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INSTRUMENTS AND OBSERVING METHODS

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CATALOGUE OF NATIONAL STANDARD PRECIPITATION GAUGES

by

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FOREWORD

Conventional precipitation gauges are rather simple meteorological instruments. Many meteorological services have thus traditionally used domestic or even self-made precipitation gauges in their observation networks. On one hand this practice has been quite economic but on the other hand it has led to a wide variety of national standard precipitation gauges with varying dimensions and performance characteristics.

A survey conducted by the World Meteorological Organization in 1987 showed that there are more than 150,000 gauges in use among which there are 50 types of national standard precipitation gauges. This report summarizes the results of the survey and discusses technical aspects of the subject including a review of the problems of precipitation measurements and related data compatibility.

The report has been written by two renowned experts who have for many years contributed to the work of CIMO. Dr. B. Sevruk received in 1987 the WMO Professor Dr. Vilho Vaisala Award for his papers on precipitation measurements and Mr. S. Klemm was for several years as senior scientific officer in the WMO Secretariat being responsible for all CIMO activities. I am most grateful to them for their work in preparing this report.

(Seppo Huovila)
President of CIMO

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SUMMARY

A survey of the World Meteorological Organization in 1987-1988, including replies from 136 countries of the WMO Members (of a total of 160) and covering an area of $121 \times 10^6 km^2$ showed that there are more than 50 types of national standard precipitation gauges, PGs, used worldwide at present. The area not covered by the survey amounts only to 10×10^6 km^2, equal to that of Canada. The total number of PGs is over 150,000.

The PGs differ considerably in design, shape, size and material. The orifice area varies from 7 to 1000 cm^2, most gauges having an area of 100-200 cm^2. Materials used are primarily galvanized iron sheet and copper but plastic is popular at present as well. The height of installation of PGs varies between countries from 0.2 to 2.0 m. Only a few types of PGs, seven in total, are permanently fitted with a wind shield of different design.

The most widely used PGs appear to be the German Hellmann gauge, followed by the Chinese PG and the English Snowdon Mk2 gauge. These types of PGs account for one-half of all PGs, yet they are concentrated in an area of only 31×10^6 km^2, thus demonstrating a very uneven distribution. Most of them are in developed countries, mainly in valleys and inhabited areas.

In 50 countries changes in national standards such as the replacement of the long-used type of PG, lowering or increasing the installation level of PG above ground, etc. took place in the last 30 years. The most decisive change was carried out in Japan in 1986 when automatic PGs were introduced instead of standard manual ones. Considering the variety of types of PGs and the changes in standards as well as the fact that there are no regulations with regard to the degree of exposure of the gauge sites, which varies from exposed to over-protected, the state-of-the-art of the global precipitation measurement appears not to be sufficient at all.

The precipitation data are not compatible and time series show multiple inhomogeneities and consequently, they are hardly suitable to be used to compute the "climatic norms" and to study precipitation trends and climate changes or make conclusions concerning global precipitation. The introduction of corrections of precipitation values for systematic error of precipitation measurement, particularly due to wind, wetting and evaporation, could considerably improve the quality of global precipitation data.

The present report contains tables with information on the national standard PGs of the WMO Members, including cross-sections of PGs, a brief review of the problems of accuracy of precipitation measurement, and of the results of wind tunnel tests regarding aerodynamical characteristics of PGs and correction procedures of the wind-induced error, wetting and evaporation.

LIST OF SYMBOLS AND ABBREVIATIONS

A	aluminium
A_o	area of orifice, in cm^2
A_w	total area of the inner walls of the gauge collector, cm2
B	brass
C	copper
CIMO	Commission for Instruments and Methods of Observation of the World Meteorological Organization
D	distance
G	galvanized iron sheet
H	height above the gauge orifice
ISPMI	International Solid Precipitation Measurement Intercomparison
L	lacquered iron sheet
N	parameter of precipitation structure
P	plastic
PG	precipitation gauge
PGs	precipitation gauges
P_E	intensity of evaporation
P_g	precipitation values as measured at 0.3 m level above ground
ΔP	difference between measured values of precipitation of two gauges
Re	Reynolds number
S	steel
s	snow gauge
SEP	systematic error of precipitation measurement
U	wind speed above the gauge orifice
U_{max}	maximum wind speed as measured over the gauge orifice in wind tunnel
U_o	wind speed in wind tunnel
U_{ph}	wind speed during the precipitation periods in the level of gauge orifice
dU	product of wind speed and saturation deficit
WMO	World Meteorological Organization
1-04-P	code of a particular type of precipitation gauge, see Appendix II for explanation
+	wind shield permanent
(+)	wind shield sporadic
*	bird protection ring used

I. INTRODUCTION

According to Hellmann (1890), the first European describing a simple cylindric precipitation gauge (PG) consisting of a can having the height equal to two diameters, was Castelli in Italy in 1639. Since then an abundance of historic literature has described one or the other type of PG as used throughout three centuries. This was briefly reviewed by Sevruk (1981), and Rodda (1973) compiled an annotated bibliography on the subject. However, only Kurtika (1953) strove to get a somewhat complete picture on PGs as used in the first half of this century, including technical descriptions and pictures. His main objective was to select an instrument suitable to unattended automatic weather station operation.

In the meantime the automatic PGs, mostly tipping-bucket gauges, some of them heated to be used also in the winter season, could be found in almost every national meteorological network. For instance, in Switzerland automatic PGs have completed the network of standard PGs (the Hellmann type) through the inclusion of 70 new automatic weather stations and in Japan there are 1000 such PGs used instead of older, manual standard PGs. These changes as due to the use of new technology, new, cheaper and lighter materials such as plastic and improvements in the shape of PGs with regard to their aerodynamic properties, pose some serious problems concerning the elimination of inhomogeneities in precipitation time series and corrections of the systematic error of precipitation measurement, SEP. The correction procedures have to be developed for each new type of PG and parallel measurements of the old and new PGs have to be carried out at each gauge site to check the time series for inhomogeneities. Thus there is a need to know the worldwide state-of-the-art of precipitation measurement techniques, particularly the relevant construction parameters of PGs and elevation level of PGs above ground in a given country, which are responsible for the variability of SEP among the different types of PGs.

To close the gap, this report provides basic information on the standard precipitation measurement techniques as used at present by the Members of the WMO. The ultimate objective is to contribute to the worldwide standardization of correction methods of SEP.

The results of the report are based on the analysis of a questionnaire which was prepared by the CIMO Rapporteur on Precipitation Measurement in co-operation with the WMO Secretariat, in particular Mr.S. Klemm of the WWW Department. A copy of the questionnaire appears in Appendix I. It was distributed in 1987 - 1988 to all Members of the WMO. The high response rate of replies received (from 136 out of 155 Members and 5 Territories) indicates the responsible attitude of the Meteorological and Hydrological Services which are well aware of the problems of precipitation measurement and which recognized that such material will be of great help in studying global climatological and hydrological processes.

The report consists of the general part, with the introduction to the problem of precipitation measurements and the analysis of the questionnaires, including tables with the information on numbers, density and the type of PG in a particular country, the height of the PG orifice above ground and pictures of a cross-section of almost each type of PG. A code number has been given to each type of PG consisting of the information on the area of orifice, depth of the collector, material and wind shield. The countries are grouped together according to the type of PG used, type of wind shield and the height of orifice above ground. The total number of PG of a given type worldwide was also assessed. In addition, the changes of precipitation measurement techniques during the last 30 years in each country are listed. Yet there is no specific information available on the size and the shape of orifice rim of a particular type of PG. Because both are very important variables affecting the wind-induced error, the missing information will be included in a report by the CIMO rapporteur on precipitation. Nevertheless, in Figure 2 of this report, seven types of orifice rim are specified and the wind fields as measured in a wind tunnel are parametrized.

2. PROBLEMS ENCOUNTERED IN PRECIPITATION MEASUREMENTS

2.1 Standard precipitation gauge

A variety of different types of PGs exists. They differ in size and shape, material, colour etc. As shown in Appendix II, a common type of PG consists mainly of an upright cylinder exposed above the ground. In Figure 1 a cross-section of a representative, standard PG , such as the Hellmann gauge is shown. This type of PG seems to be the one most commonly used. There are approximately 30,000 such PGs used in many parts of the world, as seen from Table 4 in Appendix III. The Hellmann PG consists of the collector and the container, where the accumulated water and melted snow are stored between the observational times, generally 24 or 12 hours. The upper edge of the gauge is reinforced with a thicker orifice rim to prevent its deformation, hence the possible change in the strictly defined size of the orifice area. The Hellmann PG has an open rim hanging inside over the orifice like a console. Other types of PGs are more likely to have a solid rim of a different size and shape as shown in Figure 2. A calibrated jar is used for volumetric measurements of precipitation. This and similar types of PGs are used for the standard method of measurement of the daily and half-daily sums of precipitation, in tenths of millimeters or hundreds of inches (less frequently). 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. Apart from the standard PGs there are recording and storage gauges which are used to measure precipitation sums of time intervals shorter and longer than one day, respectively. These types of PGs are generally bigger than the standard PGs. Moreover a lot of special types of PGs exists which are used by researchers and hydrologists for different purposes (stereo PGs, tilted PGs, vectopluviometers, etc.).

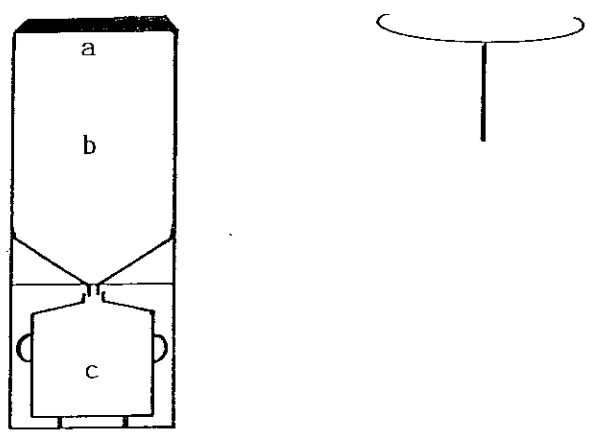

Fig. 1 : Cross-section of the cylindrical precipitation gauge of the Hellmann type (left) and of a hypothetical gauge with a superior aerodynamical shape of a shallow plate (right). a - orifice rim; b - collector; c - container.

The reasons for differences among the types of standard PGs with regard to the size, orifice area, material, etc. are partly historical and of course, they are also due to different climatic conditions in the countries of the gauge origin. Most types of standard PGs have been developed in the last century and are used to measure rain and snow as well. Thus PGs as developed in countries with much snow generally have larger collectors or, as for example in the case of the Chinese, Tretyakov and the Swedish gauges, they are equipped with a removable funnel which is taken away during the winter time to increase the collector depth. In addition, most of them are equipped with a wind shield and elevated at least 1 - 2 m above ground.

The differences in materials of PGs tend more to reflect the specific national preferences for materials in the last century than a scientific preference.

Thus copper was a popular material for technical instruments in England (Mk2 gauge), and galvanized iron sheet in Germany (Hellmann gauge). A further factor, contributing to the variety of PGs was the status of scientific knowledge of the error of precipitation measurement in a particular country. For instance, evaporation from a PG seems to be recognized as the first source of errors in England and France as early as in the 17th century. As a result precipitation was measured more frequently each

day, even after each storm, and PGs were technically improved, separating the collector and container or putting a funnel and a container into the collector to prevent evaporation loss. Similarly, the observation in England in the 19th century that the wind affects precipitation measurement led originally to lower and standardized installation heights and to improved aerodynamic shapes of PGs. Later, wind shields were developed in the USA.

Rank	Type of gauge	Orifice area [cm²]	Height [cm]	Re (10^4)	Cross-section of orifice rim
I	ASTA*	200	46	2.9	with bird protection ring
II	ASTA	200	46	2.9	no bird protection ring
III	Hellmann	200	48	2.6	-"-
IV	Tretyakov	200	39	2.2	-"-
V	Mk2	127	40	1.8	-"-
VI	China	315	60	2.7	-"-
VII	Wild	500	36	3.5	-"-

Fig. 2 : Cross-section of orifice rim, and construction parameters of various types of precipitation gauges as mentioned in Figure 6, according to Sevruk et al (1989). Re is Reynolds number and * indicates bird protection ring.

2.2 Comparison of precipitation gauges in the field

Hundreds of intercomparison measurements of PGs have been carried out in various parts of the world in the last two centuries. A historical perspective is given by Sevruk and Hamon (1984). Goodison et al (1989) refer to the recent WMO International Solid Precipitation Measurement Intercomparison, ISPMI. The earlier WMO intercomparisons were carried out in the 1970s (Sevruk and Hamon 1984) and the 1950s (Poncelet 1959).

The objectives of early intercomparison measurements in the last century were mainly of scientific interest to explain the observed differences between precipitation values as measured using the same type of PGs when installed at different heights. Later when the explanation was found in the adverse wind effect, the objectives were either to select most suitable and most accurate PGs or to obtain reduction coefficients

between various types of national standard PGs as well as to evaluate and to correct the SEP. For instance, the above-mentioned ISPMI has been designed:

- to determine the wind induced error in national methods of solid precipitation measurement, including consideration of wetting and evaporation losses,

- to derive standard methods for correcting solid precipitation measurement, and

- to introduce a reference method of solid precipitation measurement for general use, to calibrate any type of PGs.

