WORLD METEOROLOGICAL ORGANIZATION

COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATION

OPAG-SURFACE

JOINT CIMO EXPERT TEAM ON SURFACE-BASED INSTRUMENT INTERCOMPARISONS AND CALIBRATION METHODS
First Session

AND
INTERNATIONAL ORGANIZING COMMITTEE (IOC) ON SURFACE-BASED INSTRUMENTS INTERCOMPARISONS
First Session

Trappes, France, 24-28 November 2003

Distr.: RESTRICTED

CIMO/OPAG-SURFACE/
/ET-SBII&CM-1/IOC-1/Doc. 4.2

(28.X.2003)

ITEM: 4.2

Original: ENGLISH ONLY

Organization and Planning of WMO Intercomparisons of Rainfall Intensity Gauges

(Submitted by the Secretariat)

Summary and purpose of document

This document provides outcome of the Expert Team Meeting on Rainfall Intensity (RI) Measurements, Bratislava, Slovakia, April 2001, as regards the organization, planning and procedures of WMO RI Intercomparisons.

Action proposed

The meeting is invited to take into account information presented in this document when discussing Laboratory Intercomparisons of Rainfall Intensity Gauges.

Organization and Planning of WMO Intercomparisons of Rainfall Intensity Gauges

1. The *Expert Meeting on Rainfall Intensity Measurements* (Expert Meeting) was held in Bratislava, Slovak Republic, from 23 to 25 April 2001 and discussed issues related to intercomparison of Rainfall Intensity (RI) Measurements.

2. The ET developed proposals for Organization and Planning of WMO RI Intercomparisons and made Recommendations on Carrying out a WMO Laboratory Intercomparison(s) and on Methods of calibrations. It also suggested the possible laboratories to carry out laboratory tests.

3. The Final Report of The *Expert Meeting on Rainfall Intensity Measurements* is in the Annex.

W O R L D   M E T E O R O L O G I C A L   O R G A N I Z A T I O N

COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATION

Expert Meeting on Rainfall Intensity Measurements

Bratislava, Slovakia

23 to 25 April 2001

FINAL REPORT

AGENDA

1. ORGANIZATION OF THE SESSION

1.1 Opening of the session

1.2 Election of the chairman

1.3 Working arrangements for the session

1.4 Adoption of the agenda

2. PURPOSE AND SCOPE OF THE MEETING

3. INFORMATION ON THE EVALUATION OF RESULTS OF THE WMO QUESTIONNAIRE ON RECORDING PRECIPITATION GAUGES

4. INFORMATION ON RESULTS RELATED TO RAINFALL INTENSITY (RI) MEASUREMENTS OF WMO AND OTHER INTERCOMPARISONS OF PRECIPITATION MEASUREMENTS

5. CONSIDERATIONS ON ERROR SOURCES OF RI MEASUREMENTS

6. PRESENT AND FUTURE REQUIREMENTS FOR RAINFALL INTENSITY (RI) MEASUREMENTS

7. PROPOSAL FOR ORGANIZATION AND PLANNING OF A WMO RI INTERCOMPARISON, IF APPROPRIATE

8. PREPARATION OF RECOMMENDATIONS

9. ANY OTHER BUSINESS

10. CLOSURE OF THE SESSION

****

GENERAL SUMMARY OF THE WORK OF THE SESSION

1. ORGANIZATION OF THE SESSION

1.1 Opening of the session

The *Expert Meeting on Rainfall Intensity Measurements* (Expert Meeting) was held on the kind invitation of the **Slovak Hydrometeorological Institute** (SHMU) at its Headquarters building in Bratislava, Slovak Republic, from 23 to 25 April 2001. The lists of participants and their addresses are attached as **Appendix A** and **Appendix B**.

The session was opened on Monday, 23 April 2001 at 10.00 a.m. by Dr S. Skulec, Director-General of SHMU and Permanent Representative of Slovakia with WMO. He welcomed the participants in Bratislava and noted SHMU's pleasure in hosting the session. He then underlined the importance of getting reliable and accurate information precipitation for various applications and he especially underlined the challenging task to develop recommendations and guidelines on how to proceed best related to intensity measurements.

