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Point precipitation measurements: why are they not corrected?

BORIS SEVRUK
Department of Geography, Swiss Federal Institute of Technology, Winterthurerstr. 190, CH-8057 Zürich, Switzerland

ABSTRACT Knowledge of precipitation is based on point measurements obtained from can-type gauges exposed above ground-level, a technique applied and unchanged ever since the early days of civilization. Such measurements are subject to a systematic error of up to 50%. This error has been known and efforts to eliminate it been made since the seventeenth century. From that time, a myriad of papers has been published suggesting protection measures or correction procedures. Yet the precipitation measurements are still not corrected. The reasons for this state of affairs are analysed and future prospects discussed.

Les valeurs de précipitation: pourquoi ne sont-ils pas corrigés?

RESUME Presque toutes nos connaissances concernants les précipitations sont basées sur des mesures de point effectuées par des pluviomètres du type de seau, une technique qui n'a pas changé depuis les débuts de la civilisation. Des mesures de ce genre peuvent avoir pour conséquence une erreur systématique jusqu'à 50%. Son existence est connue depuis le dixseptième siécle et en conséquence on a essayé d'améliorer les pluviomètres. Des lors des milliers de publications qui documentent le problème de l'erreur systèmatique et qui supposent des mesures de protection où des méthodes de correction ont paru. Mais cette erreur elle n'est toujours pas corrigée. Les raison pour cette situation sont analysées et les perspectives sont discutées.

INTRODUCTION

The can-type gauge exposed above ground-level still appears to be a common feature of the present standard method of precipitation measurement, as it was centuries ago. Such a gauge generally consists of two parts: the collector and the container, the latter usually in the form of an upright-cylinder, connected by means of a funnel. The precipitation collected in the container is either emptied into a graduated glass and read against a scale or its depth is measured with a graduated dip-stick or scale, one or two times per day. This is the principal way most precipitation data all over the world have been and still are measured, and knowledge of precipitation relies very largely on such data.

It may be hardly believable for a non-specialist that such a strikingly simple arrangement is subject to appreciable systematic error of a magnitude up to 50%. Yet climatologists are well aware of the inconsistent precipitation data series due to changes of either the type of gauge or gauge site characteristics and of the discordant results of comparing measurements from various types of precipitation gauges installed at the same site. There are two prominent cases which indicate the existence of the systematic error. If, for example, an exposed gauge site has been afforested, a gradual increase of measured precipitation values will emerge a few years after the afforestation, when the height of growing trees increases above the level of the gauge orifice. Consequently, despite the same location as well as the same type of gauge, precipitation data before and after afforestation will not be the same and it would seem that the climatic conditions at the location had changed. Sometimes attempts are made to relate such effects to the natural influence of the forest causing an increase in precipitation. However, the truth is that the larger precipitation values are due to the increasing protection of the growing trees against the wind, which results in a smaller systematic error in the rainfall collected by the gauge. The wind systematically distorts the precipitation measurements by preventing the smaller liquid precipitation particles from entering the gauge. These are carried to beyond the lee side of the orifice of the gauge (Folland, 1986). Thus, the amount of precipitation caught by the gauge is smaller than the amount of incident precipitation and the error increases as the proportion of small drops gets larger and as the wind speed increases. Due to the increasing protection of the growing trees around the gauge, however, the wind speed above the gauge orifice decreases and the wind induced loss becomes smaller. This effect is more obvious at gauge sites which were exposed before the afforestation than at protected ones and is more obvious for snow than for rain which consists of considerably heavier particles. This explains why the increase in precipitation in afforested gauge sites is greater in the winter season than in the summer, as shown in Fig.1.

Similarly, comparisons of measurements of different types of precipitation gauges installed at the same site indicate differences between the precipitation values, which vary also according to the season (Sevruk, 1971). This seasonal pattern shown in Fig.2 is due to the varying magnitude of the systematic error of gauges of different design during the year. In contrast to the above-mentioned effect of growing trees, beside the wind-caused losses, other components of the systematic error also contribute to the different precipitation values, in this case. Such components are: the wetting of the inner walls of both gauge and collector during the rain or after the melt of snow and the residual wetting of the gauge container when emptied; the evaporation of water accumulated in the gauge container in the time between the end of a precipitation event and the measurement; the insplash and outsplash or blowing and drifting snow etc. The magnitudes of all these components can be different for various types of gauges. For example, the largest