Nevertheless, the results of intercomparison measurements do not only confirm the fact that considerable differences arise between precipitation values measured with different types of PGs, or at different heights above ground and under different climatic conditions or gauge site exposure, but they also show that these differences have a physical meaning. As shown in Figure 3, the differences have a distinct seasonal pattern and they increase with increasing installation height above ground. Generally they are small in protected locations and large in exposed ones. This indicates some regularities which reveal physical reasons for differences.

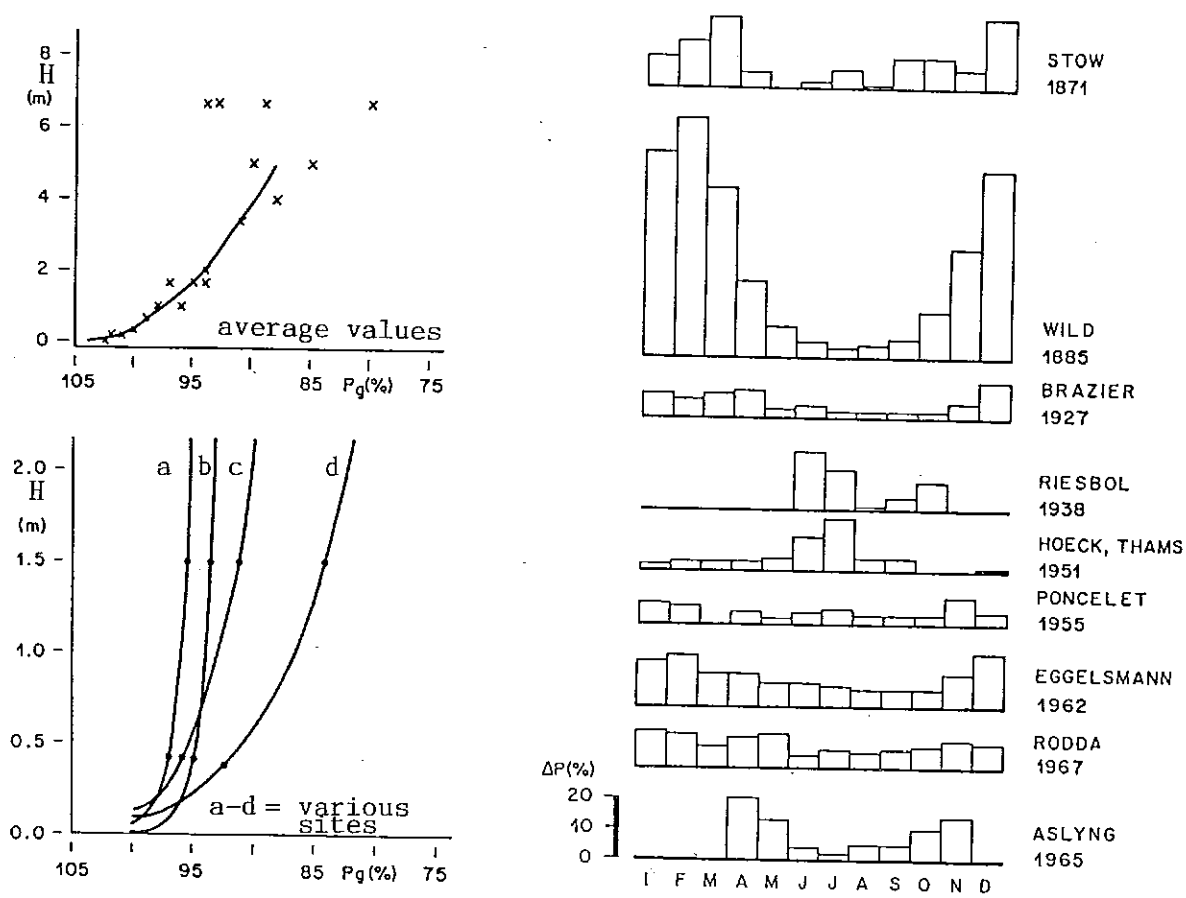

Fig. 3 : Decrease of precipitation measurement values with increase of the gauge orifice level, H, above the ground (left) and the seasonal pattern of the difference, ΔP, of measured values between two gauges (right), according to various authors as compiled by Sevruk (1981). P_g indicates precipitation values as measured at 0.3 m level above ground and J, F, M... etc are abbreviations of the months of January, February, etc.

2.3 Systematic error of precipitation measurements

The reasons for differences of precipitation measurements are of a systematic nature and are mainly due to the following physical processes: Wind field deformation above the orifice of PG, wetting of the inner walls of the gauge collector and container, evaporation of accumulated water and snow between the observational times and splash-out of water drops or blow-out of snow from the gauge. Because the physical processes mentioned are related to the instrumental parameters and climatic factors, as shown in Figure 4, the magnitude of SEP varies considerably even at the same site, according to the type of PG.

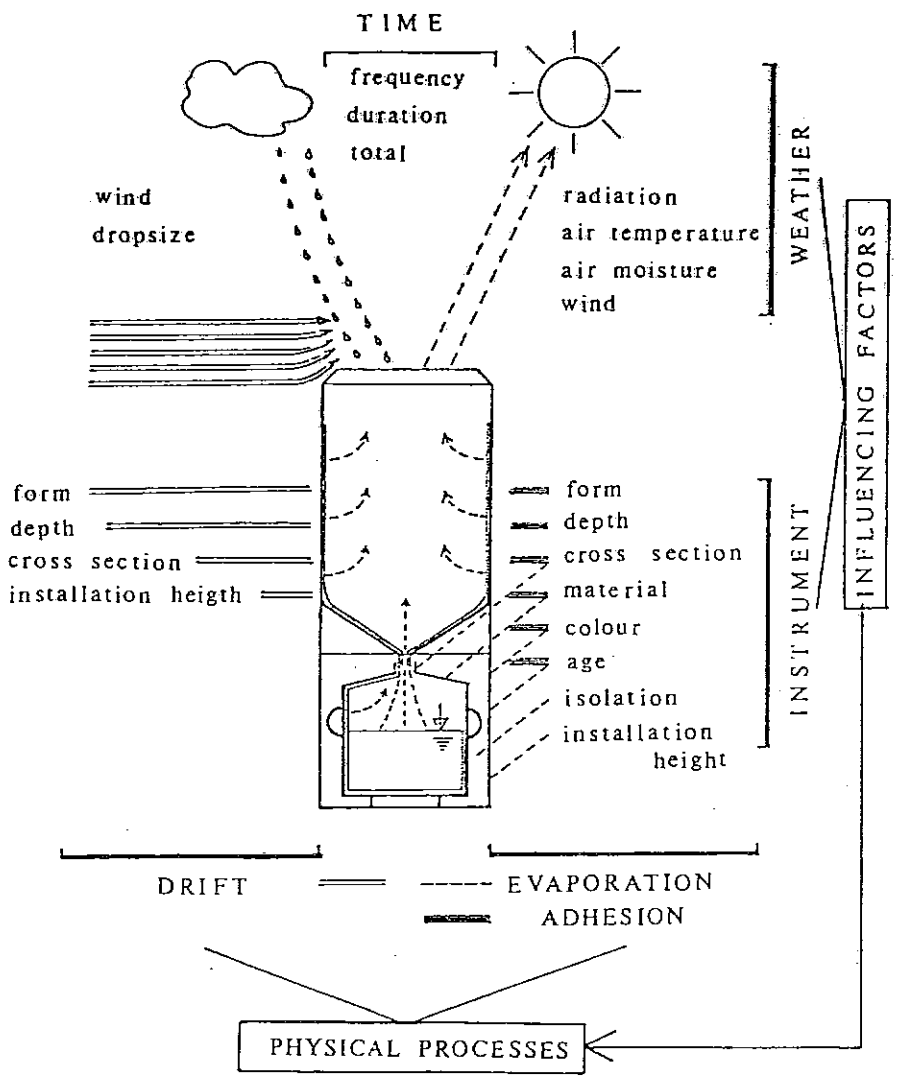

Fig. 4 : Schematic representation of relevant physical processes affecting the systematic error of precipitation measurement, according to Sevruk (1981). In the upper part are most important climatic variables, in the centre are instrumental variables and at the bottom are the physical processes, such as wind field deformation (drift), (left), evaporation and adhesion (right). Each process is represented by a special legend as follows: empty double solid line indicates wind field deformation, dashed line indicates evaporation and the filled double solid line indicates adhesion (wetting).

2.3.1 Wind-induced error

When considering the comparison of cross-sections of the two types of PG in Figure 1, of which one is a real PG of the Hellmann type in the shape of a cylinder and the other a hypothetical PG having the aerodynamically more suitable shape of a shallow plate, one can imagine that the body of a free-exposed, cylindrical PG systematically distorts the wind field, causing the wind speed to increase above the gauge orifice and forcing the development of eddies around and in the gauge. A simulated wind field above the orifice of the Swedish PG (with wind shield) is shown in Figure 5. As indicated in this figure the adverse wind action prevents the smaller liquid and solid precipitation particles from entering the gauge. Due to wind speed, which can be considerably greater than the falling velocity of particles particularly snow, these are carried to beyond the lee side of the gauge orifice.

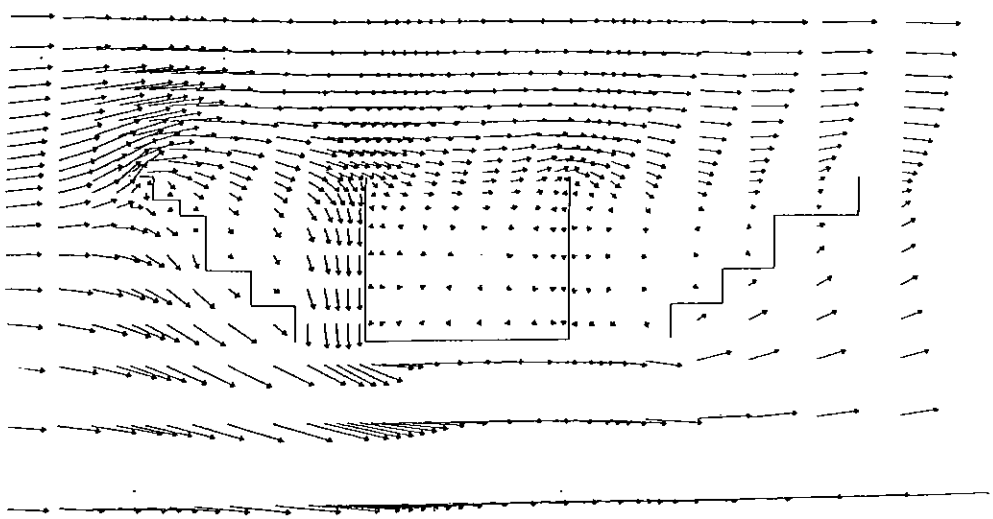

Fig. 5 : Simulated wind field above the orifice of the Swedish precipitation gauge (with wind shield), according to Carlsson and Svensson (1984). The arrows indicate both the direction of air flow and the relative wind speed (by the length of the arrow).

Thus, the amount of precipitation caught by an elevated gauge is generally smaller than the amount of incident precipitation, and the loss of measured precipitation increases as the proportion of small drops and light snow particles get larger and the wind speed increases. This helps to explain the two facts as observed in intercomparisons and as shown in Figure 3: Firstly, why already minor changes in the height of installation can cause a difference of up to 10% in the precipitation measurement data of two PGs even of the same type, and secondly, why these differences regularly show a seasonal pattern. Because wind speed quickly changes near the ground the PGs installed in the lower levels show greater precipitation values than those in higher levels. Moreover, the differences in mid-latitudes are generally small in the summer, because the summer precipitation contains mainly larger rain drops in contrast to the winter when a considerable part of precipitation contains small raindrops or snow. However, it is clear that despite all the possible shapes of gauges, different levels of installation and changes in the form of precipitation, the wind-induced differences of precipitation values are definitely small in well protected locations and large in exposed ones. Only a gauge with its orifice level with the ground will be free of wind-induced error.

2.3.1.1 Comparison of precipitation gauges in a wind tunnel

The physical reasons of the wind-induced error can be confirmed also by wind tunnel experiments. For instance, Figure 6 shows the maximum increase of wind speed above the orifices of seven types of PGs as measured in a wind tunnel windward and leeward of the gauge orifice and above the centre of the orifice area. The maximum wind speed

increment varies according to the type of PG between 30 and 50%. If a rank number were given to each gauge according to the size of the orifice rim, as shown in Figure 2: rank I for the largest rim of ASTA* gauge to rank VII for the smallest rim of Wild gauge, it is evident from the comparison of Figures 2 and 6 that the wind speed increment would decrease with decreasing size of orifice rim.

The greatest values of all seven investigated PGs, i.e. the upper curve in Figure 6, shows the Swiss heated tipping bucket PG, ASTA* with large orifice rim fitted with a bird protection ring. The smallest values, i.e. the curve in the bottom of the diagram, represent the old Finnish PG of the Wild type (without wind shield), which has the smallest orifice rim and the largest orifice area of 500 cm^2 of all the PGs investigated.