He informed the participants that SHMU is operating a comprehensive network of climatic stations and is very interested in the results of the Expert Meeting. Since SHMU has recently started an intercomparison of rain gauges at 2 comparison sites, he believed that his experts could contribute to the success of the Meeting. He emphasized the advantage of organizing a related WMO intercomparison in getting more experience on this difficult subject. Finally, Dr Skulec offered any support by him personally as well his staff and wished the Expert Meeting every success.

Mr K. Schulze welcomed as representative of the WMO Secretariat the participants in Bratislava and conveyed the best wishes and the gratitude from Professor G.O.P. Obasi, Secretary-General of WMO, to the participants. It was also of great pleasure for him to pass on to the meeting the best regards of Dr Srivastava, India, and especially that of Dr Canterford, Australia, President and Vice-president, respectively, of the Commission for Instruments and Methods of Observation (CIMO). He expressed his gratitude to SHMU for the invitation to organise this Expert Meeting in Bratislava and for the excellent working conditions provided.

Mr Schulze noted with appreciation the efforts of Member countries of WMO to enable their experts to participate. He underlined the importance of undertaking steps in this field of common concern for getting more reliable precipitation data which widely will meet the needs of the variety of users, such as for operational purposes as well as in the field of climate research. He underlined that it will be a challenging task to develop the urgently needed guidelines and recommendations for rainfall intensity measurements and to develop a proposal on whether carrying out an intercomparison might be a suitable solution towards the goal of the meeting. He finally thanked all experts for arranging their participation and wished the session every success in its work and the participants an enjoyable stay in Bratislava.

1.2 Election of the chairman

Dr B. Sevruk, *Co-rapporteur on Point Precipitation and Evapotranspiration Measurements* and member of the *CIMO Working Group on Surface Measurements* was unanimously elected as chairman of the Expert Meeting.

1.3 Working arrangements for the session

The session determined its working hours for the Expert Meeting. The participants were also informed on the local arrangements. English was selected as the working language. It was agreed to have an excursion for visiting one of the 2 precipitation test sites on the afternoon of 24 April 2001 with the objective getting information on how such a comparison facility could be equipped and being informed on preliminary test results.

1.4 Adoption of the agenda

The Chairman introduced the Provisional Agenda and invited the participants to provide comments. The session agreed on a minor amendment and adopted the Agenda as basis for its work with the understanding that it could be amended during the session, if necessary. The finally agreed agenda can be found in front of this report.

2. PURPOSE AND SCOPE OF THE MEETING

The chairman briefed the participants on the results of the discussion held at the twelfth session of the *Commission for Instruments and Methods of Observation* (CIMO-XII, Casablanca, Morocco, 1998) related to the need for standardization of the measurement of rainfall intensity and, in particular, on the considerations for the need and possibility of organizing a *Rainfall Intensity Measurement Intercomparison* (global, regional, or national). In recognition of this, CIMO-XII agreed that, if a review of user requirements determined, an expert meeting on this matter should be convened to determine objectives, constraints, and the feasibility of carrying out a related WMO intercomparison.

The Expert Meeting was also informed that CIMO-XII decided to nominate *Co-rapporteurs on Point Precipitation and Evapotranspiration Measurements* to support, among others, this matter of common concern. It agreed that Dr B. Sevruk (Switzerland) and Mr J. Mishaely (Israel), who are serving as members of the *CIMO Working Group on Surface Measurements*, should deal with it. According to their terms of reference, the Co-rapporteurs prepared in 2000 a questionnaire for reviewing the present situation related to the operationally used instrumentation for precipitation measurements as well as Member's need for carrying out an intercomparison on rainfall intensity (RI) measurements. The evaluation of the replies received (see agenda item 3. below) showed their great interest in this matter and provided important background information for this Expert Meeting. It was agreed to concentrate the Meeting's considerations primarily on rainfall intensity measurement, the main scope as decided at CIMO-XII. It was considered to discuss some items concerning solid and mixed forms for precipitation as well. It was decided, however not to discuss these issues because of restricted amount of time and because the meeting was focussing on *rain intensity* only.

