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Description and preliminary results of a 100 square meter rain gauge

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SUMMARY

Rainfall is one of the most crucial processes in hydrology, and the direct and indirect rainfall measurement methods are constantly being updated and improved. The standard instrument used to measure rainfall rate and accumulation is the rain gauge, which provides direct observations. Though the small dimension of the orifice allows rain gauges to be installed anywhere, it also causes errors due to the splash and wind effects. To investigate the role of the orifice dimension, this study, for the first time, introduces and demonstrates an apparatus for observing rainfall called a giant-rain gauge that is characterised by a collecting surface of 100 m^2. To discuss the new instrument and its technical details, a preliminary analysis of 26 rainfall events is provided. The results suggest that there are significant differences between the standard and proposed rain gauges. Specifically, major discrepancies are evident for low time aggregation scale (5, 10, and 15 min) and for high rainfall intensity values.

1. Introduction

Precipitation is a key input in a variety of environmental studies, especially in hydrology, where it is pivotal for achieving appropriate modelling and simulation (e.g., Larson and Peck, 1974; Vaze et al., 2011) of floods. The total amount of liquid precipitation (in mm) is traditionally measured using rain gauges (e.g., weighting type and tipping-bucket type), and these direct observations are considered the "true" amount at ground level. The small orifice size (usually in the range 100–300 cm^2) makes this instrument enough versatile to allow dense observation networks, but the limited dimension is in contrast with the high space–time variability of precipitation. Indeed, rain gauges provide point measurements from which it is challenging to determine the spatial rainfall distribution or extend the estimated amount at the catchment scale. Moreover, assuming that rain gauges are carefully maintained to avoid clogging of the gauge funnel and that they are periodically re-calibrated, some sources of error are possible due to the wind effects (e.g., Kurtyka, 1953; Robinson and Rodda, 1969; Sevruk, 1989; Hughes et al., 1993; Hanna, 1995), wetting losses (e.g., Sevruk, 1989; Sevruk and Klemm, 1989), evaporation (e.g., Sevruk, 1986), and splashing effects (e.g., Rodda, 1967). Among them, wind triggers the most important systematic error, which occurs in the range of 2–10% (Nešpor and Sevruk, 1999).

In contrast, measurements obtained from remote sensing devices (such as satellite-borne, airborne sensors and ground based radar) can provide rainfall estimation over significantly larger areas (thousands of km^2). Weather radar on the ground can be useful for monitoring a precipitation event and predicting its short-term evolution because it offers the advantage of gaining insights into the characteristics of ongoing precipitation processes. However, ground weather radar provides indirect observations that are quantified by converting radar power (or phase) measurements into a rainfall rate using conversion relations. Quantitative precipitation estimations from ground-based weather radar can be affected by many sources of errors (e.g., Brandes et al., 1999; Villarini and Krajewski, 2010; Sebastianelli et al., 2013), which can be related to errors in radar measurements (i.e., radar mis-calibration and attenuation effects) or in the conversion of the radar output into the rainfall rate at the ground (i.e., the vertical variability of the precipitation system and the assumption concerning the drop size distribution for applying rainfall algorithms (Adirosi et al., 2014)). Furthermore, comparing the weather radar and rain gauge measurements is arduous because of temporal and spatial sampling uncertainties (Villarini et al., 2008). The spatial sampling error occurs because the estimation of the areal

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amounts use point measurements. The accuracy of quantitative precipitation estimation from radar measurements is determined by comparing the radar-rainfall output with the "true" rain gauge measurement. However, the large difference between rain gauges and the radar resolution area (around nine orders of magnitude) leads to large differences in the spatial sampling properties. Austin (1987) noted that even if rain gauge and radar measurements are not affected by errors, discrepancies would remain between the devices due to the different sampling areas. Ciach and Krajewski (1999) identified a lack of accurate area-averaged rainfall data as one of the major issues in radar rainfall estimates. In the literature, many authors (such as Zawadzki, 1973; Rodrìguez-Iturbe and Mejìa, 1974; Seed and Austin, 1990; Kitchen and Blackall, 1992; Ciach and Krajewski, 1999; Habib et al., 2001; Habib and Krajewski, 2002; Ciach, 2003; Wood et al., 2000; Jensen and Pedersen, 2005; Villarini et al., 2008) have studied the effects of different sampling areas in the radar-rain gauge comparison and the correlated errors. Habib and Krajewski (2002), for example, found that in Florida, the spatial sampling error ranges from 40% to 80% of the total discrepancy between the radar and rain gauge measurements, whereas Jensen and Pedersen (2005) found high variability (approximately 100%) of the rainfall accumulation measured by nine rain gauges within a single radar pixel (500 m $\times$ 500 m).

Despite the variety of literature regarding the error in the rain gauge-radar comparison due to the huge difference in their sampling area, to date, the consequence of this issue on the estimation/validation of the rainfall rate from remote sensing measurements is not fully documented or understood (Ciach and Krajewski, 1999), though it is a key topic in several disciplines.