The practical consequences of wind tunnel experiments are demonstrated by the following example. The curves of wind speed increment for two PGs as extracted from Figure 6 are compared in Figure 7. The fact that the Mk2 gauge indicates smaller increment of wind speed than the Hellmann PG as shown in Figure 7 (black area) should be reflected in slightly greater precipitation values as measured by this gauge in the field. Reviewing the literature for field intercomparisons of both types of PGs, such evidence was actually found by Poncelet (1955), who presented 2-yr intercomparison data from Uccle in Belgium indicating an annual surplus of 5% for the Mk2 gauge. However, this gauge was elevated 0.3 m and the Hellmann gauge 1.0 m above ground. Considering this different level and the slightly greater wetting losses of the Hellmann PG which would mean 2 - 3 % less, the Mk2 gauge showed approx. between 2 and 3 % more annual precipitation than the Hellmann PG. Another comparison was carried out in Birmensdorf near Zurich in Switzerland over a total of 15 months, in the summer periods of 1979 - 1981. The Hellmann PG was elevated 2 m and the Mk2 gauge 0.3 m above ground. The intercomparison site was fairly well protected. The average wind speed at a level of 2 m during the precipitation periods was 1.4 m s^{-1}. Here, the Mk2 gauge showed on average 1 - 2% more summer precipitation than the Hellmann PG.

In addition, an intercomparison over a period of six years at Geneva Airport showed that the Swiss heated tipping bucket PG, ASTA* measured 14% less annual precipitation than the Hellmann PG. The former has the largest orifice rim of the seven investigated PGs and is fitted with the bird protection ring as seen in Figure 7, top right. This PG indicates the greatest increase of wind speed in Figure 6 and 7. Thus the field intercomparison results from Uccle, Birmensdorf and Geneva appear to confirm the wind tunnel data and finally, to explain experimentally the physical reasons for the phenomenon of wind-induced error of precipitation measurement.

A graphical representation of wind fields above the orifice of both PGs through isoplets of wind speed increment is shown in Figure 8. Yet the differences among the wind fields are less visible here than compared with the curves in Figures 6 and 7. This indicates that the maximum wind speed increment appears to be a better variable for studying differences between PGs than the isoplets of the wind speed increment in Figure 8. A further possibility are the wind profiles as directly measured in a wind tunnel. Such wind profiles for the Mk2 gauge and the above-mentioned Swiss tipping bucket PG are compared in Figure 9. Again, the differences between both PGs are more evident here than in Figure 8.

This indicates that the analysis of aerodynamical characteristics of PG should be based on the curves of the maximum increment of wind speed or wind profiles rather than on isoplets of wind speed increment alone. The analysis of intensity of turbulence as shown by the black area in Figure 9 presents a further possibility, but this subject is not very well known at the moment.

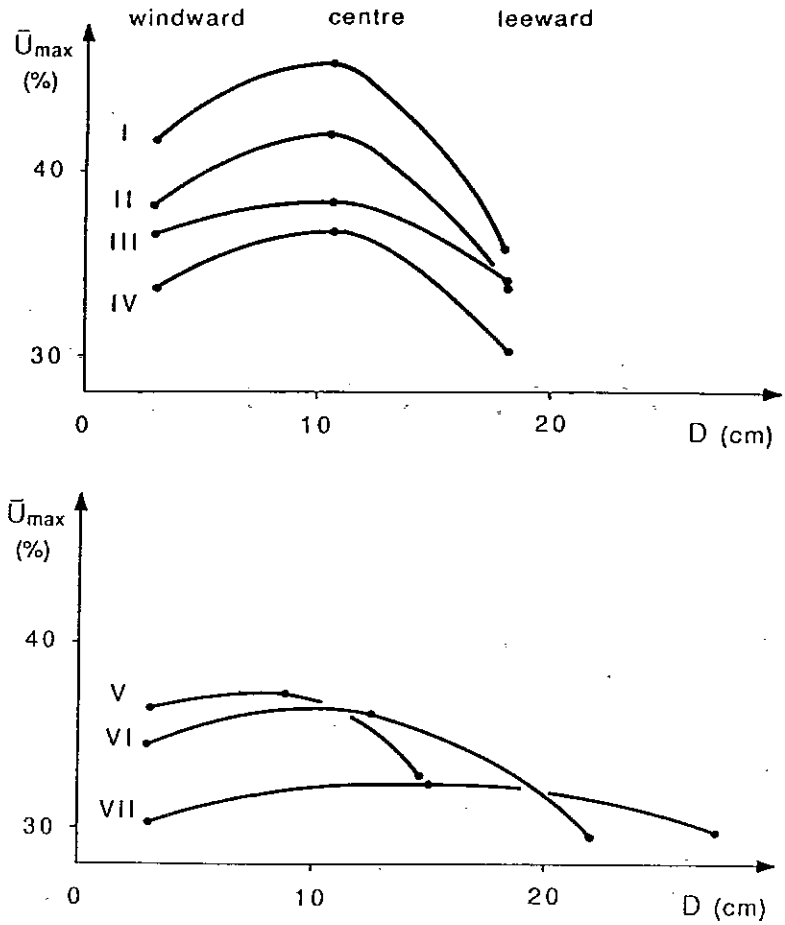

Fig. 6 : Average percentage increment of maximum wind speed U_{max} for windward, centre and leeward profiles. Top; four precipitation gauges with the same orifice area of 200 cm^2. Below: three precipitation gauges with different orifice areas from 127 to 500 cm^2. Roman numerals indicate the rank according to the size of the gauge orifice rim (see Fig. 2) and D is distance.

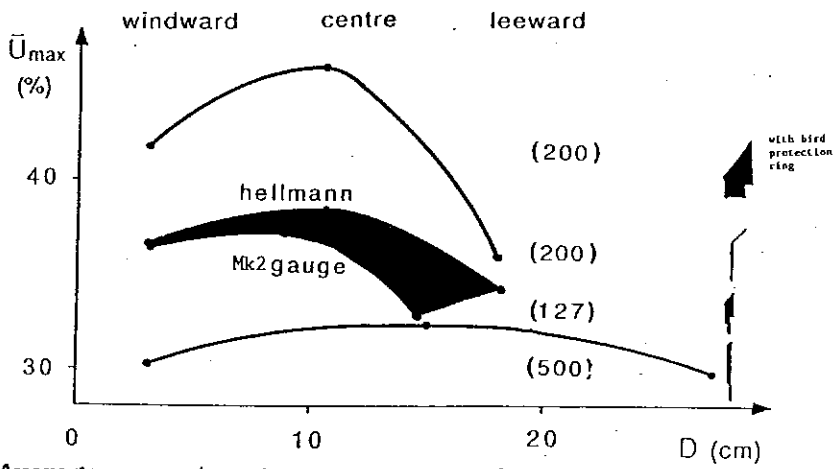

Fig. 7 : Average percentage increment of maximum wind speed U_{max} for windward, centre and leeward of the gauge orifice as measured in a wind tunnel. Adapted from Sevruk at al. (1989). Black area indicates the values between the Hellmann gauge (top) and the Mk2 gauge (bottom). The curve above the Hellmann gauge curve and below the Mk2 gauge curve shows the total range of U_{max} for seven types of gauges. On the right in brackets is the orifice area in cm^2, and on the far right is the cross-section of orifice rim. D is distance in cm.

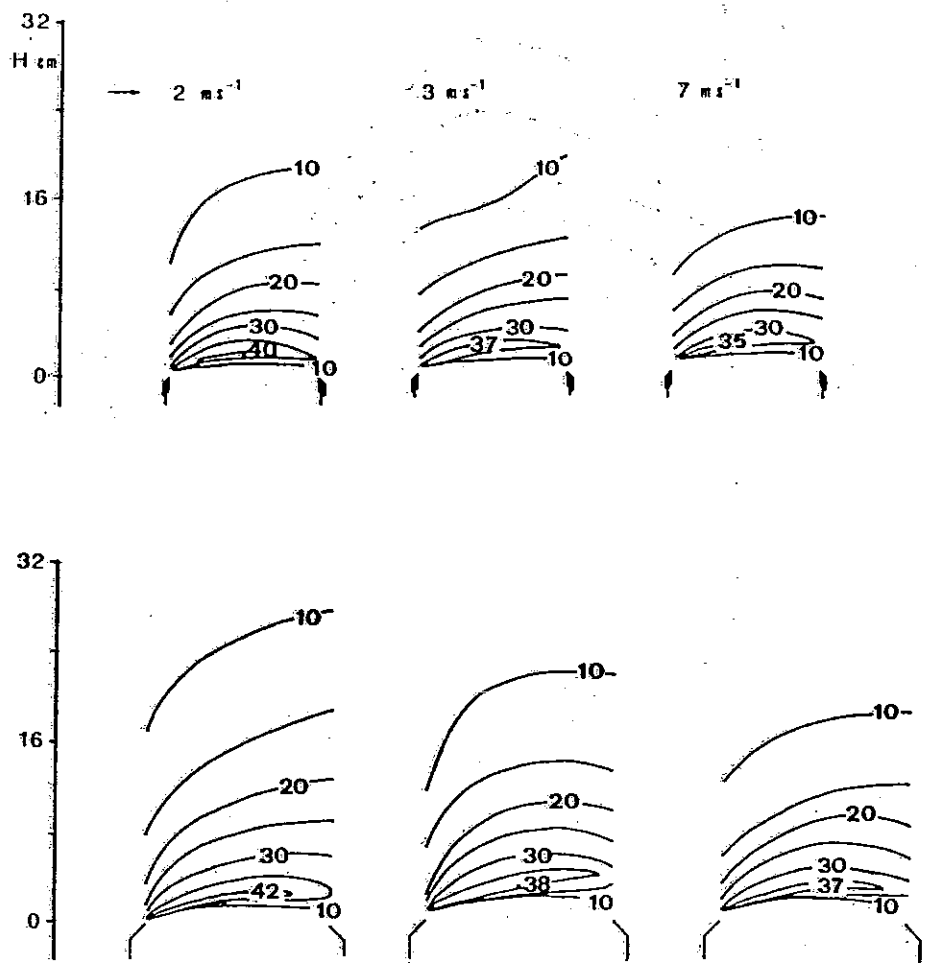

Fig. 8 : Wind fields above the orifice of the Mk2 gauge (top) and the Hellmann gauge (bottom) for three tunnel air speeds of 2, 3 and 7 m s^{-1} (from left). The numbers indicate the percentage increment of wind speed (isoplets) with the maximum measured value, immediately above the gauge orifice and H is the height above the gauge orifice.

The methods of wind tunnel tests on which the above mentioned results are based have been described by Sevruk et al (1989). Wind profiles above the orifices of PG were measured using a carefully calibrated, hot wire anemometer. The profile measurements have been made in vertical intervals of less than 0.01 m and the total profile height was equal to the height of the gauge. The profiles were situated windward and leeward of the gauge orifice, always inside of the orifice rim and above the centre of the orifice area, all in the plane parallel to the direction of wind. The wind speeds applied were 2, 3 and 7 m s^{-1}.

2.3.2 Wetting loss

The wetting loss is large for PGs having a small orifice area and a deeper collector and vice versa, and is also dependent on the material of the gauge. The ratio of the area of inner walls and the orifice area provide an index of the magnitude of wetting loss. The dependency of wetting losses from such a ratio is demonstrated in Figure 10. Roughly one half of standard PGs have ratios between 2 and 4 but the range of ratio is from 1 to 9 as shown in Figure 11. Most gauges are made from galvanized iron sheet and copper but aluminium, brass and plastic are also in use. This, of course, affects the results of intercomparison measurements, while polished metals have considerably smaller

wetting losses than galvanized ones. Thus the difference due to wetting loss of different types of gauges can amount to up to 0.2 mm per rainfall, as shown in Figure 10. The wetting loss for PGs having a separate container increases due to the water resting in the container after emptying. Such an increase, however, is generally smaller than 0.1 mm.