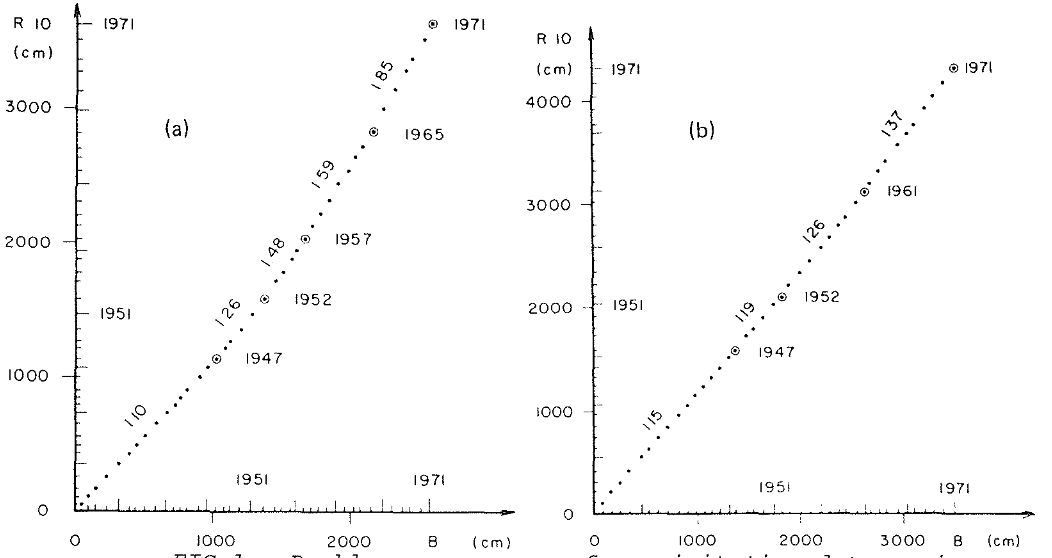

FIG.1 Double mass curves of precipitation data series for (a) the winter and (b) the summer season at an afforested location in the Swiss Alps (Sevruk, 1973).

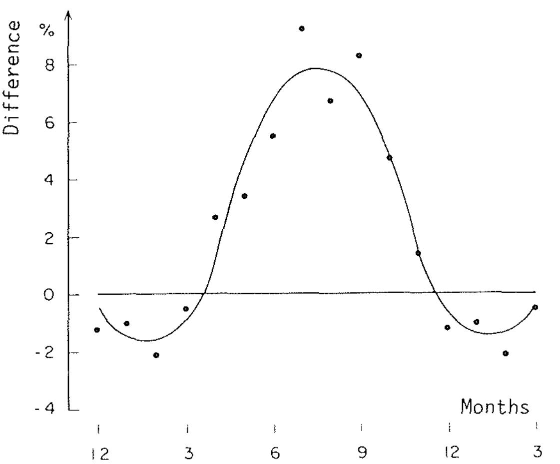

FIG.2 Seasonal pattern of the difference of measured precipitation between the Hellmann gauge and the Swiss totalizer (Sevruk, 1971).

difference between the totalizer and the Hellmann gauge, amounts to 8% in the summer season, (Fig.2). This is due to the larger evaporation and wetting losses of the totalizer in the summer as compared with the Hellmann gauge. In the winter season when the evaporation is small, the totalizer collects more precipitation than the Hellmann gauge. Therefore, if one type of a precipitation gauge has been replaced by a different one, an inhomogeneous precipitation data series can result at the same spot. This is going to be a very serious problem in future because of current replacement programmes of the old manual gauges with new automatic heated ones. The new gauges show a larger systematic error which is primarily due to increased evaporation losses caused by the heating of the gauge during and after the snowfall. This is likely to become a permanent effect on future networks because of a tendency to use the new technology gauges instead of the older ones.

In addition to these prominent cases which obviously demonstrate the systematic error, methods have been developed which make possible the quantitative estimation of the components of the systematic error. For example, for rainfall, the wind-caused loss can be estimated from the difference of precipitation values measured by two gauges, one exposed above the ground and the second one installed with its orifice at the ground surface (Fig.3). The latter gauge is not affected by wind. Similar methods exist for snow (e.g. double fence or bush shield - see Figs 4 and 5), for wetting, and for evaporation etc., as reviewed by Sevruk (1982). Moreover, a number of procedures are available for correction of the systematic error of precipitation measurements for various time periods and types of gauges from different countries (Sevruk 1986).

