

Table 1 Experimental conditions during the three raindrop sample acquisitions. D_{50} is the median drop volume derived from the OSP measurement.

OSP results:				Results obtained with the filter paper method:		
Nozzle	Pressure (bar)	I (mm h^{-1})	D_{50} (mm)	Author	Pressure (bar)	D_{50} (mm)
460.788	0.21	38	1.47	Poesen (1990)	0.206	2.0
				Borselli (pers. comm.)	0.30	1.2
461.008	0.36	108	2.41	Borselli (pers. comm.)	0.37	2.25

This description demonstrates that the OSP offers unprecedented advantages in the estimation of various rainfall parameters. The use of the OSP is less time consuming than the widely used filter paper or flour pellet methods. Its use in the laboratory with simulated rainfall reduces most of the underestimation problems encountered in the field. The OSP will allow us to quickly determine the raindrop properties of the simulated rainfall and to evaluate all the rainfall parameters needed for assessing rain erosivity

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