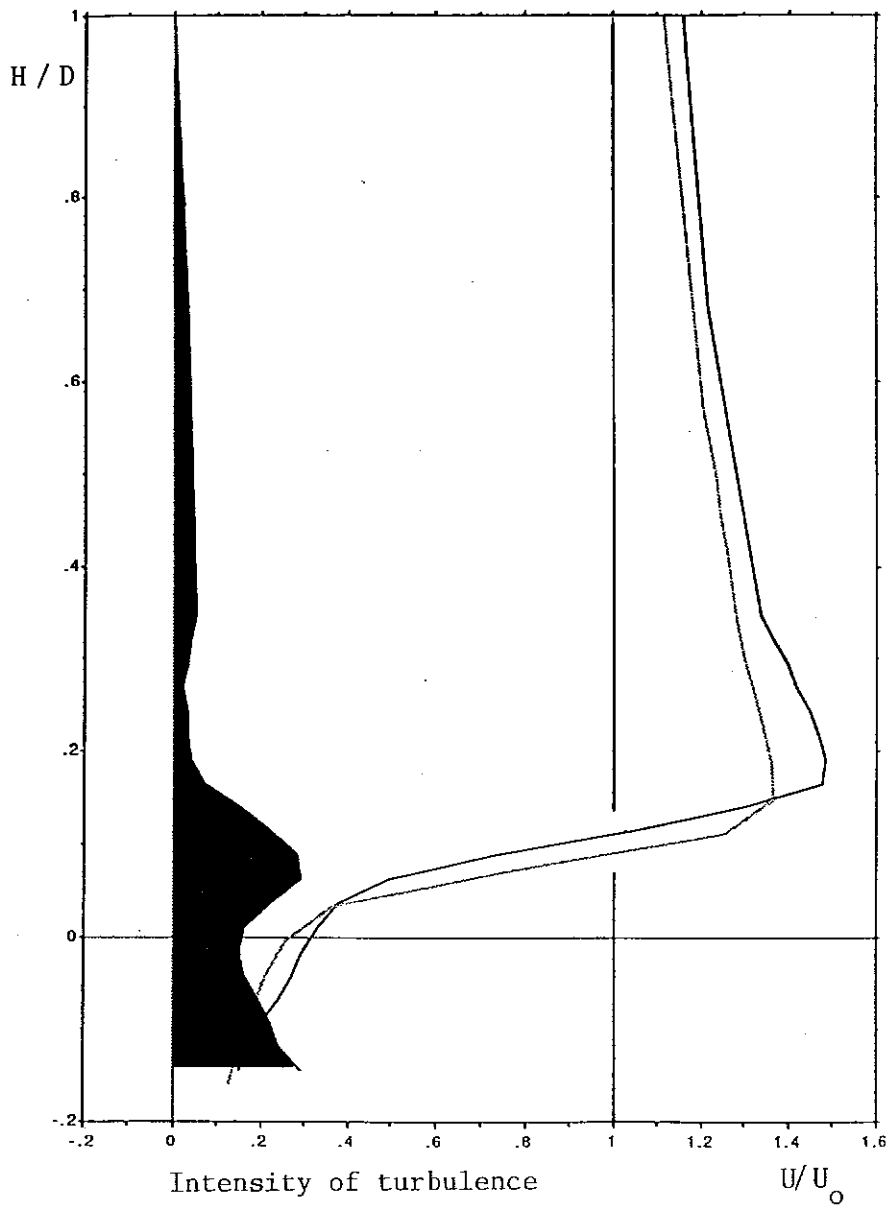

Fig. 9 : Comparison of wind profiles above the centre of the ASTA* gauge (solid line) and the Mk2 gauge (dashed line). D is diameter of the orifice, H is the height above the gauge orifice, U_0 is the tunnel wind speed and U is wind speed above the gauge orifice. Black area indicates turbulence intensity according to Sevruk et al. (1990).

2.3.3 Evaporation

The evaporation is generally small for the gauges with a protected container such as the Hellmann and Snowdon ones, but it can be 3-4 times larger for types of PGs having a removable funnel, such as the Tretyakov, Swedish and Chinese models, particularly during the wintertime, when the funnel is taken out of the gauge and the accumulated water in the container is exposed to sunshine and wind. The compact gauges with a fixed container such as Nipher PG, Dutch PG and Finnish Wild PG always have the smallest evaporation losses because of restricted ventilation. Most types of PGs show

evaporation losses similar to that of the Hellmann PG (curve 2 in Fig. 12). Apart from the type of PG the evaporation loss depends on the saturation deficit and wind speed as shown in Figure 12. However, the type of PG seems to play the most important role. Differences between evaporation losses of various types of PG under the same climatic conditions could be up to 5 orders of magnitude, as shown in Figure 12.

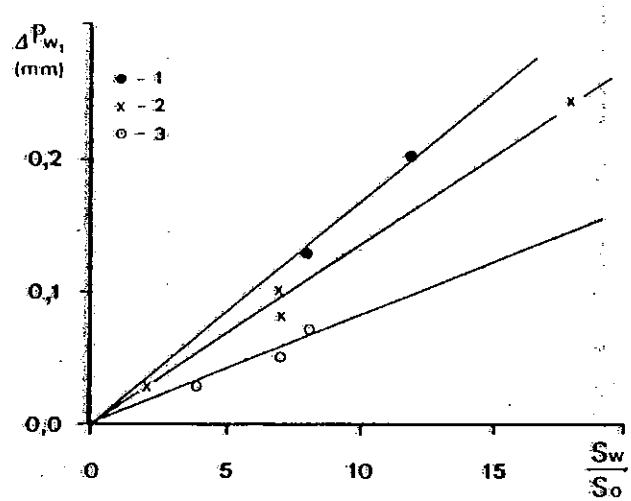

Fig. 10 : Wetting loss ΔP_{W1} as a function of the ratio of the total area of inner walls, S_W, of precipitation gauge collector and the orifice area, S_O for various materials, according to Golubev (1986). 1 galvanized steel sheet, 2 lacquered steel sheet, 3 polished metal or glass.

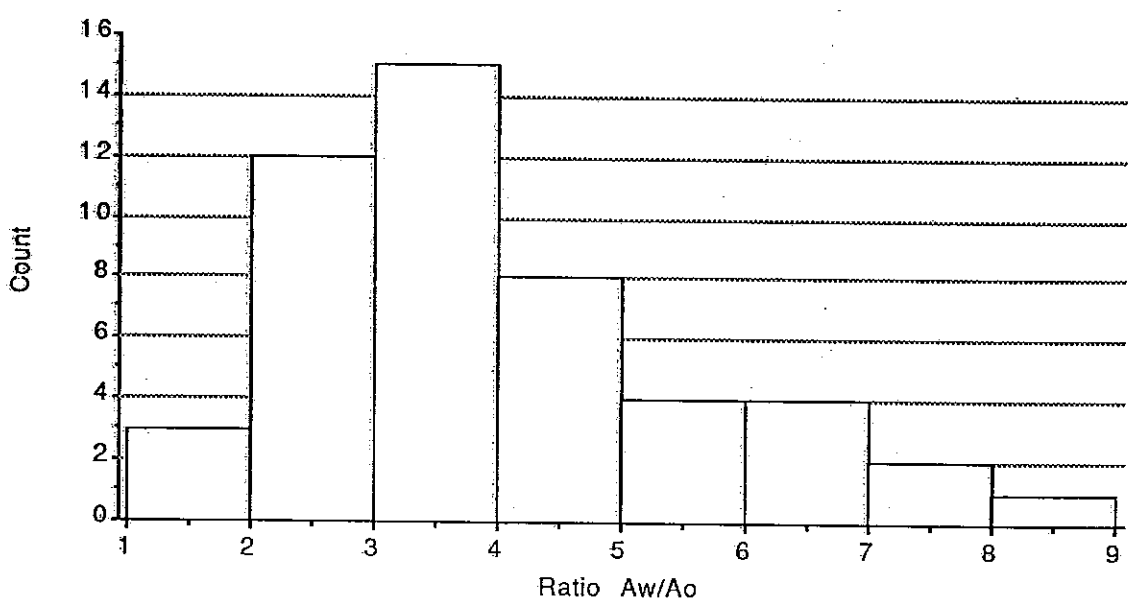

Fig. 11: Frequency diagram of the ratio of the total area of inner walls and the orifice area, S_W/S_O, for 54 types of national standard precipitation gauges. This diagram is based on data in Appendix II.

2.4 Corrections

It is not well known to many users of precipitation data that such data as published in the year-books of national Meteorological Services still represent only the non-corrected, measured values of precipitation and are thus lower than the incident precipitation. Therefore, in order to know the amount of "true precipitation", corrections of measured precipitation values for SEP are necessary. They generally amount to 3-15% of measured precipitation for rain and over 20-100% for snow.

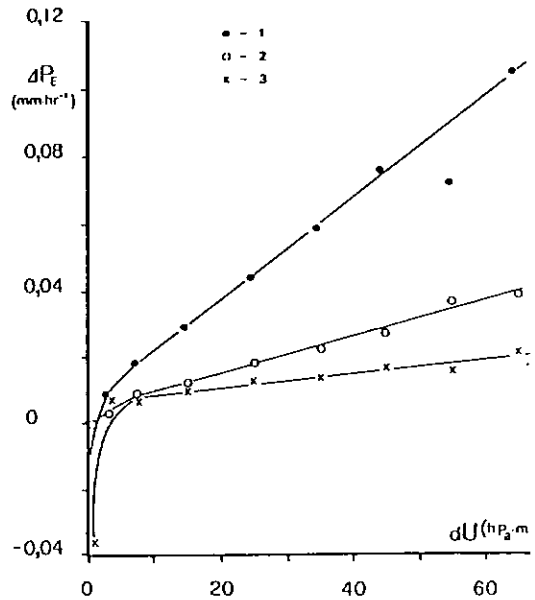

Fig. 12: Intensity of evaporation, ΔP_E, from the precipitation gauge container as a function of the product of the saturation deficit and wind speed, dU, for various gauges, according to Golubev (1986). 1 Tretyakov gauge with removable tunnel, 2 Hellmann gauge with fixed funnel and removable container, 3 Nipher compact gauge with fixed funnel and container.

The literature on correction of SEP has been reviewed by Sevruk (1981, 1982). The recent developments can be found in the publication entitled "Correction of Precipitation Measurement" (Sevruk 1986). The problems of the correction of global precipitation were dealt with in a report by UNESCO (1979) and quite recently by Legates and Willmott (1989).

The correction procedures are mainly based on results of field intercomparisons, which have empirical character and are costly (Sevruk, 1982). In the case of wind-induced error the ground level PG is used as a reference for rain measurement and the double fence for snow (Goodison et al. 1989). The difference in precipitation values between an elevated and ground level PG of the same type is related to the wind speed during precipitation and to a parameter of precipitation structure N (Sevruk, 1989) as shown in Figure 13. On the basis of these known variables, the correction for a specific type of PG can be estimated.

Considering the nature of the wind-induced loss from a point of view of fluid dynamics, it is clear that field intercomparison measurements are strictly valid only for a particular PG type, defined by relevant parameters. All in all, there are at present more than 100 PG types used worldwide, having very different parameters such as the orifice area, size and shape of orifice rim, depth of collector, shape of body, etc. Appendix II contains 54 types of national standard PGs but there are a many of other types of gauges. Moreover, wind protection shields of various design and bird protection rings are used on some PG types, in a regular or irregular manner. This is why the intercomparison measurements of PGs evidence a wide range of magnitude of losses depending on the PG type used, wind speed and the intensity and the form of precipitation, etc. As Figure 13 shows, a Tretyakov PG with a wind shield catches at least twice the volume of snow as compared to the unshielded Hellmann PG. The difference increases quadratically with increasing wind speed and decreasing air temperature steering the snow structure. Consequently, PG field intercomparisons aiming to develop correction procedures for wind-induced error have to be repeated for

each different PG type. Unfortunately, there are only a few types of PG for which similar relationships as that in Figure 13 have been developed and it is designed to fill that gap with the aid of the current WMO International Solid Precipitation Measurements Intercomparison, ISPMI, in which 15 countries participate.

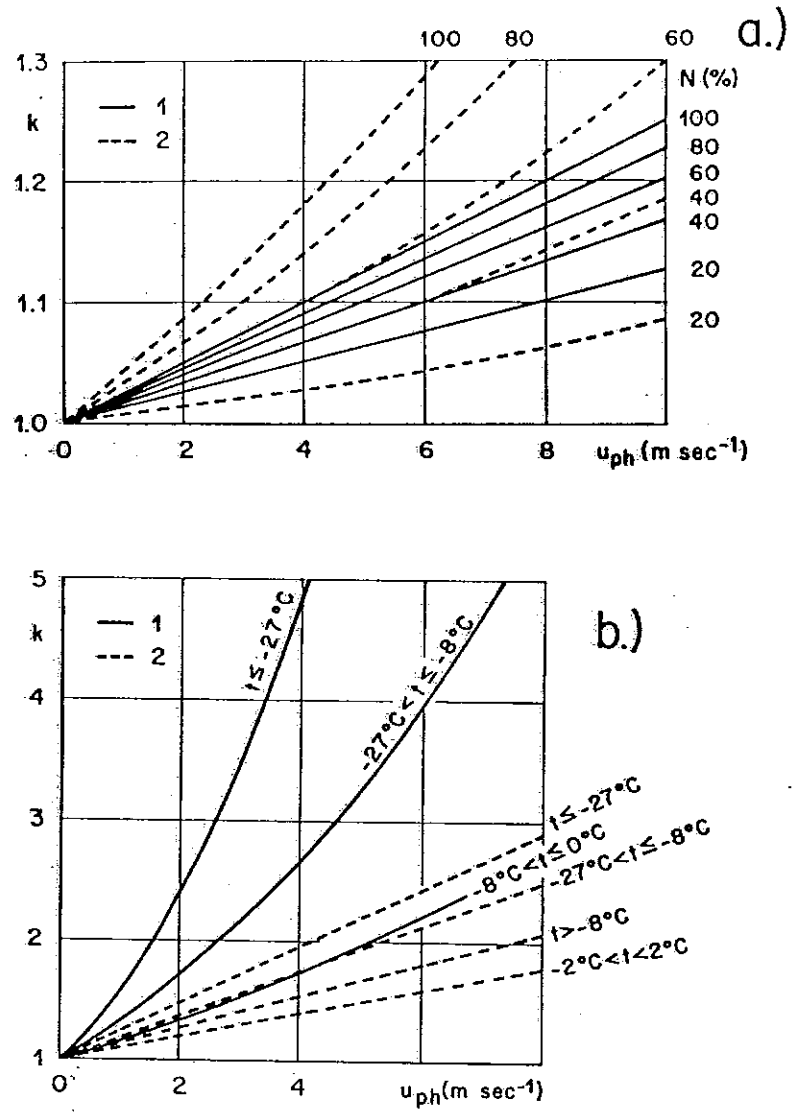

Fig. 13 : Conversion factor, k, of measured precipitation values as a function of the wind velocity, u_{ph}, during precipitation periods at the installation height of precipitation gauge and the structure parameter, N, for rain (a) and air temperature t for snow (b). Adapted by Sevruk (1982) from UNESCO (1978). 1 Hellmann precipitation gauge, 2 Tretyakov precipitation gauge.