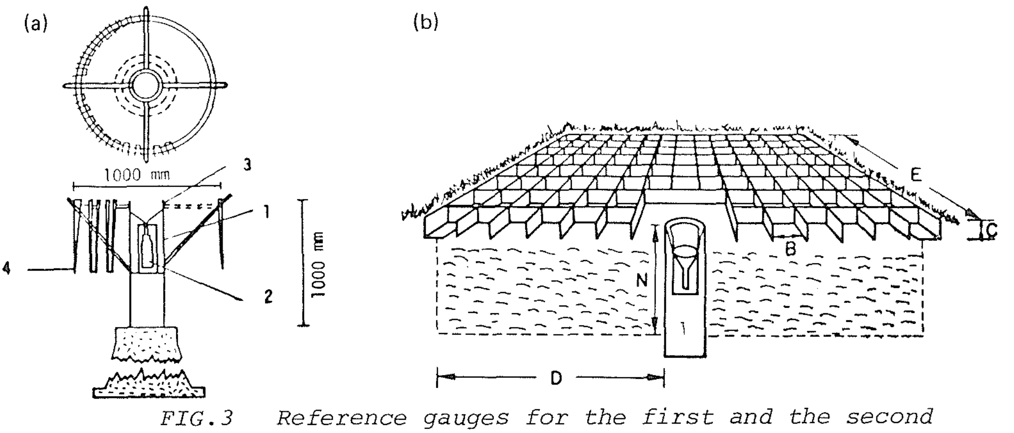

FIG.3 Reference gauges for the first and the second international comparisons of precipitation gauges: (a) elevated gauge with windshield and (b) pit gauge with a splash protection

The main problem of the systematic error of precipitation measurement seems to be the fact, that despite its considerable magnitude of up to 15% for rain and 20-50% for snow, it is not taken into account by most meteorological and hydrological services. When compared with the level of precision for other meteorological observations, this attitude is surprising.

It is obvious that the current practice of precipitation measurement must be a considerable source of error in hydrological computations. The water balances on a regional, national, continental, or even global basis are still computed with uncorrected precipitation values. It follows that under such circumstances, neither precipitation nor evaporation nor groundwater amount can be properly assessed. This is why, hydrologists and other precipitation data users have long been calling for corrections of systematic error, but with virtually no success. It is the purpose of the present paper to analyse the reasons for this state of affairs and to discuss the future prospects. For this aim, a digression into the history of the problem might be useful.

THE PAST (SEVRUK, 1982, 1986)

The existence of errors in precipitation measurements has been known in Europe and efforts have been made to improve precipitation gauges since the seventeenth century, when evaporation from raingauges was discovered as being the major source of error. First attempts to correct the wetting loss, a very obvious loss, were made by the end of the eighteenth century. The start of the long history of correcting precipitation measurements was made, however, by William Heberden's (1769) famous paper on the difference between precipitation values measured in the garden of Westminster Abbey and on its towers.

Since then, many papers have been published that document the findings by Heberden and suggest protection measures such as wind shields and fences or natural protection by trees or buildings. During the last century, series of comparative measurements were carried out in many countries to establish the most accurate precipitation gauge and its installation conditions. Although it was soon proven that guages that are level with the ground and protected against splashing always caught the largest quantity of rain, these pit gauges were for practical reasons never generally used. Occasionally, one or the other formula to correct measured precipitation was suggested, but no physically based correction procedure was available before 1944, when Korhonen in Finland applied such corrections to snowfall measurements. It was not until the sixties that a major breakthrough took place. This time, it was the Soviet Union that took the decisive step forward in the development of correction procedures, although quite accidentally. While replacing the old Nipher raingauge, (the standard gauge in the Soviet Union since the 19th century), by the new Tretyakov precipitation gauge, it was observed that the precipitation data as measured by the new gauge were inconsistent with the old ones and could not be adjusted to the old data series simply by using a constant reduction coefficient, which had long been the procedure for eliminating inconsistencies in precipitation data series by the meteorological services. Because the coefficients contained considerable seasonal, regional and exposure variations, all components of the systematic error of both instruments were investigated in order to find a better solution. This led to a series of papers by Struzer, Bogdanova, Nechayev, Golubev, Bryazgin and Gorbunova (Sevruk, 1982). They proved that the only way to eliminate the inconsistencies in data series is to correct the measured precipitation for both types of gauges, for their systematic errors. They showed that there are physically-based correction procedures which are operationally applicable to the precipitation gauge networks through the use of the routinely measured meteorological elements. The Soviet Union was the first country to accept precipitation data corrections. In the meantime, the first international comparison of precipitation gauges was initiated by Poncelet in 1955 and organized jointly by the World Meteorological Organization (WMO) Commission for Instruments and Observation Methods (CIMO) and the International Association of Hydrological Sciences (IAHS). Its objective was to obtain reduction coefficients for various national standard gauges by means of an elevated gauge as a reference. Because the systematic error was not fully taken into account, this first international comparison was not a success. Later, a similar comparison took place but this time with a pit gauge as a reference (both gauges are shown in Fig.3). As a consequence, new correction procedures emerged for a number of national precipitation gauges (Sevruk, 1986).