Following these premises, the limited dimensions of the rain gauge orifice and the sampling discrepancy with the radar stimulated us to propose a special apparatus with an unprecedented sampling area (10 m $\times$ 10 m) called a *giant-rain gauge,* which has been designed, built and installed at Tuscia University in Italy.

To the best of the authors' knowledge, there is no similar device currently at one's disposal, and the only remotely similar approach was developed by de Jong et al. (2011) . We believe that the analysis of the data collected by the giant-rain gauge can provide information useful to better understand the sources of rain gauge errors for high precipitation intensities. This new apparatus is expected to reduce typical rain gauge errors (splashing and wind effect) and to better understand the role of the rain gauge orifice size with respect to the spatial drop distribution. Compared with radar, advantages are related to the reduced difference between the sampling areas of the two devices (the giant-rain gauge decreases the latter difference by almost three orders of magnitude).

In this study, we provide a description of the proposed apparatus (Section 2) and details on its calibration and practical use (Section 3); moreover, we present some preliminary results illustrating the measurement comparison among the giant and four benchmark standard rain gauges during 26 rainfall events, focusing on high precipitation intensities (Section 4). A comparison with radar data and a specific investigation of the possible reduction of error due to splashing and wind effects will be the subjects of a future study.

2. Giant-rain gauge apparatus description

In this section, the technical details of the proposed apparatus are provided. The installation is located in Viterbo Province in central Italy, on the experimental farm of Tuscia University, in a flat and open area with an elevation of 300 m a.a.s.l. (Fig. 1). The general setup (Figs. 1 and 2) consists of a 100 m^2 square surface that collects rainfall in a small cylindrical tank. The four vertexes of the square surface are 302.5 m a.a.s.l., and four standard rain gauges are installed in their proximity (1 m from each vertex and at 303.5 m a.a.s.l.; Fig. 2a) to provide a benchmark for the precipitation estimated using the giant-rain gauge.

Rainfall is collected first in two separate stainless steel corrugated sheets mounted on small wood pillars: the sheets (10 m $\times$ 5 m each) are surrounded on the external sides by a 20-cm vertical border to prevent water losses due to the splash effect, and they have a 20% slope to allow the water to move toward the centre line of the 100 m^2 surface.

The water flowing in the corrugated sheets is accumulated in a triangular stainless steel channel characterised by a 90° angle at the bottom, two 15 cm sides, and 1% longitudinal slope. The elevations of the triangular channel are, respectively, 301.5 m and 301.4 m a.a.s.l. in the upper and in the lower extremities. The triangular channel is designed to allow water flow up to 10 l/s (i.e., equivalent to a precipitation of approximately 350 mm/h intensity) and to collect it in a vertical plastic pipeline with a diameter of 100 mm that pours water into a cylindrical tank (Fig. 2b and c).

The cylindrical tank, at the end of the triangular section channel, is on ground level. It is characterised by a 50 cm diameter and 1 m height, and it has a weir 30 cm from the bottom (Fig. 2d). The weir has a lower triangular section with a 53° angle, which becomes rectangular at a height of 4 cm and has a constant 4 cm width reaching to the upper part of the tank. The weir mixed section has been adopted to obtain a significant water level for small precipitation amounts. A water level of 5 mm corresponds to 0.1 mm/h rainfall intensity. At the bottom of the tank, a high-resolution water level sensor is present and allows for discharge flow measurement outside the tank using an appropriately calibrated weir equation (see Section 3).

Once the discharge is estimated, it is possible to quantify the rainfall occurring on the giant-rain gauge by dividing it by the 100 m^2 "orifice" area. In Section 3, details of the apparatus optimal time resolution are provided.

The instruments installed in the giant-rain gauge are as follows:

- 4 standard tipping bucket rain gauges SBS-500 Campbell Scientific: the collector area is equal to 500 cm^2, the overall height is 440 mm and the tip sensitivity is 0.20 mm of rain. The four rain gauges are installed as a benchmark for the rainfall estimated by the proposed apparatus.
- 1 high-resolution water level sensor STS ATM.1ST/N: this is built of stainless steel and was specifically designed for a water column with a height less than 1 m and an accuracy of 0.3%.
- 1 SS2 PT100 standard air thermometer, 1 Vector Instruments A100H anemometer, and 1 LI-200SA LI-COR pyranometer sensor that were designed to obtain field measurements of global solar radiation are present as ancillary instruments to complete the proposed apparatus.
- All instruments are powered by a photovoltaic panel and are linked to a Campbell Scientific CR10X data logger to store the data at user-defined timescales, averaging the values that are recorded by the single instruments once per second.

During the first tests of the giant-rain gauges, two particular issues were faced, mainly during high rainfall intensity: (a) the water flowing from the two sheets toward the triangular channel was characterised by high velocities, which resulted in overtopping of the channel sides and falling directly to the ground without reaching the tank; and (b) the water surface inside the tank was characterised by high turbulence, which resulted in a water level sensor signal with excessive noise. The turbulence was present, though the plastic pipeline ended at the bottom of the tank and 30 cm of water was available to reduce the flow kinetic energy.