Yet, the wind tunnel tests make it possible to study the effects of a particular PG parameter separately from the other ones, and to manipulate variables such as wind speed and the size of particles in a very convenient manner and under controlled laboratory conditions, which is hardly possible to maintain in the field.

Correction models as based on the physics of phenomenon are needed. Although a few combined correction models exist to be used for some selected special situations, only Folland (1988) developed a correction model for practical use which fully includes the results of wind tunnel measurements in its structure. The ultimate purpose is to develop a universal model, allowing the corrections to be applied to each PG type without any additional field intercomparisons, if the relevant PG parameters are known. The methodology of such a procedure can be based on the results of wind

tunnel experiments as indicated in subsection 2.3.1.1 or as suggested by Folland (1988). For instance, the maximum wind increment curves as presented in Figures 6 and 7 have to be known for each type of PG and various wind speeds. From the comparison of such curves with the results of field intercomparison measurements, conclusions can be drawn for a particular type of PG as to the possible magnitude of wind-induced error. Groups of PGs having approximately the same magnitude of error could finally be delineated and diagrams for estimation of conversion factors, similar to that in Figure 13, designed. This would help to standardize the correction procedures among WMO Members.

This indicates that the development of a universal correction model based on wind tunnel tests would be of considerable benefit for national Meteorological and Hydrological Services.

Figures 10 and 12 present a good basis for the correction of wetting and evaporation losses, yet additional data could be included for different types of PGs and different materials as well.

2.5 Inhomogeneities and compatibility of precipitation data

Due to frequent changes in this century of gauge sites, measurement technique standards and observers, the various precipitation time series show multiple inhomogeneities and consequently, they are hardly suitable to be used to compute the "climatic norms" and to study precipitation trends or make conclusions concerning global precipitation. Since through the empirical adjustment factors the homogeneity relative to the adjacent gauge sites can be restored, the wind-induced error of precipitation measurement, which is the real culprit of inhomogeneities, cannot be eliminated unless the specific correction procedures are applied to precipitation time series from different types of PGs. Moreover, the correction of this error helps to reduce the effects of notoriously different exposure of gauge sites in a particular national network.

As precipitation values are influenced by a number of variables, the measured values in the valley and mountain stations and at various altitudes and landscape zones etc., cannot be compared with one another even if they originate from a unit national network. The SEP magnitude can vary considerably because, for instance, the gauge sites in forest areas usually are better protected against wind than those in open areas, which means that SEP values are smaller. Differences in SEP also result from the fact that at low altitudes snowfall occurs less often than at higher ones.

The situation is getting noticeably worse if measured precipitation values are to be considered on a global basis. In this case, not only the types of PG often differ from country to country but the degree of latitude, too, appears as an important source of errors. With increasing geographical latitude the snow percentage increases and the SEP for snow is considerably higher than for rain because the sensitivity to wind of snow measurements is considerably higher.

Taking all this into consideration the corrections of SEP are helpful for eliminating the effect of different precipitation measurement standards as used in different countries. Thanks to this, the leaps of isohyets at the borders of countries disappear and the global compatibility of precipitation time series could be established. Thus the application of corrections opens new ways for dealing with the spatial and temporal inhomogeneities of precipitation data. It makes the studies of global precipitation all the more conclusive. In addition, the corrections are also necessary for hydrological computations such as the global hydrological cycle, the world water balance, local and regional water balances, precipitation-runoff modelling and a lot of other environmental tasks.

3. CHARACTERISTICS OF NATIONAL STANDARD PRECIPITATION GAUGES

The national standard PGs as used at present by national Meteorological Services of 136 countries are described in Appendix II. They are listed in order of the magnitude of orifice area. Each type of PG has two numbers: the first one is the usual order number and the second one is the code number, describing the gauge type more comprehensively in terms of the magnitude of orifice area, total depth of the gauge collector and material. By referring to these two numbers, the cross-sections of all PGs are contained in the annexed figures in Appendix II.

Apart from the automatic PGs of the tipping-bucket type which are used as standard gauges only in Japan and partly in Switzerland at present, three groups of manual, standard PGs can be distinguished with respect to the construction of the body and the magnitude of evaporation losses.

There are most numerous groups of gauges having a removable collector with a fixed funnel and protected, removable container. Generally such gauges evidence small evaporation losses if the collector fits snugly into the lower part of the gauge (i.e. the protecting can) and consequently, ventilation in the gauge is not extensive. Examples are the Hellmann PG in Figure 1 and the Mk2 Snowdon PG. Further gauges are: Nos. 3-17, 20, 22-25, 27, 29, 35-42, 45, 48-51, 53 in Appendix II. The evaporation losses for these PGs can be assessed from the curve 2 in Figure 12.

The gauges of the second group consist of a compact body, thus joining the collector and container via the fixed funnel. The water is poured out through a tap. The evaporation losses are generally small and can be assessed according to the curve 3 in Figure 12. Such gauges are represented by the following numbers : 19, 21, 31, 46 and 52.

The smallest group including only three types of PGs, such as the Swedish gauge, the Tretyakov gauge and the Chinese gauge (Nos; 18, 26 and 35) evidence large evaporation errors (curve 1 in Figure 12). The gauge consists of a single body having a removable funnel. In the wintertime the funnel is removed to enlarge the volume of the collector. Thus the accumulated water is exposed to sunshine and wind. In the summertime the funnel should protect the gauge against the evaporation, but it seldom fits perfectly so that ventilation is large and consequently the evaporation losses as well.

The ratio of the total area of inner walls and the orifice area is important with reference to wetting losses. It varies considerably between 1 and 9 but lies between 2 and 5 for almost 70% of all types of PGs, as shown in Figure 11. The material also has to be accounted for.

The smallest PG, made of hardened PVC, in Israel has an orifice area of only 7 cm^2. It is 12 cm high. The largest PG has an orifice area of 1000 cm^2 and is 44 cm high. It is made of lacquered iron sheet by Siap in Italy. There are 5 types of PGs having an orifice area of 100 cm^2 and 500 cm^2 respectively. Most types of PGs have an orifice area of 200 cm^2 followed by 314-324 cm^2, 127 cm^2 and 400 cm^2. Already 9 types of PGs are made from plastic and 3 from aluminium, but the most popular material seems to be galvanized iron sheet (21 PGs) and copper (11 PGs). Yet brass, bronze and steel are also in use. Most gauges are 0.4 - 0.6 m in height, but as many as 10 PGs are higher than 0.6 up to 0.9 m.

The depth of collector varies between 5 and 50 cm, most gauges being approximately 20 cm deep.

PGs come in a wide variety of shapes. From the point of view of the wind-induced error, however, the critical factor is wind shield use. The gauges fitted with a wind shield have smaller wind-induced error, particularly in the winter during snowfall. Unfortunately, there are many types of wind shields, and only a few types of gauges use them permanently. The solid Nipher type wind shield is preferred in Belgium, Canada, Norway and Sweden (Nos; 6, 15, 18, 29, 31, 34 and 52). In Finland and the USSR the Tretyakov semi-solid wind shield is used (No 26). More information is given in Table 3

in Appendix III, where the countries are grouped according to the type of wind shield used.

In Table 1 in Appendix III the number and type of PGs in each country as well as the elevation height are summarized. The elevation height varies between 0.2 and 2 m above ground. As seen from Table 4 (Appendix IV), the same type of gauge can be situated at different heights, according to the country. The gauges are affixed in very different ways, sometimes on a wooden or a metal pole and sometimes they are placed directly on the ground or in a special structure.

All in all there are approximately 150,000 PGs unevenly distributed over the globe. The most widely used type of PG is the German Hellmann gauge (approx. 30,000) followed by Chinese PG (20,000) and the English Mk2 Snowdon PG (18,000). Together these gauges account for 50% of all PGs yet they are distributed over an area of only 31 x 10^6 km^2, thus demonstrating a very uneven density of networks of PGs.

4. CONCLUSIONS AND RECOMMENDATIONS

The accurate precipitation data and homogeneous precipitation time series represent one of the basic pillars of hydrological and climatological modelling. Because there are systematic errors involved in precipitation measurement and these errors depend considerably on the construction characteristics of precipitation gauges and elevation of gauge orifice above ground as well as on the degree of exposure of a gauge site, the knowledge of the above mentioned variables is of essential importance to assess the measurement error and to standardize correction procedures.

An analysis of replies to the questionnaire from 136 members, covering more than 90% of the global land area on six continents and various islands showed that there are approx. 50 different types of national standard precipitation gauges commonly used worldwide at present to provide precipitation data and that these gauges are installed at various heights above ground varying from 0.2 to 2 m. Due to frequent changes in gauge sites, measurements techniques standards and observers in this century, the precipitation time series show multiple temporal and spatial inhomogeneities.

Consequently, the precipitation data are hardly suitable to be used to compute the "climatic norms" and to study precipitation trends or make conclusions concerning global precipitation unless the specific correction procedures are applied to precipitation time series from different types of precipitation gauges. In addition the corrections are also necessary for hydrological computations such as the global hydrological cycle, the world water balance, precipitation-runoff modelling and a solution of many other environmental tasks.

The corrections of systematic measurement error help not only to reduce the effects of different exposure of gauge sites in a particular unit national network but also to eliminate the effect of different precipitation measurement standards as used in different countries. Thanks to these corrections, the leaps of isohyets at the borders of countries disappear and the global compatibility of precipitation time series could be established.

The solution of these problems requires international co-operation. One possibility for achieving this is presented by the WMO International Solid Precipitation Measurement Intercomparison. Furthermore World Centers of Precipitation Measurement should be established by the WMO, and the national Meteorological Services should be urged

> to check all precipitation time series, PTS, for inhomogeneities and to eliminate them or at least to make a comment in the year-books on the quality of a particular PTS

to introduce in the year-books at least four quality degrees of PTS as follows:

I protected homogeneous PTS
II homogeneous PTS
III non-homogeneous PTS
IV exposed non-homogeneous PTS

to introduce corrections in the current precipitation measurements and to publish both corrected as well as measured values of precipitation

to start to correct for systematic error the historical PTS .

However, further studies into the physics of precipitation gauges at a national level using wind tunnel experiments, for example, have to be undertaken to enable development of combined numerical correction models for each type of precipitation gauge based on its relevant construction parameters.

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APPENDIX I

WORLD METEOROLOGICAL ORGANIZATION

QUESTIONNAIRE ON PRECIPITATION GAUGES

Member: .....

Type of standard precipitation gauge: .....

Material of gauge: .....

Area of orifice: .....

Height of the gauge orifice above the ground: .....

Type of gauge shield (if used): .....

Number of precipitation measurement per day and station: .....

Number of gauge sites in the country: .....

Changes in the measurement technique in the last 30 years (height of gauge and/or type of gauge etc.): .....

.....

Simple drawing or a picture of the gauge should be enclosed to this questionnaire

---

This questionnaire has been completed by:

Name: .....

Date: .....

Signature: .....

Institution address: .....

.....

The completed questionnaire should be sent by 15. Sept. 1987 to:

The Scretary-General
World Meteorological Organization
Case postale 5
CH-1211 Geneva 20
Switzerland

APPENDIX II

Types and parameters of manual standard precipitation gauges ordered according to the magnitude of the area of the gauge orifice

Legend

+ wind shield permanent (+) wind shield sporadic * no pictures available s snow gauge
A_W = total area of the inner walls of the gauge collector, in [cm^2]

NOTE: Code consists of two numbers and one letter.

The first number indicates the gauge orifice area, in [10 cm^2].

The second number indicates the total depth of the gauge collector from the top of gauge rim to the lowest point of the funnel (outflow), in [cm].

The last letter indicates the material of gauge as follows:

A	aluminium	L	lacquered iron sheet
B	brass	P	plastic
C	copper	S	steel
G	galvanized iron sheet		

Empty space in the code indicates missing information (not available).

No	Code	Area of orifice A_O [cm^2]	Name	Country of origin	Material	Depth of collector [cm]	Height of gauge [cm]	$\frac{A_W}{A_O}$
1	1-04-P	7	Small	Israel	hardened P.V.C	4.5	12	5.0
2	4-18-P	36	Tru-chek	Oman	plastic	18	18	9.0
3	8-10-P	81	Nylex 1000	New Zealand	plastic	10	35	3.1
4	10-08-P	100	Amir	Israel	hardened P.V.C	8	50	2.1
5	10-10-P(+)	100	AES Type B	Canada	plastic	10	38	2.7
6	10-11-S +	100	IRM P50	Belgium	stainless steel	11	35	2.9
7	10-16-G	100	MP 100	Mauritius	galv. iron	16	66	5.0
8 *	10- -G	100	Indonesian	Indonesia	galv. iron	--	--	--
9	13-15-C	127	Mk 2	U.K.	copper	15	46	4.2
10 *	13-15-S	127	Mk 2	New Zealand	steel	15	46	4.2
11 *	13-15-P	127	Mk 3	U.K.	fibreglass	15	46	4.2
12	13-16-G	127	Burma	Burma	galv. iron	16	36	1.4
13	13-20-C	127	Snowdon	U.K.	copper	20	46	5.8

cont. next page

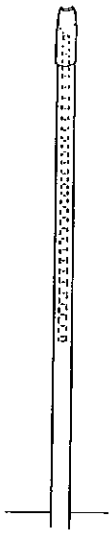
App. II cont.