The chairman informed the participants that the national meteorological services of some of developed countries attempt in the next years to reorganize the precipitation measurement networks, which consist of conventional (manual) gauges and recording precipitation gauges (RPGs) and to increase the number of RPG. Specific attention should be given to climatological applications (this means amounts). For this aim they need a new better type of RPG as has been in service in the last 30 years. Mostly it was the tipping-bucket gauge. The results of a WMO intercomparison of RPG measurements would show the advantages and disadvantages of different types of RPG. This would be a good guidance for the selection of the most reliable and modern type of RPG to be used in national meteorological networks to record both the amounts of precipitation and the instantaneous RI with the same accuracy.

The Meeting noted with appreciation that several experts submitted documents containing valuable information on their experience and results of test related to the field of considerations. These documents significantly facilitated the discussion at the short meeting. A list of documents received is contained in **Appendix C**.

3. INFORMATION ON THE EVALUATION OF RESULTS OF THE WMO QUESTIONNAIRE ON RECORDING PRECIPITATION GAUGES

To provide the meeting with necessary background information on the state of the art of rain intensity measurement technologies a questionnaire was send out by WMO to all Members. In this questionnaire the need for an intercomparison of precipitation measuring devices was requested as well.

In evaluation of the replies received from 111 countries to the *Questionnaire on Recording Precipitation Gauges* (RPG) which was distributed by WMO to all Member countries in April 2000, the chairman briefed the participants on the results. A concise overview is contained in document Doc. 3[1] submitted by the Co-rapporteurs to the Expert Meeting, while a full evaluation report was in preparation and is intended to be published by WMO in due course prior to CIMO-XIII.

One of the most important questions in preparation of the Expert Meeting was related to Members' interest in carrying out a rainfall intensity measurement intercomparison. The majority answered with "Yes" while out of these, 50 Members expressed their interest in actively supporting its organization.

---

[1] Can be provided by the WMO Secretariat on request.

The main results of the Inquiry can briefly be summarized as follows:

a) There are about 30,000 RPGs in operational use within the countries, which provided information. Considering that some 70 out of 185 WMO Members did not respond to the Questionnaire (such as the USA with at least 3,500 RPGs), the number of RPGs operationally applied can be assessed to more than 40,000. This amounts to roughly 20% of all standard gauges of approximately 200,000 globally used, as assessed by Sevruk and Klemm in 1989[2].

b) The total numbers of the float and tipping-bucket types are more or less constant over the years but that of the modern weighing RPGs is modestly increasing. Most RPGs are to be found in developing countries.

c) The number of manufacturers of RPGs is unexpectedly high and amounts to some 70. The most widespread RPGs are provided by 4 German companies, followed by providers from UK, France, Italy, and China. It was also found that in many countries different types of RPGs from various manufacturers are in use side by side. Most RPGs originate from the Chinese companies

d) The oldest method of precipitation recording, the pen on time chart is still used in most countries (94), followed by the modern data logging (58) and combined with other methods. Punched paper tape is used only in 4 countries.

e) The mostly used method of data transmission is still via postal service (77 countries), followed by telephone- (57), radio- (35), and satellite-transmission (16), while data loggers, telex, e-mail, telegraph, and PC-networks are also being applied. Several countries are using combinations of different data transmission methods.

f) Significant differences in the installation heights (IH) do exist not only among but also within the responding countries. In many cases the IH chosen depends on the gauge type in use. The IH ranges from 15 to 600 cm according to the information received. The following excerpt provides a very concise overview on the outcome, such as: The most frequently used IH is 100 cm (26 countries), followed by 200 cm (19 countries). An IH of 30 cm is used in 15 countries and in 19 countries IH ranged from 30 to 60 cm. Various types of RPGs installed at different heights are applied within 47 countries.

