Measurement of precipitation in montane tropical catchments: Comparative performance of conventional, spherical and ‘potential’ rain gauges

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Introduction

Information about local surface slope and aspect as well as precipitation inclination and direction are needed for the proper estimation of atmospheric water inputs to montane areas of complex topography. The inclination of precipitation ($\boldsymbol{\alpha}$) is expected to vary as a function of wind speed and turbulence, even over small scales. Furthermore, fog is intercepted differently by tall forest and short pasture vegetation. As such, spatial variability of rainfall, drizzle, and fog deposition in montane areas is high and this needs to be accounted for if reliable estimates of spatial inputs are to be obtained. The total liquid water in near-surface montane air consists of any rain, drizzle and fog present and these may precipitate onto a surface or stay in suspension depending on droplet size, wind speed and turbulence. The *potential precipitation* ($\boldsymbol{P_{pot}}$) at a given point may be defined as the potential water depth (mm) reaching a plane that is orientated perpendicularly to the average trajectory direction of the water drops over a specified period of time. The vertical component of $\boldsymbol{P_{pot}}$ is measured as precipitation ($\boldsymbol{P}$) by a conventional rain gauge. Precipitation ($\boldsymbol{P}$) must be considered as being non-conservative because of its dependence on wind speed (hence $\boldsymbol{\alpha}$) and as a result site exposure. Potential precipitation, on the other hand, can be considered a conservative parameter for small catchments. Local turbulence determines the inclination of the precipitation and hence the actual input at a given slope. Determination of $\boldsymbol{P_{pot}}$ is therefore the first step for the estimation of spatial precipitation inputs in montane catchments.

Methodology

This paper explores two approaches to quantify $\boldsymbol{P_{pot}}$, viz. (i) spherical rain gauges, and (ii) a specifically designed ‘potential precipitation gauge’, at a wet and windy mountain site at 1500 m elevation in northern Costa Rica. Spherical rain gauges are designed to present the same effective gauge orifice independent of precipitation inclination and so should allow measurement of $\boldsymbol{P_{pot}}$. Two such gauges were installed next to a conventional rain gauge between 9 March and 3 May 2005 on top of a 25 m tower above a cloud forest canopy (Fig. 1). The alternative approach (ii) separately measured the vertical component of potential precipitation ($\boldsymbol{P}$) with a regular orifice, and the horizontal component ($\boldsymbol{HP}$) with a passive fog gauge. $\boldsymbol{P}$ was corrected for wind-loss due to flow distortion around the gauge orifice. The catching efficiencies for rain and fog of the passive fog gauge have been described by Frumau et al. (2006a). $\boldsymbol{HP}$ represents the sum of: (i) the horizontal component of inclined (wind-driven) rain and (ii) fog. $\boldsymbol{P_{pot}}$ and its effective angle can then be derived from corresponding measurements of $\boldsymbol{P}$ and $\boldsymbol{HP}$, using simple trigonometry.

Results and Discussion

The conventional and potential rain-gauge measurements of $\boldsymbol{P}$ were corrected for wind-loss. Several expressions exist to compute wind-loss in flat terrain (Yang et al. 1998; Forland et al. 1996) but a more appropriate correction was derived that took local conditions into account. For this several gauges were placed at different heights in nearby montane pasture (Frumau et al. 2006b). The use of inclination of precipitation (***α***) rather than wind speed ***u*** allowed the derivation of a more generally applicable expression for montane terrain as ***α*** incorporates the influence of ***u*** (both up- and downslope) and turbulence on rain droplets and therefore their susceptibility to being deflected. Significant corrections were obtained only for small droplets with this model, thereby avoiding the large corrections normally obtained for large droplets with models based on ***u***. The precipitation total measured by the conventional gauge for the experiment amounted to 179 mm vs. 210 mm after correction for wind-loss (17.3%). Total ***HP*** caught by the potential precipitation gauge was 615mm. Total $\boldsymbol{P_{pot}}$ was then derived from ***α***, ***P*** and ***HP*** as 652 mm and 660 mm before and after correction of ***P*** for wind-loss. The small difference reflects the dominance of events with ***α*** >70° (79% of $\boldsymbol{P_{pot}}$).

Figure 1: Comparative rain-gauge experiment.

Installation on top of the tower with two spherical, a conventional and a potential precipitation gauge (left to right). Spherical gauges using concentric cylinders (right top) and vanes (right bottom).