14	13-20-C`	127	Octapent	U.K.	copper	20	69	5.7
15 s	13-50-C+	127	Nipher	Canada	copper	50	52	s
16	13-27-C	127	5``		copper	27	76	8.0
17	20-14-G	200	Portuguese	Portugal	galv. iron	14	43	4.0
18	20-15-A+	200	SMHI	Sweden	aluminium	15	35	3.9
19	20-16-G	200	Indonesian	Indonesia	galv. iron	16	90	2.8
20	20-16-C	200	Cyprus	Cyprus	copper	16	49	3.4
21	20-19-B	200	SPGN	Netherlands	brass	19	29	4.3
22	20-20-G	200	Typo B	Paraguay	galv. iron	20	46	4.6
23	20-22-G	200	Standard	Israel	galv. iron	22	50	4.6
24	20-22-P	200	Indian	India	fibre glass	22	50	4.9
25	20-24-G	200	IMC	Romanie	galv. iron	24	45	6.0
26	20-24-G+	200	Tretjakov	U.S.S.R.	galv. iron	24	40	6.0
27	20-27-G	200	Hellmann	FRG and GDR	galv. iron	27	43	7.1
28	20-27-A	200	Tognini	Switzerland	aluminium	27	50	6.0
29	20-30-G	200	Icelandic	Iceland	galv. iron	30	56	7.7
30 *	20- -A	200	200-100	Colombia	aluminium	--	--	--
31	22-25-C +	225	Norwegian	Norway	copper	25	25	3.1
32 *	31- -G	314	Anagnostou	Greece	galv. iron	--	--	--
33	31-20-B	314	RT-1	Japan	brass	20	40	3.6
34	31-20-B+	314	RT-4	Japan	brass	20	45	3.7
35	31-22-G	314	China	China	galv. iron	22	59	3.5
36	32-07-G	324	Manual 1508	Australia	galv. iron	7	30	1.2
37	32-14-C	324	S 203 DRG	Malaysia	brass	14	38	2.4
38 *	32-16-C	324	ML 17	Iran	copper	16	36	2.9
39 *	32-19-S	324	Nepal 203	Nepal	steel	19	59	3.5
40	32-19-C	324	Casella	U. K.	copper	19	56	3.5
41	32-20-C(+)	324	USWB 8"	U.S.A	copper/steel	20	68	3.2
42	38-36-G	380	Typo A	Bolivia	galv. iron	36	88	3.4
43	40-13-S	400	Ville Paris	Brasil	stainless steel	13	63	2.5
44	40-14-P	400	SPIEA MN	France	fibre-glass	14	44	2.0
45	40-15-G	401	Mexican	Mexico	galv. iron	15	36	1.7
46	40-17-C	400	Van Dorn	Netherlands	copper	17	40	3.0
47	40-23-G	400	Association	France	galv. iron	23	30/38	2.3
48	40-45-P	400	C Type NM	France	fibre-glass	45	80	6.8

cont. next page

App. II cont.

49	50-15-G	500	Mountain	Austria	galv. iron	15	56	2.4
50	50-24-G	500	Kostlivi	Austria	galv. iron	24	77	3.4
51	50-25-G	500	Wild	Bulgaria	galv. iron	25	44	3.3
52	50-30-B+	500	Wild	Finland	bronze	30	36	2.6
53	50-33-G	500	Metra 886	CSSR	galv. iron	33	66	3.9
54	100-10-L	1000	SIAP UM8300	Italy	lacquered iron	10	44	2.3



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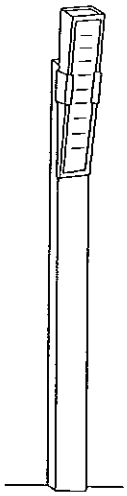

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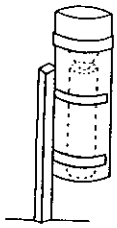

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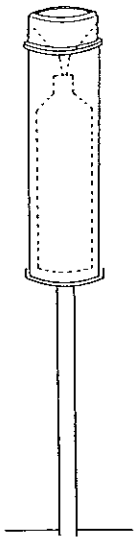

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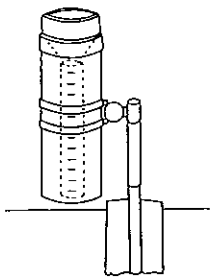

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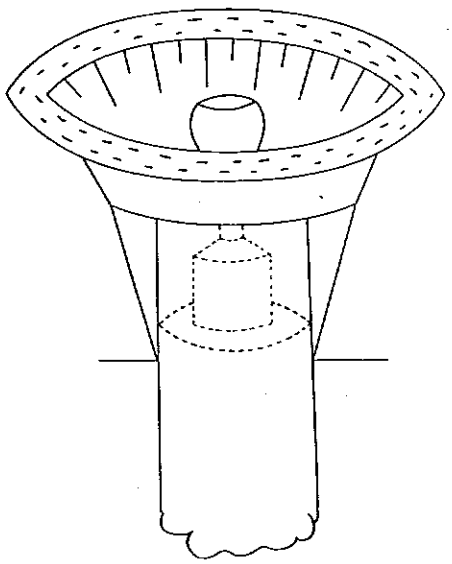
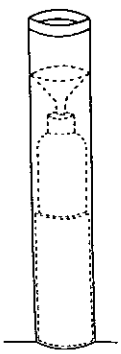
10-10-P(+)



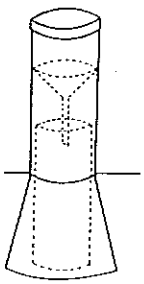
6

10-11-S +



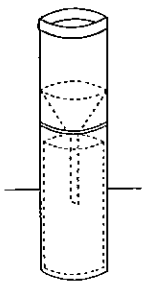
7

10-16-G



9

13-15-C



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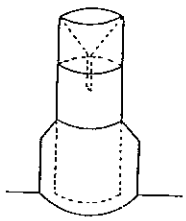
13-16-G



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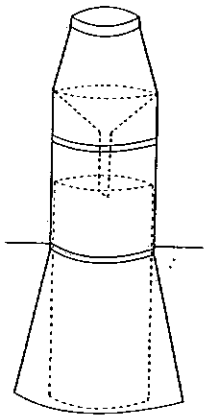
13-20-C



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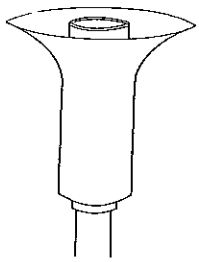
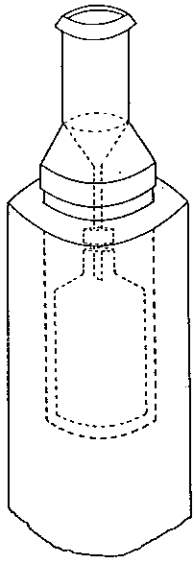
13-20-C`



15 s

13-50-C+



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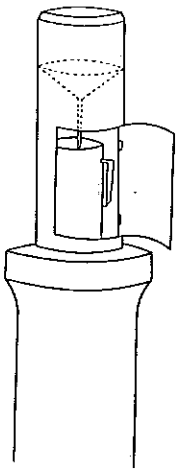
13-27-C



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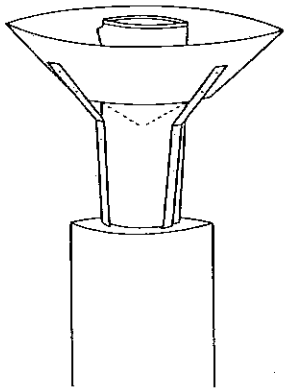
20-14-G



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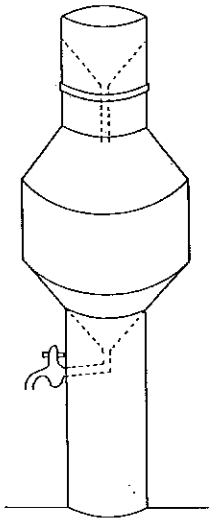
20-15-A+



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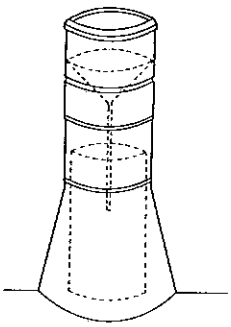
20-16-G



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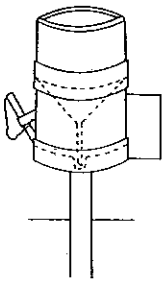
20-16-C



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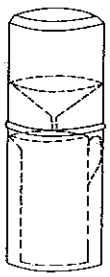
20-19-B



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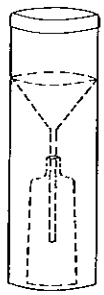
20-20-G



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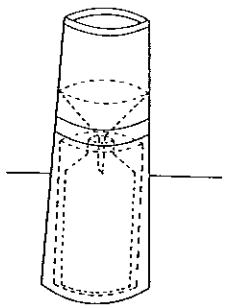
20-22-G



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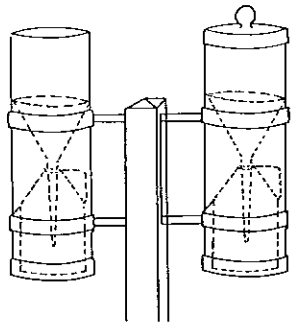
20-22-P



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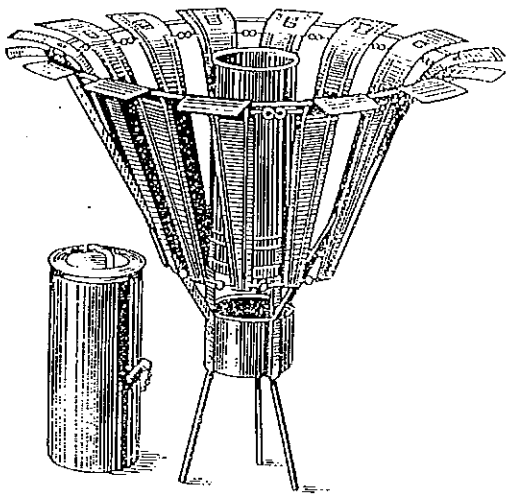
20-24-G



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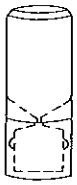
20-24-G+



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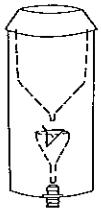
20-27-G



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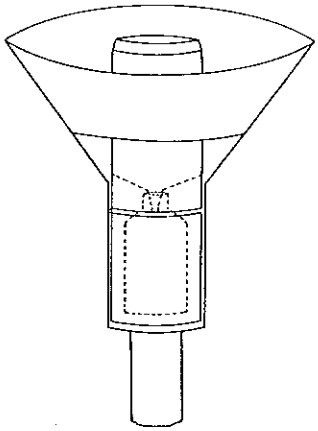
20-27-A



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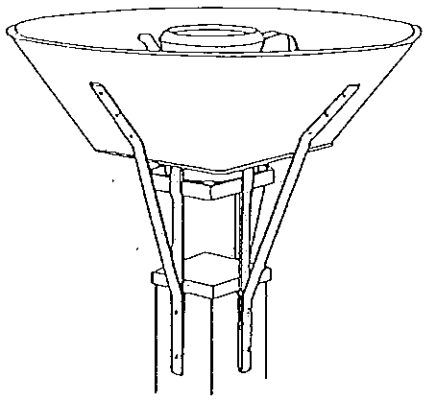
20-30-G



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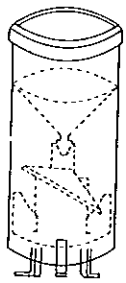
22-25-C



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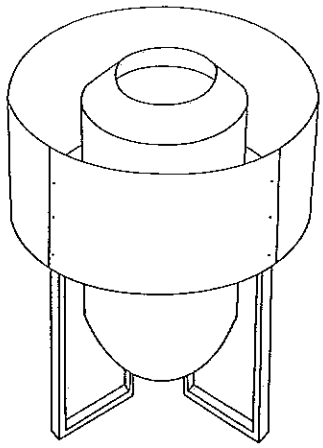
31-20-B



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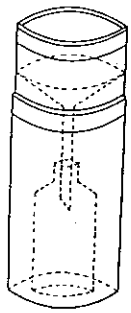
31-20-B+



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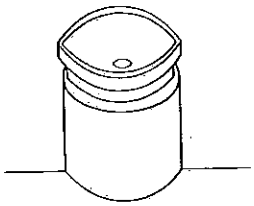
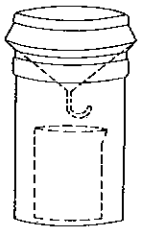
31-22-G