g) Regarding the orifice of gauges there is a tendency to use larger areas than found in the earlier survey for standard gauges (Sevruk and Klemm, 1989). An catching area of 2000 cm^2 was applied by four countries, eight were using 1000 cm^2, areas of 650-750 cm^2 were in use by 11, 500 cm^2 by 27, 400 cm^2 by 14 and 320 cm^2 by 23 countries. It was found that the majority of 37 countries was still using gauges with on orifice of 200 cm^2 while around 125 cm^2 were applied by 17 countries.

It was concluded that precipitation recording gauges have sufficient potential for measuring *rainfall intensity* (RI). Nevertheless there is only limited experience available to inform Members on the most suitable methods applied.

4. INFORMATION ON RESULTS RELATED TO RAINFALL INTENSITY (RI) MEASUREMENTS OF WMO AND OTHER INTERCOMPARISONS OF PRECIPITATION MEASUREMENTS

Dr Sevruk briefly informed the Expert Meeting on operational experience regarding precipitation measurements obtained at various test carried out under the auspices of WMO with different types and systems of recording precipitation gauges (float/siphoning, tipping-bucket, mechanical and electronic weighing systems, distrometers, optical gauges, etc.). Although they are not specifically related to rainfall intensity (RI) observations, some essential conclusions related to the need and feasibility of the RI Intercomparison project could be derived, as reflected later in this report. A concise summary of the main features of these tests was contained in Doc. 3. The main purpose of the WMO intercomparison measurements as summarised in Tab.1 was to evaluate the systematic error of precipitation measurement, particularly the wind induced error and to develop correction procedures. The following excerpt should provide a brief overview only:

[2] Catalogue of national standard precipitation gauges. World Meteorological Organization, Instruments and Observing Methods Report, WMO/TD-No. 313, 50 pp., 1989

Table 1: WMO international precipitation measurement intercomparisons

	WMO Intercomparisons on …		
Subject	**Precipitation**	**Rain**	**Solid Precipitation**
Time period	1960-1975	1972-1976	1986-1993
Purpose	Reduction coefficients between the catches of various types of national gauges	Rain catch differences between the various types of national gauges and the pit gauge. Correction procedures.	Wind-induced error, standard correction procedures. (Wetting and evaporation losses considered)
Reference standard	Precipitation gauge, consisting of Mk 2 gauge* elevated 1 m above ground and equipped with the Alter wind shield	Pit gauge consisting of the Mk 2+), which is installed in a pit, the orifice flush with the ground and surrounded by anti-splash grid	Double-Fence, consisting of the shielded Tretyakov gauge++) encircled by two octagonal lath-fences+++)
Participants	Belgium, Czechoslovakia, Hungary, Israel, U.S.A. and the former Soviet Union	Basic stations: 22 countries. Evaluation stations: Australia Denmark, Finland, USA	Canada, China, Croatia, Denmark, Finland, Germany, Norway, Romania, Russia, Slovakia, Sweden, U.K.
Results	Non-conclusive	Wind-induced loss depends on wind speed, rainfall intensity and the type of gauge. It amounts on average to 3% (up to 20 %) and to 4 - 6 % if wetting and evaporation losses are accounted for.	Wind-induced loss depends on wind speed, temperature, type of gauge. Unshielded gauges show greater losses than shielded ones (up to 80 % vs. 40 % for windspeed of 5 m/s and temperature t <8°C).
Reference	Poncelet (1959) Struzer (1971)	Sevruk and Hamon (1984)	Goodison et al. (1998)

+) British Meteorological Office standard gauge of Snowdon type
++) The Tretyakov gauge is the Russian standard gauge
+++) Diameter of the inner fence is 4 m and of the outer fence is 12 m. The respective heights are 3 and 3.5 m

References:

Poncelet, L.: Sur le comportement des pluviomètres. Inst. Météorol. Belg. Publ. Ser. A, Bruxelles, No. 10, p. 3-58, 1959.

