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RANDOM AND SYSTEMATIC ERRORS IN PRECIPITATION AT AN EXPOSED SITE

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ABSTRACT

The result of an experiment to determine the random and systematic errors in precipitation measurement at an exposed site in coastal Otago is recorded. It is shown that random errors of up to ±10 percent can occur using standard gauges, but these are reduced to ±4 percent if ground-level gauges are used. The most important factors affecting the systematic errors are wind speed and the height of the gauge rim above ground. It is suggested that an exposed rainfall station should consist of a ground-level gauge, a standard gauge, a gauge at a suitable height above ground, fitted with an Alter shield, and a cup-counter anemometer.

INTRODUCTION

The most complete method of hydrometeorological network design – that of Optimum Interpolation, which was developed in the USSR mainly under the direction of Drozdov and Sepelevskij (1946) and Gandin (1970) – recognizes that in any estimate of an areal or point value of a meteorological element, there are four sources of error, namely

(a) systematic spatial and altitudinal variations of the element,

(b) systematic measurement errors,

(c) random measurement errors,

(d) random errors due to the nature of the sample, i.e. for a point estimate, due to the distances between measuring points and the point at which the element is to be estimated, or for an areal estimate, due to the necessity of representing an areal value by some function of the point values.

Of these four sources of error, two (b and c) refer to the actual methods of taking measurements. Since either or both of these

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sources can produce considerable errors or uncertainties in any desired estimate, it is important to identify the manner and values of these errors for a wide range of natural conditions.

Systematic errors involved in precipitation have already received attention by research workers, but most of the effort has been concentrated on lowland moderate conditions, while relatively few have concentrated on the conditions which may be expected in exposed highland situations such as may be found over a large part of New Zealand.

Investigations into random errors are almost unknown, partly because there has been little awareness that such errors exist, except in the USSR and Hungary, and partly because these errors can be estimated by statistical methods within the method of Optimum Interpolation.

The investigation, the results of which are presented here, was therefore aimed at quantifying, for one particular exposed site, these systematic and random errors.

Experimental Procedure

The experimental site was situated on a ridge at an altitude of 550 metres above sea level, in a position 1100 metres southwest of Mount Cargill, which lies just to the northeast of Dunedin. The condition of the site was maintained in a manner similar to any remote, exposed, operational site; for example, the natural grass ground cover was scythed periodically, rather than mown regularly. Instrumentation included cup-counter anemometers, standard 127-mm (5-inch) orifice raingauges, recording gauges, and various fitments, including Alter shields. One major difficulty was the lack of a recording anemometer, and wind speeds were therefore calculated, either from cup-counter readings just before and after storms, or during storms from readings separated by 10 minutes.

RANDOM RAINGAUGE ERRORS

Random raingauge errors arise from three causes. One is the small microclimatological variations across the climatological measuring site. Another is due to variations in gauge manufacture, even within one design, and the third is due to the spatially and temporally variable nature of precipitation as it falls. Thus one gauge observation at a site is only one estimate, subject to random statistical error, of the average depth of precipitation falling on the site.

As random statistical error cannot be estimated from only one gauge, 12 manual gauges (later reduced to 5) of identical design were installed at the standard rim height of 305 mm (1 ft) above ground level, scattered randomly over the 10 m×10 m site.

Since storm by storm the 12 readings from each gauge were statistically independent, an estimate of the true mean and the standard deviation can easily be calculated. Of particular importance is the standard deviation, since it is this quantity which estimates the random error of an observation from a single raingauge. The standard deviations (calculated without small sample correction) from 78 storms (21 with 12 gauges, the rest with 5) of various intensities are plotted against storm intensity in Fig. 1A and replotted as coefficient of variation in Fig. 1B. The curve from which Table 1 is calculated was plotted by eye. The inference from these graphs is that the random error associated with a single gauge reading may be quite considerable, falling from 10 percent for light