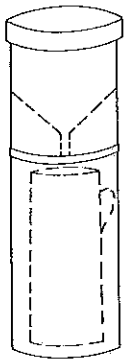
36

32-07-G



37

32-14-C



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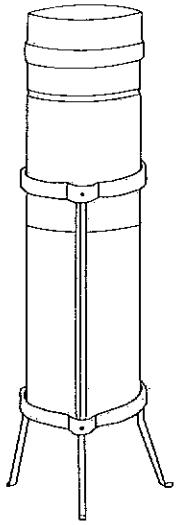
32-19-C



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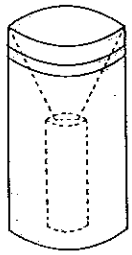
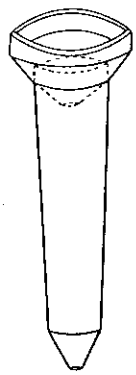
32-20-C(+)



42

38-36-G



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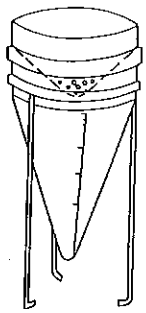
40-13-S



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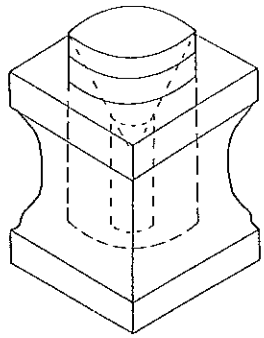
40-14-P



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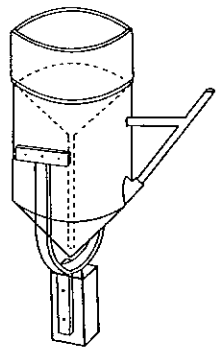
40-15-G



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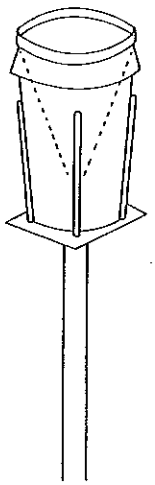
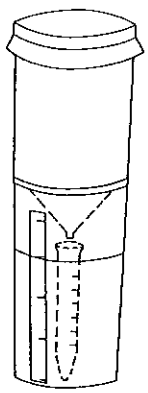
40-17-C



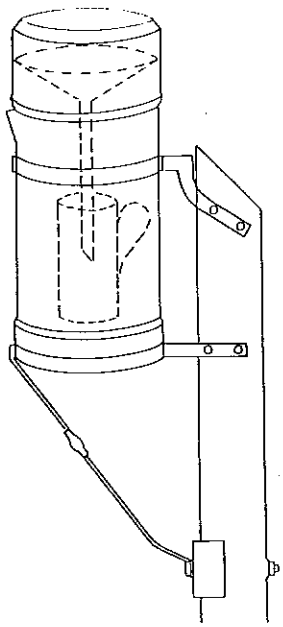
47

40-23-G



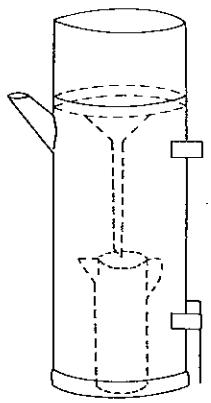
48

40-45-P



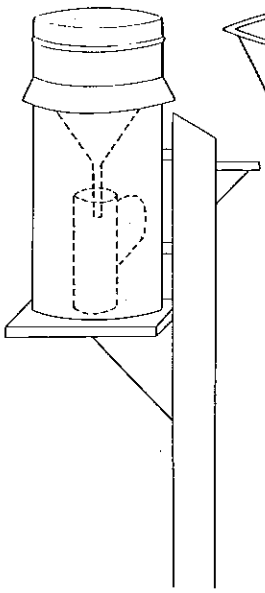
49

50-15-G



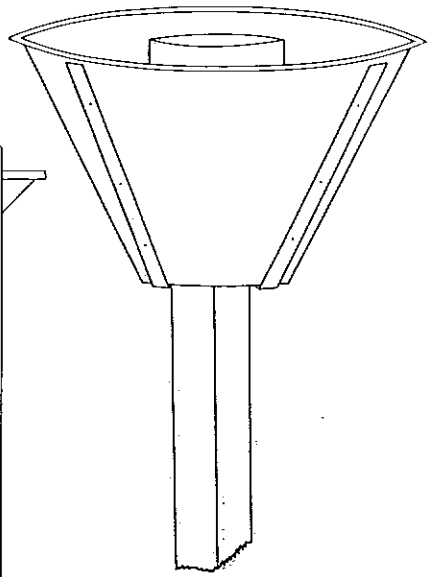
50

50-24-G



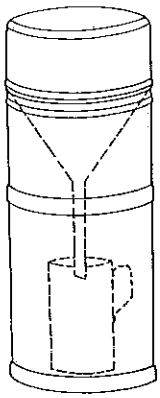
51

50-25-G



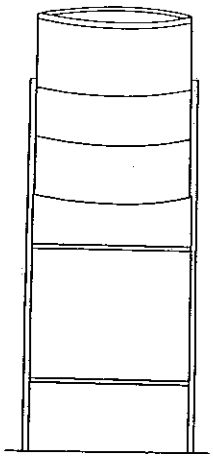
52

50-30-B+



53

50-33-G



54

100-10-L

APPENDIX III

Table 1

List of countries including information on precipitation gauges such as the number, type and installation height above ground

Legend

* Change of method of precipitation measurement during the last 30 years, see Appendix IV
** see Note in Appendix II (+) windshield used sporadically
\+ windshield used permanently

Country	Area [1000 km^2]		Precipitation gauge Number	Code**	km2 per gauge	Height above ground [m]
Abu Dhabi Emirate	65		1	13-15-C		0.28
			1	13-20-C		
	0.51					
			1	recording		0.50
			1	recording		0.60
		Σ	4		16	
Afghanistan +	650		56	20-24-G	11600	0.4
Albania	29		231	100-10-G		1.5
			50	recording		1.5
		Σ	281		103	
Angola	1247		-	13-20-C	-	1.0
Argentina	2777		4200	20-20-G	661	1.5
Australia *	7687		6600	32- 7-G	1165	0.3-(1.3)
Austria (+)	84		800	50-15-G		1.0-1.5
			760	50-20-G		0.8-1.0
				20-22-G		0.8-1.0
		Σ	1560		54	
Bahamas	11		56	32-20-C	196	0.75
Bahrain	0.6		1	13-15-C	0.6	0.15
Bangladesh	143		33	32-20-S	4333	0.7
Barbados	0.4		50			
Belgium +	31		280	10-11-S	111	0.6
Belize	23		53			
Benin	116		65	40-23-G	1780	1.5
Bolivia *	1099		594	38-36-G	1850	1.5
Botswana	575		300	13-27-C		1.2
			10	recording		1.2
		Σ	310		1855	
Brazil	8512		6950	40-13-S		1.5
			1200	recording		
		Σ	8150		1040	

Table 1 cont.

Country	Area		Number	Code	km²/g.	Height
Brunei	6		16	13-20-C		0.6
			1	recording		1.0
		Σ	17		352	
Bulgaria	111		634	50-25-G	175	1.0
Burkina Faso	274		154	40-23-G	1779	1.5
Burma	678		675	13-16-G	1004	0.3
Burundi *	28		110	20-27-G	280	0.6
Cameroon *	475			40-23-G		1.5
				40-14-P		1.5
		Σ	360		1319	
Canada * +	9976		2500	10-10-P		0.35
			485	recording		0.76
			175	recording		1.50
			10	recording		1.50
			350	13- -C		1.50
		Σ	3520		2834	
Central African Rep.	623		130	40-23-G	4792	1.5
Chad *	1271		150	40-14-P	8473	1.5
Chile *	757		278	20-22-G	2723	1.5
China *	9561		17972	31-22-G	532	0.7
Colombia *	1139		1358	20- -A	839	1.0
Congo	349		178	40-23-G	1961	1.5
Costa Rica	51		345	20-27-G	148	1.5
Cyprus	9		137	13-15-C	66	0.3
Czechoslovakia	128			50-33-G		1.0-1.5
				recording		1.5
		Σ	1468		87	
Denmark	43		700	20-27-G	61	1.5
Djibouti	0.6		21	40-14-P	29	1.5
Dominican Rep. *	48		80	20-27-G	600	1.5
Ecuador	455		540	20-27-G	843	1.2
Egypt *	1000		38	recording	26316	0.84
El Salvador	21		210	20-27-G	100	1.5
Ethiopia *	1222		956	31-22-G	1278	1.0
Fiji	18		300	13-15-C	60	0.3
Finland * +	360		634	20-24-G	568	1.5

Table 1 cont.

Country	Area		Number	Code	km²/g.	Height
France *	550			40-14-P		1.0
				40-23-G		1.0
				40-45-P		1.0
		Σ	3500		157	
French Polynesia *	4		15	40-14-P	267	1.0
Guadeloupe *	2		74	40-14-P	27	1.0
Guyana *	215		49	40-14-P	4387	1.5
Martinique *	1		77	40-14-P	13	1.0
Reunion *	3			40-14-P		1.5
			67	40-23-G		1.5
			34	40-45-P		1.0
			13	recording		
		Σ	114		26	
St. Pierre *	0.2		1	40-14-P	200	1.0
Gabon	265		70	40-23-G	3785	1.5
Gambia*	10		45	13-15-C	222	0.8
German Dem. Rep. (+)	108		1200	20-27-G	90	1.0-2.0
Germany, Fed. Rep. of	249		4000	20-27-G	62	1.0
Ghana	239		427	13-15-C	560	0.3
Greece	132		116	31- -G	1138	1.3
Guatemala	109		213	20-27-G	512	1.5
Guinea	246		75	40-23-G	3280	1.5
Guinea-Bissau *	36			20-27-G		1.5
				20-24-G		1.5
		Σ	21		1714	
Guyana *	215		180	13-20-C	1194	1.0
Haiti *	28		170	20-15-A	165	1.5
Honduras	112		34	20-27-G	3294	1.5
Hong Kong	1		3	recording		0.5
			134	13-15-C		0.3
		Σ	137		7	
Hungary	93		900	20-22-G	103	1.0
Iceland +	103		119	20-30-G	866	1.5-2.0
India	3288		10975	20-22-P	300	0.3

Table 1 cont.

Country	Area		Number	Code	km²/g.	Height
Indonesia	1920		54	recording		4.2
			15	recording		0.4
			16	recording		1.4
			2	recording		1.4
			3	recording		0.8
			4000	10- -G		1.2
		Σ	4090		469	
Iran *	1648		971	32-16-C	1697	1.0
Iraq	434		120	13-15-C		0.3
			35	recording		
		Σ	155		2800	
Ireland	70		750	13-15-C	93	0.3
Israel *	21		320	20-22-G		1.0
			80	07-04-P		1.0
			50	10-08-P		1.0
		Σ	450		47	
Italy	301					
Jamaica	11		360	13-15-C	31	0.3
Japan * +	370			31-20-B (recording)		0.5
				31-20-B+ (recording)		
		Σ	1313		282	
Jordan	98		25	20-27-G	3920	1.2
Kenya	583		1800	13-15-C	324	0.3
DPR of Korea	121		184	20-23-G	658	1.5
Kuwait	20		15	recording	1333	0.6
Lebanon*	10		143	40-14-P	70	1.5
Lesotho	30		80	13-15-C	270	1.0
Libyan Arab Jam.	760		244	100- -L	3115	1.5
Luxembourg	3		35	20-27-G	86	1.0
Madagascar	587		213	40-23-G	2756	1.5
Malawi*	94		785	13-20-C	120	0.75
Malaysia	331		380	13-15-C		0.3
			717	32-14-C		1.35
		Σ	1097		302	
Maldives	0.3		12	13-15-C	25	0.3
Mali*	1204			40-14-P		1.5
				40-23-G		1.5
		Σ	300		4013	
Mauritius*	2		250	10-16-G	8	1.0

Table 1 cont.

Country	Area		Number	Code	km²/g.	Height
Mexico	1972		300	40-15-G		1.0
			78	recording		1.0
		Σ	378		5217	
Mongolia+	1565		350	20-24-G	4471	2.0
Morocco*	622		1035	20-27-G	601	1.0
Mozambique	785		70	32-20-C	11214	1.0
Nepal	141		254	32-19-S		1.0
			12			
		Σ	266		528	
Netherlands	36		320	20-19-B	113	0.4
Netherlands Antilles	1		65	40-17-C	15	1.25
New Caledonia	19		52	40-14-P		1.0
				40-45-P		1.0
				40-23-G		1.5
			29	recording		
		Σ	81		235	
New Zealand	269		1712	13-15-S		0.3
			12	8-10-P		0.36
			160	recording		0.6
			28	recording		0.4
			27	recording		1.2
			60	12-20-C		0.3
		Σ	1999		142	
Niger*	1182			40-14-P		1.5
				40-23-G		1.5
		Σ	200		5910	
Nigeria	924		1200	13-15-C	7700	0.5
Norway*+	324			20- -C		1.5
				20-15-A		
		Σ	775		418	
Oman	212		8	13-15-C		0.3
			8	4-18-P		
			5	recording		1.8-2.0
		Σ	21		16308	
Pakistan*	804		570	13-15-C	1411	0.3
Panama*	76		223	20-27-G	341	1.5
Papua New Guinea	223		989	32- 7-G	225	0.3
Paraguay	407		193	20-20-G	2110	1.5
Philippines*	300		461	32-20-C	650	0.8
Poland	312		1737	20-27-G	180	1.0-1.5
Portugal	92		675	20-14-G	136	1.5

Table 1 cont.