Struzer, L. R.: Practicability analysis of rain gauge international comparison test results (published in Russian language only). Trans. Voeykov Main Geophys. Observ., Vol. 260, p. 77 - 94, 1971

Sevruk B. and W. R. Hamon.: International comparison of national precipitation gauges with a reference pit gauge. Instruments and Observing Methods Rep., No. 17, 135 p., WMO/TD-No. 38, Geneva. 1984

Goodison, B. E., P.Y.T. Louie, and D. Yang: WMO solid precipitation measurement intercomparison, WMO/TD-No. 872, 212 pp, 1998

Supplementary information on related experience regarding the *WMO Solid Precipitation Measurement Intercomparison* was provided by Mr P. Louie (Canada), since he was deeply involved in the evaluation of its results. In addition to the above summary, he noted the need for a reference standard which had been developed and was a primary requirement in all the previous intercomparisons but is currently lacking for rainfall intensity measurements. He also noted that the time and resource commitments and the logistic requirements to complete a major intercomparison study involving multiple field sites are enormous and they are often underestimated.

In addition to these valuable information and conclusions, participants informed on experience obtained from other intercomparisons related to rainfall measurements in general and RI observations specifically.

In this regard Mr Leroy (France) briefly informed on RI related results derived from the WMO Present Weather Sensor / Systems Intercomparison. The data provided (see Doc. 4[3]) clearly show the great fluctuation of rainfall intensity in very short time intervals. This calls for a definition of RI measurements especially related to the lowest required rainfall rate within the smallest interval. Considerations on this issue were continued under item 6. of the agenda and are reflected there.

The Meeting was informed by Mr B. Chvila (Slovakia) on some preliminary results obtained at a combined precipitation- / RI- comparison. This experiment has been running for only 3 months at the Test and Research Station in Jaslovske Bohunice, Slovakia, which was visited by the participants. It was found that the first results are very valuable and helpful for an IOC in case of any forthcoming WMO intercomparison on rain intensity measurements. These preliminary results are summarized as follows:

SHMU carries out Intercomparison Measurements of recording precipitation gauges using two pit gauges and two elevated gauges at 1 m height, each of weighing type and the conventional, manual Hellmann gauge and finally the heated tipping-bucket gauge at the standard height of 1 m at the Research Station Jaslovske Bohunice near Bratislava. The pit recording gauge registered, as expected, considerably more precipitation and longer time periods of precipitation than the elevated ones. The average difference in measured values over the period of three months, i.e. from January to March 2001, amounted to less than 10 % for liquid precipitation and increased with the wind speed to more than 20% for snow, as known.

5. CONSIDERATIONS ON ERROR SOURCES OF RI MEASUREMENTS

Based on the submitted documents, the Expert Meeting discussed sources for systematic and random measurement errors related to precipitation observations with specific attention to RI observations in considering the various operationally applied measuring systems. To obtain a more comprehensive overview on the issues of interest, various existing measuring systems have been taken into account in the discussion, i.e. it included for *in situ* measurements: conventional mechanical systems which were considered suitable for automation, the more sophisticated gauges, optical systems, and small Bi-static X-band based radar sensors; and for areal measurements using remote sensing: weather radar and space based remote systems.

Following these considerations, the Expert Meeting referred to the compatibility of RI measurements obtained from these different types of instruments. The discussion also included calibration- and quality control- and data adjustment- procedures. It briefly considered temporal and spatial inhomogeneities too.

The results of the comprehensive discussion are concisely reflected in the following sub-sections.

5.1 Advantages and error sources of gauges and measurement methods

The Meeting agreed upon the following classification for provision of a summary of the most important and already well know error sources and deficiencies valid for the various rainfall measurement systems:

- *In situ catchment type gauges (conventional instruments which catch and directly measure the rainfall).* Most RPG are of this type and capable to determine RI.
- *In situ non-catchment type sensors (sensors based on optical, acoustic, bi-static X-band radar, and other indirect measuring technologies)*
- *Areal measurement of rainfall using remote sensing (include weather radar and satellite sensors)*

[3] Can be provided by the WMO Secretariat (E-mail) on request.