At the same time, WMO increased its activities in this field. In 1977, a rapporteur was nominated to review the latest developments in improving the accuracy of precipitation measurements. Moreover, five significant reports were published: a report on the accuracy of precipitation measurements (Rodda, 1971); a bibliography of precipitation measurement (Rodda, 1973); a review on correction procedures (Sevruk, 1982); the results of the second international comparisons of national precipitation gauges with a reference pit gauge (Sevruk & Hammon, 1984) and the proceedings of the Workshop on the Correction of Precipitation Measurements, held in Zürich in 1985 (Sevruk, 1986).

THE PRESENT

It is clear that insofar as there were no correction procedures in the past, it was not possible to correct the precipitation values for the systematic error. In addition, the correction of individual precipitation events can be quite a complex task. More variables than simply precipitation are needed, such as the wind speed during the events at the level of the gauge orifice, the intensity of precipitation, temperature, frequency of precipitation, proportion of solid precipitation etc. These variables may not be available at each gauge site. This fact can pose additional problems. However, the longer the time interval included, the simpler the correction procedure and the smaller the error of estimation.

Considering that the first studies of the systematic precipitation measurement error were made a few centuries ago, the correction thereof is relatively recent. Many a problem seemed to be impossible to solve until very recently, the first operationally applicable correction procedures having become known only at the beginning of the sixties. The accuracy of those initial short-term corrections (day, week) was not very high. Since then, the subject of correction procedures has developed and will develop still further. In the meantime, new and better methods of precipitation measurements have been suggested. In the light of this considerable progress, the state-of-the-art of precipitation measurement in almost all national networks seems to be disappointing: in brief,

(a) no corrections of systematic error are generally applied;

(b) new techniques of point precipitation measurements are little used in most countries;

(c) no regular checking of precipitation gauges at the sites against a reference is made;

(d) inconsistencies due to the systematic error are not eliminated from time series.

There are, however, some measures available for reducing the magnitude of the systematic error, but in practice, they are not very effective and not easy to follow. It is recommended, for instance, in some countries, for precipitation gauges to be installed in sheltered sites, i.e. the distance from the gauge to the nearest objects should be between 0.5-1.0 times their height above the gauge orifice. Even if this is possible, the wetting and evaporation losses will hardly be reduced by this arrangement.

The question is: What are the reasons for this state of affairs and what could be made at present to change it?

The new measurement techniques are more expensive than the simple traditional installation of gauges. The ground level or pit precipitation gauge for instance reduces the wind effect to a minimum and is thus a particularly efficient raingauge in summer. The preliminary preparations are illustrated in Fig.3: excavation, possibly drainage of a pit, and erection of a grid to protect against splashing. However, wetting and evaporation losses must be corrected. Another considerable disadvantage of the pit gauge is the fact that it is an unreliable snow gauge. Snow drifts can falsify measured values as additional snow gets into the snow gauge. Thus a second exposed precipitation gauge is required for seasons with snowfall, e.g. one surrounded by a double snow fence as depicted in Fig.4. This gauge is far more reliable than the conventional precipitation gauge with a wind shield, although it does not provide complete protection against the wind. With wind speeds exceeding 3 m s^{-1}, the wind-caused loss may be above 5%, which means that corrections may be required, too. In any case, wetting and evaporation losses must be corrected just as with ground-level precipitation gauges. The double snow fence has other disadvantages: it is very expensive and needs a lot of space, i.e. a few hundred square metres instead of only a few square metres for a conventional installation.

The so-called "bush shelter" measurement technique (see Fig.5) is more reliable both in summer and winter, but it is also more expensive. The gauge is set up in the middle of a patch of shrubs or young wood of about two to three acres which have to be regularly trimmed to the height of the gauge. The wind-caused distortions are irrelevant. As far as snow measurements are concerned, this arrangement is comparable to the ground level gauge, with the additional advantage of the absence of drifting directly into the gauge. If this precipitation gauge is equipped with a weight recording device, there is no need to correct wetting and evaporation losses. Is this then the answer to the problem? Not really, since it is very expensive and such locations are very rare. To plant shrubs around every gauge is not feasible either.