The $\boldsymbol{P_{pot}}$ collected by the two types of spherical gauges ($\boldsymbol{P_{sph}}$) (vanes and cylinders; Chang and Flannery 2001) was very similar (±1-2%), as also reported by Chang and Harrison (2005). The catch of the spherical gauge was linearly related to that of the potential precipitation gauge (Fig. 2a) with $\boldsymbol{P_{sph}}$ being 504 mm or 76% of the potential precipitation gauge catch, possibly suggesting that $\boldsymbol{P_{pot}}$ as derived from the potential precipitation gauge is too high. However, just like conventional gauges experience wind-loss, the non-pervious spherical gauges may also be subject to some flow distortion. Chang and Harrison (2005) obtained very similar catches for spherical gauges irrespective of gauge height (between 1-3m) but their test was conducted for ***u*** < 3 m/s. In addition, their spherical gauges recorded on average only 6-9% more than the conventional gauges, whereas the present $\boldsymbol{P_{sph}}$ was 240% of conventionally measured ***P***. This difference in spherical gauge performance is indicative of smaller droplet sizes and larger ***α*** values in montane Costa Rica. Chang and Harrison (2005) recognized the importance of wind tunnel tests or experiments subjected to lower rainfall intensities and higher wind speeds. In addition to flow deflection the effective gauge orifice of 316 cm^2 valid for vertical precipitation needs to be corrected for the partly open structure of the lower half of the sphere which presents a reduction in effective gauge surface for the large ***α*** values encountered during the experiment. Two correction models for the spherical gauges were compared: model 1 applied a constant wind-loss of 15% and an effective gauge surface that varied as a function of ***α***, whereas model 2 applied the wind-loss correction found for conventional rain-gauges. Both models gave similar results with total $\boldsymbol{P_{sph}}$ of 636 and 612mm, respectively (Fig. 2b). Catch differences between spherical and potential precipitation gauges were evident at low precipitation intensity (Fig. 2c; cf. Chang and Harrison (2005) their evaluation against conventional gauges). Although the wetting / evaporation losses referred to by these authors must play a role, the inefficient catching of fog by the spherical gauges compared to the potential precipitation gauge constitutes the main source of disagreement. Figure 2d shows the catch by the two types of gauges for a large event (460 mm, 4.5 days) with a mean ***u*** of 6.1 m/s and correspondingly large ***α*** (75°). Agreement between the potential precipitation gauge and the spherical gauge is observed to break down for foggy conditions as occurring at the start and end of a precipitation event (Fig. 2d).

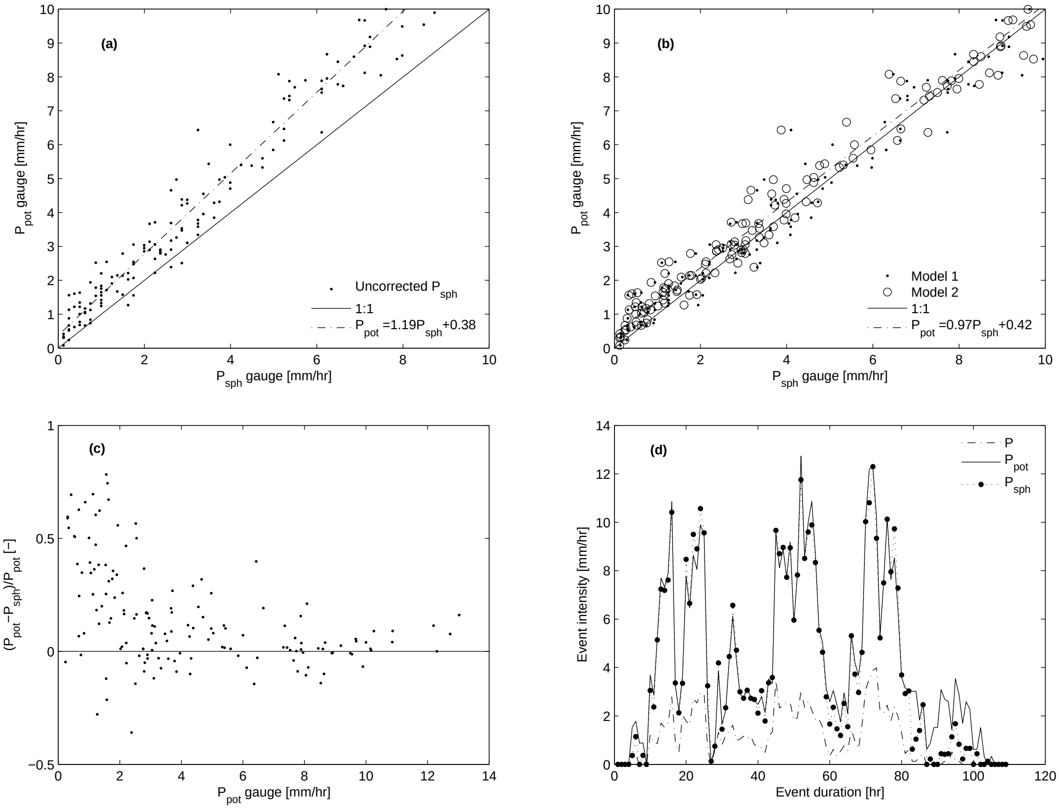

Figure 2: Potential rain and spherical gauge collections. Potential rain gauge vs. (a) uncorrected spherical gauge collection, (b) corrected spherical gauge, (c) weighted gauge differences, (d) and comparisons during a major precipitation event (d).

The good agreement between spherical gauges and potential precipitation gauge after application of the respective corrections lends confidence to the use of these types of gauges for the estimation of potential precipitation. The use of the potential precipitation gauge is to be preferred, however, because it also allows the determination of fog and, more importantly, precipitation inclination (***α***). The latter, in turn, allows estimation of the actual precipitation input at a given slope. Furthermore, wind-loss effects and catch efficiency are better defined for the potential precipitation gauge (Frumau et al. 2006a).

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