The various instruments and method for measuring the rainfall amount and especially RI are classified accordingly and only the most obvious and important deficiencies are reflected below while further details can be found in related publications.

5.1.1 In situ catchment type gauges

- *Conventional RPGs, capable to determine RI, can briefly be characterised as follows[4]:* (concisely summarised for the tipping bucket-, weighing-, and siphon-principle)

- Can be calibrated in the laboratory
- Able to measure RI (within sampling time intervals depending on the measurement method used, ranging from a couple of seconds to several minutes)
- Do have a reasonably good reproducibility and long-term stability
- Are widely used operationally and cost effective (the still significant higher price of weighing gauges has to be taken into account as an exception)
- Regular maintenance, calibration and servicing is needed, such as cleaning (it is lower for the weighing principle than for the others)
- Wind induced catching losses may be significant (depending on appropriate wind shielding other than the recommended pit hole)
- Evaporation losses (only partly applicable)
- Wetting losses (not applicable for the weighing principle)
- Systematic non-linear and significant measuring errors, strongly dependent on rainfall rate, especially with higher intensities, such as >20% (typically for the tipping bucket type, not applicable for the weighing principle) while suitable rainfall-rate dependent corrections can be applied for sophisticated tipping bucket gauges in real time operation, either at the sensor directly or at the data acquisition system. Such corrections can reduce the measurement errors related to the rainfall rate (and total amount) under laboratory conditions to ≤2%.

- *Drop counters can briefly be characterised as follows:*

- Calibration is difficult and with high uncertainty errors
- Determination of RI is possible, while the total amount measurements are not very accurate
- Field operation needs great attention and service
- Limited long-term stability
- Mainly applicable for research
- Not suitable under all weather conditions
- Equipment is expensive

5.1.2 In situ non-catchment type sensors

The primary use of non-catchment type sensors is not for rainfall intensity measurement but rather for present weather observations or other research applications. They are generally very expensive and are not intended for use in large networks. With the exception of some sensors based on optical systems, which have found limited operational used, most of these sensors are still primarily research tools. A direct calibration of these type of sensors might be difficult to be done and not be feasible over the full range of rain intensities. Since there is no primary or reference standard for those types of gauges, indirect calibration is usually based on comparison with catchment type gauges, which therefore limit their accuracy.

- *Acoustic systems (Distrometers):*

- Primarily a research instrument for determining drop size distribution
- Expensive, not suitable for use in a large network
- Distrometers do not measure small drops (diameter less than 0.5 mm)

- *Optical systems can briefly be characterised as follows:*

- They are preferably be applied for *Present Weather Observations (PW)*

---

[4] For details, see the *Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8, Part I, Chapter 6) and the Guide to Hydrological Practices (WMO-No.168, Chapter 7, especially Table 7.1)*

- A laboratory calibration is at least very difficult or impossible in the range of operation. It can mainly be achieved in long-lasting comparisons with conventional equipment. These methods are in principle control or validation methods and not typical conditioned calibration methods, traceable to any standard. A transfer of the "calibration accuracy" to similar equipment is not very reliable.
- Accuracy depends on the drop distribution (size, falling speed, number)
- Their long-term stability is not very high
- Considering the above preconditions, they are in a certain extent suitable for RI measurements but not yet reliable for the determination of the rainfall amount in with the requested accuracy and stability
- Although designed in most cases for PW, discrimination between rain, drizzle, snow and hail is rather limited. As a consequence, due to this uncertainty, the calculation of RI from the measured scattering of light can be rather inaccurate.