On the other hand, it would be wrong to believe that all precipitation data collected in a network of conventional gauges at considerable expense are useless and new and better gauges have to be installed everywhere. The precipitation measurement error is

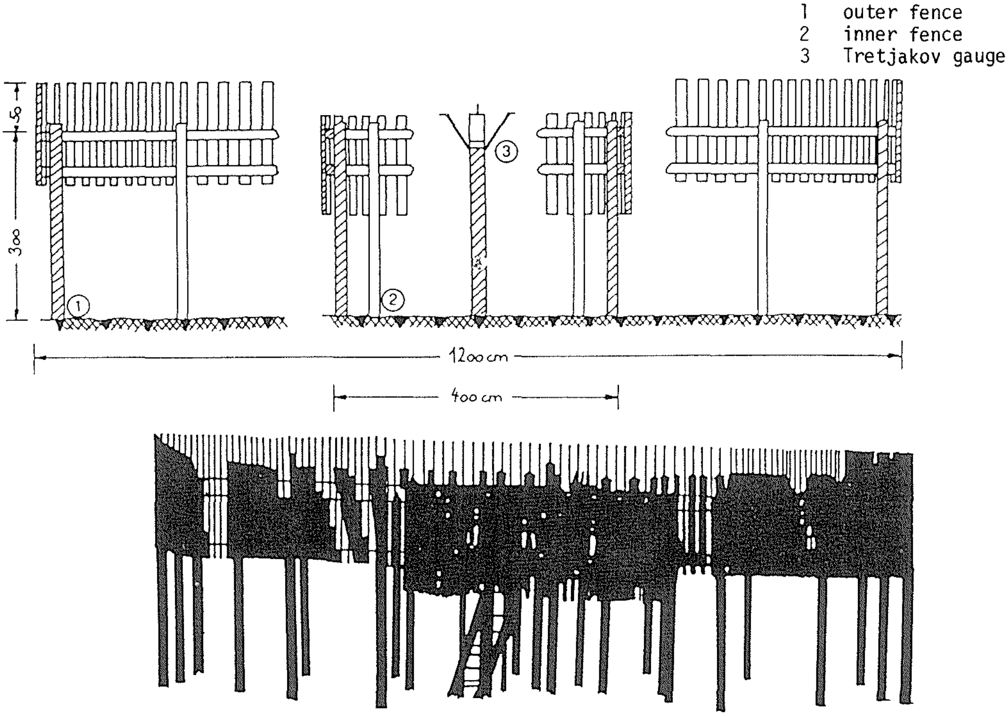

FIG.4 Reference gauge for the recent World Meteorological Organization WMO Solid Precipitation Measurement Intercomparison (double fence).

FIG.5 Bush shielded gauge.

relatively small, i.e. approx. 5% at well-protected sites and during heavy rainfalls with large drop diameters (Allerup & Madsen, 1980).

The above examples show that the widely used standard method of precipitation measurement is not the final answer to the problem. It is a compromise between the costs and benefits of a precipitation-data collection system. Thus, the only improvement possible at the present time is the introduction of corrections for the systematic error in precipitation data into the network measurements on an operational basis. To achieve this goal will demand a great deal of private and public effort.

THE FUTURE

Despite the fact that the research into the precipitation measurement error has been intensified considerably in recent years, it is apparent that the age of ready access to corrected precipitation data in every country has not yet dawned. In future, regular comparison must be made between the conventional gauges of various types and reference gauges such as the pit gauge and gauges protected by wind fences in each country. These should be complemented by laboratory tests in order to investigate the physical properties of precipitation gauges by using wind tunnels and mathematical models to derive more accurate correction procedures. Such comparisons and tests will provide the data sets required to compare and to test various correction procedures under different climatological conditions and eventually to select a suitable procedure for operational purposes, for the old as well as the new gauges. In addition, this will stimulate particular research in countries that in general do not yet apply corrections. Such an arrangement will also help to cut research expenditure. Until now, each country has been developing its own correction procedures, although suitable procedures may already be available elsewhere.

As the next step toward this goal, the WMO invited Member countries to participate in the WMO Solid Precipitation Measurement Intercomparisons (WMO, 1986). During this Intercomparison the differences in snowfall catch between all national methods of measuring solid precipitation and the reference method should be compared. The large vertical double-fence has been designated as the reference (Fig.4). All this will be an essential contribution to the worldwide introduction of corrections into current measurements of precipitation.

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