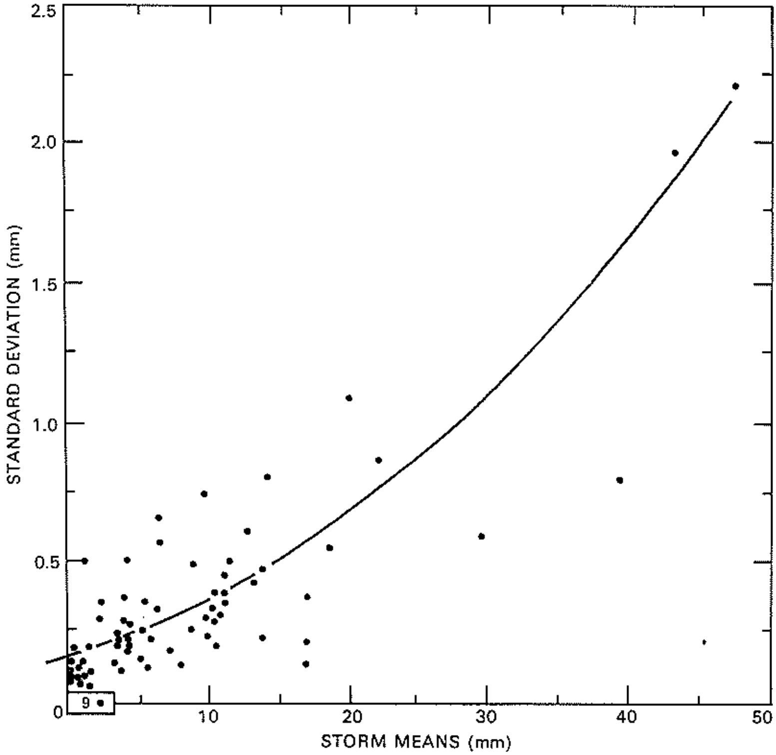

FIG. 1A — Standard deviations of estimates of mean storm rainfall.

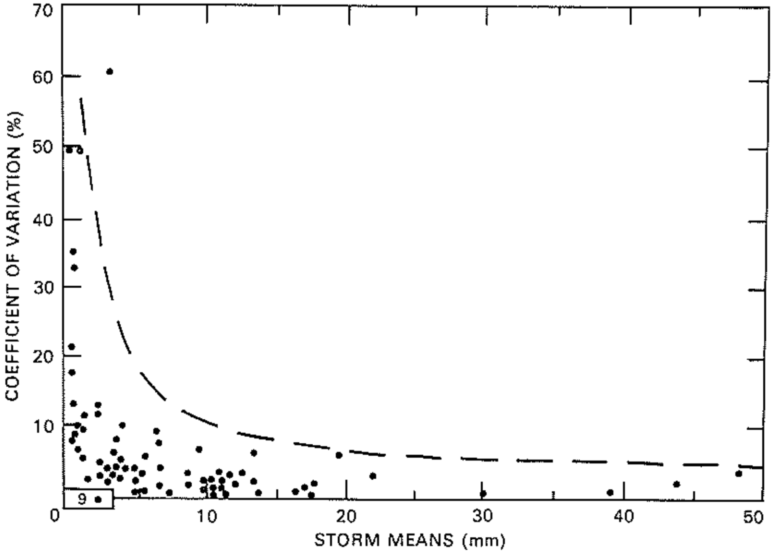

FIG 1B — Coefficients of variations of estimates of mean storm rainfall.

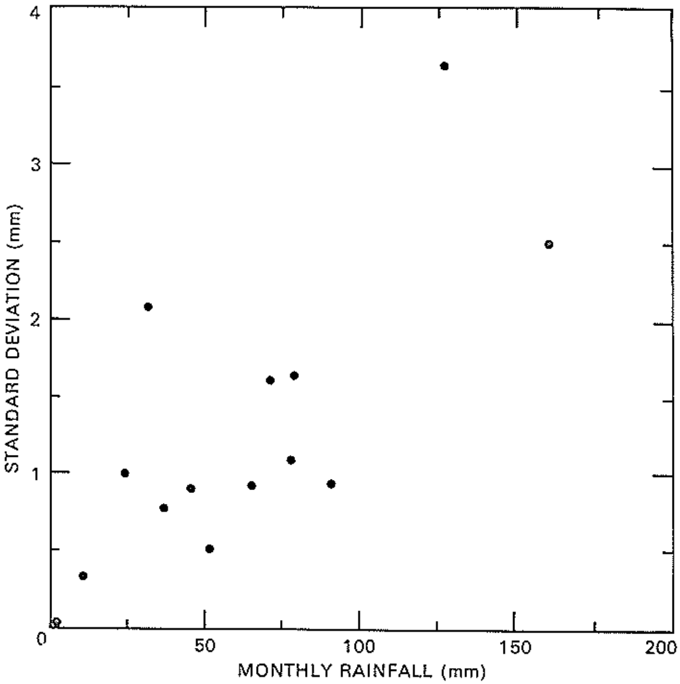

FIG 2 — Standard deviations of estimates of mean monthly rainfall.

TABLE 1 — Expected error of single raingauge readings (individual storms).

Mean (mm)	*Standard deviation (mm)*	*Coefficient of variation (%)*	*95% confidence interval (mm)*
2.5	0.2	8.0	2.1–2.9
5.0	0.25	5.0	4.5–5.5
7.5	0.3	4.0	6.9–8.1
10.0	0.35	3.5	9.3–10.7
15.0	0.5	3.0	14.0–16.0
20.0	0.7	3.5	18.6–21.4
30.0	1.1	3.7	27.8–32.2
40.0	1.7	4.2	36.6–43.4
50.0	2.4	4.8	45.2–54.8

storms to a possible asymptotic limit of 4 percent for heavy storms, taking the usual 95-percent confidence intervals.