• *Bi-static X-band-based radar sensors (can be considered):*

- Calibration is difficult, cannot be carried out in the laboratory
- Accuracy depends on the drop distribution
- Expensive, not suitable for use in a large network
- So far mainly applied for present weather observations

5.1.3 Areal measurement of rainfall using remote sensing

The use of remote sensing techniques can provide areally averaged estimates of rainfall amount and intensity. They are particularly suited for defining the areal extent and spatial variability of these parameters but the accuracy of their estimates depends very much their calibration using conventional gauge networks.

• *Weather radars*[5]

- Calibration related to RI measurements is difficult, mainly in using real time observations from a sufficiently dense network of rain gauges
- In a certain extent suitable for RI measurements while the determination of the total rainfall amount is still insufficient

• *GPS-derived precipitable water content of the atmosphere:*

The presently achieved performance characteristics related to the real time determination of RI and total amount is not yet sufficient for meeting users needs related to RI as well as rainfall amount, especially not yet for real-time observations.

• *Satellite observations*

The presently achieved performance characteristics related to the real time determination of RI and total amount is not yet sufficient for meeting the users needs.

5.2 Requirements and constraints for calibration and inspections of gauges and equipment

The following sub-sections provide a concise summary of the related requirements and constraints for calibration in laboratories and inspections in the field. The participants were informed that the European Committee for Standardization (CEN) has issued an European Standard on the design of a reference raingauge pit (EN 13798), which is in fully in line with the Guide to Hydrological Practices (WMO-No. 168). It was stated that such reference could be used as a reference for field intercomparisons, but not as a primary reference.

---

[5] **Comment:** Weather Radar and the further down mentioned GPS-derived data are very interesting and promising technologies for RI & amount measurements. However these are no point precipitation surface measurements, but area-integrated and not ground-truth measurements, i.e. data have to be validated against point precipitation measurements.

- ***Calibration in laboratories***

In giving a high priority especially to RI, it was agreed upon that the calibration of rain gauges is the primary and most stringent task. Calibration techniques for catchment type gauges have been described in the literature, however at the present time there is no standardized calibration equipment or procedure suitable for general application. Therefore the development and testing of a standardized calibration technique need to be done first and this should only be carried out in well certified laboratories. It was recognized in this context that the term "calibration" was already well defined by ISO et al. (see *International Vocabulary of Basic and General Terms in Metrology*, published by ISO, Switzerland) and should be applied for any related activities accordingly.

In considering possible error sources related to laboratory calibrations, the following issues should be considered for any related laboratory activity:

- the uncertainty (accuracy) of the standard calibration facility used should be sufficiently low (high) within the whole range of intensity required (see also section 6. below);
- the quality (purity) and the temperature of the water used for calibration should be well determined / defined;
- the reproducibility of the calibration conditions should get high priority;
- suitable control and registry equipment should be applied (such as PC-controlled);
- limited documentation on the procedures involved;
- limited calibration procedures, not taking into account environmental impacts like temperature dependency.

It was noticed that the quantity for which measurements of precipitation is reported is length (*i.e.* height) expressed in millimetres although the weighting gauges measure mass. Since the density of rain depends in the actual temperature, inaccuracy will be introduced and taken into account during calibration.

- ***Inspections under field conditions***

In considering that no suitable equipment for a precise calibration of rainfall intensity gauges under field conditions is known, it can be assumed that only the general performance of such gauges can be evaluated. As for calibration under field conditions, only the calibration stability in a relaxed range of uncertainty can be done by applying suitable travelling standards developed from laboratory calibration.

5.3 Conclusions

The Expert Meeting discussed in depth the advantages and disadvantages of the various performance characteristics of the significantly differing measuring techniques used for RI observations. It came to the conclusion that related to its main scope for the preparation of a possible intercomparison, only ***in situ* catchment type gauges** should be considered further. This is mainly because this type of gauge is the most practical and widely used in operational networks measuring rainfall intensity. In addition, laboratory and field intercomparisons of these gauges are considered to be feasible.