Country	Area		Number	Code	km²/g.	Height
Qatar	10		4	recording		0.64
			3	recording		1.18
		Σ	7		1429	
Rep. of Korea	100		748	31-22-G	134	0.2
Romania	237		1075	20-24-G		1.5
			304	recording		1.5
		Σ	1379		172	
Sao Tomé and Princ.	1		15	20-14-G	66	1.5
Saudi Arabia	2264			30-20-C		1.0
				recording		
		Σ	1144		1979	
Seychelles	0.4		27	13-20-C	15	0.76
Singapore	0.6		35	recording		1.6
			14	recording		1.1
			6	recording		0.8
			3	recording		0.5
			1	13-20-C		0.5
		Σ	59		10	
Solomon Islands	30		50	32- 7-G	600	0.3
Spain	505		4929	20-27-G		1.5
			246	recording		1.5
		Σ	5175		98	
Sri Lanka	66		357	13-20-C	185	0.46
Sudan	2506		926	30-20-C	2706	0.46
Swaziland	17		45	13-27-C	378	1.2
Sweden+	450		900	20-15-A	500	1.5
Switzerland*(+)	41		405	20-27-G		1.5
			60	recording		1.5
		Σ	465		88	
Syrian Arab. Rep.	185		390	20-27-G		0.6
Tanzania*	940		1373	13-15-C	685	0.3
Thailand	514		792	32-20-10		0.8
			100	recording		1.2
		Σ	892		574	
Togo	57		143	40-23-G	399	1.5
Trinidad	5		155	13-15-C		0.3
			55	recording		0.5-1.2
		Σ	210		24	
Tunisia	164		235	40-23-G	698	1.5
Turkey	781		1200	20-27-G	651	1.0

Table 1 cont.

Country	Area		Number	Code	km^2/g.	Height
U. S. S. R.+	22274		?	20-24-G	?	2.0
U.K.	245		600	13-20-C`		0.3
			100	(13-20-C)m		0.3
			600	13-20-C		0.3
			3800	13-15-C		0.3
			100	recording		0.45
			100	recording		0.54
		Σ	5300		46	
U. S. A.+	9363		9000	32-20-C/S		1.1
			150	recording		1.0
			1100	recording		1.4
			2200	recording		1.4
		Σ	12450		752	
Uruguay	187		403	20-27-G	464	1.5
Vanatu Rep.	12		32	8-10-P		1.0
			2	32-07-G		0.3
			7	13-15-P		0.3
			15	40-23-G		2.0
		Σ	56		214	
Viet Nam*	334		500	20-24-G	668	1.5
Yugoslavia	256		2900	20-27-G	88	1.0
Zaire	2344		145	10-11-S	161700	0.5
Zimbabwe*	389		1136	13-20-C/S/P	342	0.75-1.0

APPENDIX III

Table 2

List of countries from which no information on precipitation gauges is available

COUNTRY	Area [1000 km^2]	COUNTRY	Area [1000 km^2]
Algeria	2382	Nicaragua	
Brit. Carib. Terr.		Peru	1285
Cape Verde	4	Rwanda	26
Comoros	2	Saint Lucia	0.6
Cuba	114	Senegal	197
Dem. Kampuchea	181	Sierra Leone	72
Dem. Yemen	290	Somalia	637
Dominica	0.8	Surinam	164
Ivory Coast	320	Uganda	236
Lao People's Dem. Rep.	237	Venezuela	912
Liberia	111	Yemen	195
Malta	0.3	Zambia	753
Mauritania	1119		
Total I	4761.1	Total II	4459.6
TOTAL I+II	9220.7		

APPENDIX III

Table 3

List of countries using precipitation gauges with wind shield

Type of windshield	Country	Note
Nipher* (Different modifications of original are in use).	Austria	only in the mountains
	Belgium	
	Bulgaria	only in the mountains
	Canada	only on the Nipher gauge, 350 gauges
	GDR	only in the mountains
	Iceland	
	Norway	
	Sweden	
	Switzerland	only in the mountains
	Zaire	
Tretyakov	Afghanistan	
	Czechoslovakia	only in the mountains
	Finland	
	Guinea Bissau	
	Mongolia	
	USSR	
Alter	Canada	Fishes-Porter (185 gauges) and Belfort Universal recording gauges
	USA	Fisher-Porter (2200), Belfort Universal (1100), tipping-bucked (110) recording gauges and standard gauge USw 8"(code 32-20-C, Tab. 3) sporadically
Cylindric	Japan	in the northern part of country and in winter
Woelfle	Morocco	sporadically

APPENDIX III

Table 4

Most commonly used types of precipitation gauges classified according to country and height above the ground.

* Change of types of precipitation gauges going on at present, see Appendix IV
( ) code see Appendix II

Precipitation gauge	Height above ground [m]	Country	Total Area ($10^3 km^2$)	Total Number of gauges
Hellmann (20-27-G)	0.6	Burundi, Syria	213	500
	0.8-1.0	Austria, Egypt	1084	798
	1.0	GDR, FRG, Hungary, Israel, Luxembourg, Morocco, Turkey, Yugoslavia	2133	11590
	1.0-1.2	Colombia, Ecuador	1594	1898
	1.0-1.5	Poland	312	1737
	1.5	Argentina, Chile, Costa Rica, Denmark, Dominican Rep., El Salvador, Guatemala, Guinea Bissau*, Honduras, Portugal, Romania, Spain, Switzerland, Uruguay	4916	13557
		Σ **30 countries**	**10252**	**30080**
Chinese (31-22-G)	0.2	Rep. Korea	100	748
	0.7	China	9561	17972
	1.0	Ethiopia	1222	956
		Σ **3 countries**	**10883**	**19676**
MK 2 + Snowdon (13-15-C) (13-20-C)	0.2	Bahrain	0.6	1
	0.3	Abu Dhabi*, Burma, Fiji, Ghana, Hong Kong, Iraq, Ireland, Jamaica, Kenya, Malaysia, Maldives, New Zealand, Oman, Pakistan, Tanzania, Trinidad, U.K.	4905	12527
	0.5	Abu Dhabi*, Nigeria, Sri Lanka	990	1560
	0.6	Brunei	6	16
	0.8	Gambia, Malawi, Seychelles	104	857
	0.8-1.0	Zimbabwe	389	1136
	1.0	Angola, Sudan	3753	1500
	1.3	Guyana	215	180
		Σ **29 countries**	**10392**	**17856**
Tretyakov (20-24-G)	0.4	Afghanistan (without windshield) Finland, Guinea-Bissau* (beside the Hellmann gauge), Viet Nam (without windshield), DPR of Korea (without wind shield)	1501	1620
	2.0	Mongolia, U.S.S.R.	23839	12000
		Σ **7 countries**	**25340**	**13620**
U.S. Weather B.	0.8	Bahamas, Bangladesh, Philippines, Thailand	968	1342
(32-20-C)	1.0	Saudi Arabia, U.S.A.	11627	10000
		Σ **6 countries**	**12595**	**11342**

Table 4 cont.

India (20-22-P)	0.3	India	**3288**	**10975**
Australian (32-7-G)	0.3	Australia, Papua New Guinea Solomon Islands	7940	7639
		Σ **3 countries**	**7940**	**7639**
Ville Paris (40-13-S)		Brasil	**8512**	**6950**
SPIEA (40-14-P)	1.0	Cameroon, Chad, Djibouti, France*, Lebanon, Mali, New Caledonia*, Niger, Reunion*	4715	1805
		Σ **9 countries**	**4715**	**1807**
Association (40-23-G)	1.5	Benin, Burkina Faso, Cameroon, Congo, France*, Gabon, Guinea, Madagascar, New Caledonia*, Niger, Reunion*, Togo, Tunisia, Central African Rep.	4991	3069
		Σ **14 countries**	**4991**	**3069**

APPENDIX IV

List of countries which changed the precipitation measurement technique in the last 30 years

Legend: Code of a gauge type is in brackets (see Appendix II)

Country	Subject	Past	Present	Since	Note
Australia	measures	inches (glass)	[mm] (polycarbonate)	1974	
Bahamas	gauge	Mk II (13-15-C)	USWB 8" (32-20-C)		
Bangladesh	gauge	MK II 13-15-C	USWB 8" 32-20-S	1982	
Bolivia	height	0.4m	1.5m		
Burundi	gauge	400 cm^2	Hellmann (20-22-G)		
Cameroon	gauge	Association (40-23-G)	Association + (40-23-G)	1980	
			SPIEA (40-14-P)		
Canada	tipping-bucked	tips 0.25mm	tips 0.2mm		
	AES Type B g.	copper 64.5cm^2	plastic 100cm^2 (10-10-P)	1975	2500 stations
	height	0.3 m	1.0 m		
	windshield of Nipher g.	aluminium	fibreglass		350 stations
Chad	gauge	Association (40-23-G)	SPIEA (40-14-P)		
Chile	gauge	USWB 8" (32-20-C)	Hellmann (20-22-G)		
China	height	(0.7-2.0m)	0.7m	(1954-60)	
Colombia	gauge	200 B	200-100 (20- -A)		
	height	1.2m	1.0m		
Cyprus	gauge	MK II (13-15-C)	Cyprus (20-16-C)	1974	
Dominican Rep.	gauge	USWB 8" (32-20-C)	Hellmann (20-22-G)	1970	
	height	0.5 m	1.5 m		
Egypt	gauge	Hellmann (20-22-G)	recording		

Appendix IV cont.

Ethiopia	gauge	different	Chinese (31-22-G)		
	measuring system	dip-stick	measuring cylinder		
Finland	gauge	Wild (50-30-B)	Tretyakov (20-24-G)	1982	
France	gauge	Association (40-23-G)	SPIEA (40-14-P)		4 gauge types in use
	height	1.5 m	1.0 m		
Gambia	height	1.0 m	0.8 m		
GDR	height	1.0-1.35 m	1.0 m	1982	
Guadeloupe	gauge	Association (40-23-G)	Tretyakov+SPIEA (20-24-G;40-14-P)		
	height	1.5 m	1.0 m		
Guyana	gauge	324 cm^2	(13-20-C)	1967	
	height	0.3 m	1.0 m		
Guyana (Fr)	measure	inches	[mm]	1981	
Haiti	gauge	USWB 8",Hellmann,SIAP,Canadian gauge	SMHI (20-15-A)		
	height	1.0m	1.5 m		
Honduras	height	1.0 m	1.5 m		
Iceland	wind shield	no	yes		
India	gauge	MK II (13-15-G)	fibre-glass (20-22-P)	1969	
Iran	height	0.7 m	1.0 m	1984	
Israel	orifice area	200 cm^2	20-22-G 10- 8-P 1- 4-P	1984	g.number:320 50 80
Japan	gauge	manual	recording (31-20-B)	1986	
Jordan	gauge	tilting-syphon	Hellmann-syphon		
DPR of Korea	gauge	Chinese (31-22-G)	Tretyakov (20-24-G)	1956	
	height	0.2-0.3 m (2m)	1.5 m	1969 (1957/68)	
Lebanon	gauge	recording+ +SPIEA	SPIEA (40-14-P)	1982	
Malawi	measures	inches (glass)	[mm] (polycarbonate)	1980 1969	
Mali	gauge	Association (40-23-G)	Association+ +SPIEA	1980	

Appendix IV cont.

Martinique	gauge	Association (40-23-G)	SPIEA (40-14-P)		
	height	1.5 m	1.0 m		
Mauritius	gauge	imported	local manufactured (10-16-G)		
	height		reduced		
Morocco	gauge	Association (40-23-G)	Hellmann (20-22-G)	1975	
	height	1.5 m	1.0 m		
Netherlands	orifice area	(40-17-C)	(20-19-B)	1950	
	height	1.5 m	0.4 m		
New Caledonia	gauge	Association (40-23-G)	SPIEA (40-14-P)		
	height	1.5 m	1.0 m		
New Zealand	measures	inches	[mm]	1972	
	material	copper (13-15-C)	galv. iron (13-15-S)	1966	
Niger	gauge	Association (40-23-G)	SPIEA (40-14-P)		
Norway	gauge	Norway (22-25-C)	SMHI (20-15-A)	at present	
Pakistan	measures	inches	[mm]	1968	
Panama	gauge	USWB 8" (32-20-G)	Hellmann (20-22-G)		
	height	0.9 m	1.5 m		
Philippines	measures	inches	[mm]		
Polynesia Fr.	gauge	Association (40-23-G)	SPIEA (40-14-P)		
	height	1.5 m	1.0 m		
Reunion	gauge	Association + (40-23-G) +SPIEA (40-14-P)	Association+SPIEA+ +SPIEA MN (40-14-P) (40-45-P)		
	height	1-1.5 m	1-1.5 m		
Switzerland	gauge	Hellmann (20-22-G)	Hellmann+ +tipping-bucked	1980	
Tanzania	measures	inches	[mm]	1962	
Viet Nam	gauge	Association (40-23-G)	Tretyakov (20-24-G)	1976	only in the south
Zimbabwe	gauge	copper (13-15-G)	steel+fibre-glass (13-15-C/S/P)		
	material				