The monthly precipitation totals give lower values for the standard deviations, Fig. 2 showing the data for the 14 months of the experiment. Most coefficients of variation fall within the 1 to 4 percent range, only one value being in excess of 4 percent. The one annual value available gave a coefficient of variation of 0.2 percent, with 95-percent confidence limits of 795.6 and 802.0 mm, a variation which would be considered negligible.

The large random errors involved in measuring storm rainfall point to the desirability of reducing this error. The question of whether this was possible was studied by installing three ground-level gauges, at a late stage in the experiment. Although only nine storms were studied, Table 2 – in which the standard deviations for ground level and standard rim height are compared – shows that, on this count, it would be beneficial to use ground-level gauges.

SYSTEMATIC ERRORS

The most important of the systematic errors in raingauge measurement is that due to the disturbance of the horizontal airflow caused by the presence of the gauge. The air is deflected away from the orifice of the gauge and is speeded up across it, with a consequently decreased catch. Thus wind speed is the most important determinant of the error, but since wind speed increases with height above ground the gauge rim height is also important.

TABLE 2 — Comparison of standard deviations of ground-level and 305-mm (1-ft) gauges (mm).

Ground-level gauge:	0	0	0.02	0.13	0.15	0.15	0.25	0.46
305-mm gauge:	0	0	0.13	0.31	0.31	0.33	0.50	1.55
Ratio (%):	–	–	15	42	48	45	50	30

Variation of Catch Deficiency with Height of Rim

Although there is no absolute standard, the ground-level gauge is usually conveniently considered to give the true catch. In this case a ground-level gauge surrounded by a coir mat was assumed to provide the true precipitation. The systematic variations are set out in Table 3, which is self-explanatory. However, it is worthwhile to emphasize that the measured deficiencies are far in excess of most of those reported from the other similar experiments. For a standard gauge with a rim height of 305 mm, for example, the overall deficiency was 30 percent (25 percent for rainfall, 46 percent for snow), compared to figures of 6 percent by Rodda (1967) and 1 percent by Stanhill (1972) for lowland areas, and 5 percent given by Green (1970) for an 'exposed, hilltop' site.

TABLE 3 — Systematic errors of gauges.

Type of gauge	*Compared to ground-level mat gauge (%)*			*Compared to 1219-mm shielded gauge (%)*		
	Rain	*Snow*	*Total*	*Rain*	*Snow*	*Total*
Ground-level mat	100	100	100	128	218	142
Ground-level grid	99	90	96	104	187	129
305-mm(1-ft) standard	75	54	70	96	118	99
610-mm (2-ft) standard	73	44	67	94	96	94
1219-mm (4-ft) standard	71	40	64	92	87	91
1829-mm (6-ft) standard	68	36	61	87	78	86
610-mm (2-ft) Alter shielded	96	61	79	123	127	108
1219-mm (4-ft) Alter shielded	78	46	70	100	100	100
305-mm (1-ft) recording	75	54	70	96	118	99
305-mm (1-ft with kerosene	84	58	81	110	130	117
305-mm (1-ft) with oil	85	59	82	111	132	118
1219-mm (4-ft) Alter with snow funnel	84	39	65	85	102	88
Central orifice directional gauge (432 mm)	72	36	64	93	77	90

Variations of Catch Deficiency with Height of Rim and Wind Speed

The figures quoted in Table 3 are mean values, which are subject to variation due to variations in wind speed. Fig. 3 shows the relationship between catch deficiency, rim height and wind speed at 2 metres, for rain and snow combined. The differences between the curves indicate the importance of obtaining an estimate of wind speed.

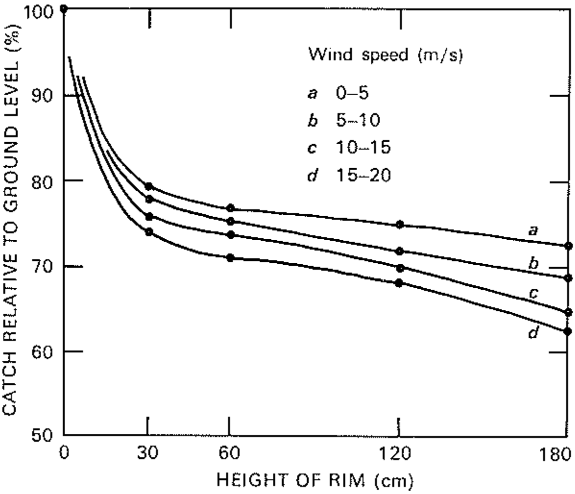

FIG. 3 — Catch deficiency in relation to rim height and wind speed.

Methods of Reducing the Systematic Error

Use of ground-level gauges. If the view is accepted that the ground-level gauge collects the (nearly) correct precipitation, the problem is easily solved in theory by using such a gauge, provided that a non-splash surround can be used. With the two types which have been tried, there are the possibilities that the mat gauge may become saturated, so providing a splashing surface and increasing the catch above true, or that the grid gauge may provide variations in turbulence conditions near the ground. Although these possibilities cannot be resolved, it was shown that there was no significant differences (at the 95-percent confidence level) between the two surrounds, in terms of the catch.

The ground-level gauge does, however, suffer from two practical disadvantages for use in exposed or remote sites. Apart from problems of constructing the required pit in the ground, difficulties of drainage of water from the pit often arise. Regular attendance or automatic pumping may be required, but not available. The other difficulty is that this gauge is virtually useless in snow. Apart from snow bridging the orifice, it can also blow in.

The ground-level gauge is therefore not the complete solution.

Use of shields. The use of raingauge shields has long been advocated. Of the various types, the Alter shield is probably the most successful. The shield attempts to provide a horizontal airflow over the gauge orifice, and the particular advantage of the Alter design, which is constructed in strips free to swing, is that snow bridging over the orifice and the shield is eliminated in all except the most extreme conditions.

Table 3 indicates that the shield, when set with rim at either 1219 mm (4 ft) or 610 mm (2 ft) does reduce the catch deficiency compared to unshielded gauges at identical heights. The improvement in rainfall measurement is noticeable at 1219 mm (22 percent deficiency compared to 29 percent), but startling at 610 mm (4 percent compared to 27 percent). These results lie within the range of previous experimental results, a selection of which is given by Weiss and Wilson (1958).

The shielded gauge thus has the advantages over the unshielded gauge at similar heights that it reduces the systematic error and almost eliminates bridging by snow. The height of the shielded gauge should be as low as possible, but high enough to avoid being covered or affected by lying snow.

CONCLUSIONS

Using single raingauges at exposed rainfall stations provides random sampling errors of up to 10 percent for standard gauges or 4 percent for ground-level gauges. This error can be reduced by multiple gauging at each station, but this is expensive in capital and maintenance costs.

The systematic error caused by having the gauge rim above ground level is dependent upon wind speed and the height of the rim, but this error can be reduced by using shielded gauges, or eliminated by using ground-level gauges where practicable.

It is recommended that an exposed rainfall station should consist of a ground-level gauge, a standard gauge for comparative purposes, a gauge fitted with an Alter shield at the lowest height consistent with non-interference by lying snow, and a cup-counter anemometer set at a standard height of, say, 2 metres. Such a station would provide the most valid estimate under all conditions, and allow any systematic errors to be estimated.

ACKNOWLEDGMENTS

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APPENDIX 1 — Experiments with fog catchers

While, in the main text, an attempt has been made to estimate the *actual* errors associated with raingauges, this is not possible for methods of estimating fog precipitation. Most precipitation from fog or mist is caused by obstructions in the horizontal airflow, such as grasses or trees, on to which the water settles. The amount caught depends on the nature and the density of the vegetation, so that any instrument will only provide a *relative* estimate.

The Grunow (1952) fog interceptor consists of a wire mesh cylinder such that the height is twice the diameter, with the vertical cross section equalling the horizontal orifice area of the raingauge. The interceptor acts as a fog trap to air passing through the mesh, the water being collected in the raingauge to which the interceptor is fitted. Nagel (1956) estimated that 10–16 percent of the fog passing through the cylinder was lost.

Because of the nature of the gauge, fog accompanied by rain cannot be measured, and 51 occurrences of fog only were metered by the fog interceptors, of which between three and six were in operation. An assessment of the random errors of these gauges gave values which were comparable to

TABLE 4 — Random errors of fog interceptors.

Mean of individual fog events (mm)	*Standard deviation (mm)*	*95% confidence intervals (mm)*
2.5	0.2	2.1–2.9
5.0	0.3	4.4–5.6
7.5	0.4	6.7–8.3
10.0	0.6	8.8–11.2
15.0	0.8	13.4–16.6
20.0	1.0	18.0–22.0
30.0	1.6	26.9–33.1
40.0	2.3	35.5–44.5
50.0	3.2	43.7–56.3

standard manual gauges (Table 4), but which nevertheless are meaningless in the context of actual fog caught, this being highly variable depending on the nature of the vegetation. It does indicate, however, the variable nature of fog intensity.

The total amount caught during the 51 occasions of fog only in 12 months was 734 mm. Not included is the amount caught during rain or snow precipitation. It is obvious, therefore, that fog interception is of the same order of magnitude as ordinary precipitation, and may indeed be greater.