The *in situ* non-catchment type sensors was not considered further at this time because the primary use of these sensor is generally not for rainfall intensity measurement but rather for present weather observations and research applications. In addition, laboratory calibration / intercomparison of these sensors are not considered to be feasible or at best, very difficult to design for the full range of rainfall intensities. Since these sensors can only be calibrated against a secondary reference, most likely a catchment type gauge, any field intercomparison will not provide the required objective results.

The Meeting also agreed that the measurement of rainfall using remote sensing techniques need not to be considered further at this time since these techniques generally provide averaged data intended for large geographical areas. Taking this into account, it was agreed that the areal measurement of rainfall was considered another problem, which should be handled separately. Furthermore, the Meeting agreed that at present, these types of remote sensing techniques cannot satisfactory be calibrated in the laboratory against any primary standard, i.e. the performance can only be determined in field tests against secondary or travelling standards using the natural variety of rainfall conditions.

6. PRESENT AND FUTURE REQUIREMENTS FOR RAINFALL INTENSITY (RI) MEASUREMENTS

The Expert Meeting noted that specifically related to RI observations there were so far no requirements defined within WMO mandatory publications. It therefore reiterated that based on the above analysis, there is a significant need to develop proposals on the requirements for present and future needs of the various data users related to RI. The related discussions included, as far as expertise was available, the needs for weather prediction, hydrological, agricultural, and climatological applications, including research in the field of climate change, for urban meteorology/hydrology, as well as for some technical applications, such as reliability of microwave transmission lines, etc. It was noted that it is recommended by WMO to report RI in mm h^{-1} (see table 4.1 of the *Guide to Hydrological Practices*[6]) and reflects due to its nature an instantaneous situation. Nevertheless confusion may arise if the quantity intensity is regarded as the total amount of rain which was fallen during an hour. As a consequence it is proposed to indicate time resolution when reporting RI. The Expert Meeting agreed that the following requirements should serve as a basis for further considerations:

(a) Minimum time resolution: Δt = 1 min (data transmission all 10 min)

(b) Required measuring range(s) and related uncertainties (ΔRI)[7][8]
(referred to the above measuring period of 1 minute)[9]

Total range: 0.02 to 2000 mm/h with the following distinction in uncertainty[10]:

0.02 to 0.2 mm/h (trace – see *CIMO Guide* (WMO-No. 8))
yes/no information (for RI > 0) as precipitation indication (or detection) - (mainly used for precipitation duration and present weather observations, such as for road meteorology)

0.2 up to 2 mm/h ΔRI = 0.1 mm/h
2 up to 2000 mm/h ΔRI = 5 %

The Meeting agreed that these accuracy requirements could be fulfilled for calibration of sensors under laboratory conditions only. The operationally achieved accuracy should be more relaxed due to additionally induced errors in the field, such as related to siting and exposure (representativity), instrumental errors including systematic ones, etc.

Since there was a strong request of WMO Members to quickly move towards the operational introduction of the BUFR code, all above requirements including the "near real-time" transmission of 1 min data within 10 min intervals could be realized in due course.

7. PROPOSAL FOR ORGANIZATION AND PLANNING OF A WMO RI INTERCOMPARISON, IF APPROPRIATE

Based on the results of the recently distributed questionnaire, i.e. that several Members proposed to organize an intercomparison, and following the above discussions, the Expert Meeting considered in depth the need, feasibility, and possible objectives of a WMO Intercomparison of Gauges Suitable for RI Measurements. The discussion included in addition to possible field tests also considerations regarding carrying out laboratory tests (such as checking the general performance and calibration of the gauges under various laboratory conditions). Furthermore, such important matters as the:

[6] *Guide to Hydrological Practices* (WMO-No. 168, Fifth ed., 1994), table 4.1, item 34.
[7] Note, SI Units are used, such as mm/h and **not** mm/min! (1 mm $h^{-1} \cong$ 1/3600 kg m^{-2} s^{-1})
[8] Uncertainty (or inaccuracy) is indicated by Δ
[9] Output averaging times of 1 min interval are also stated for other variables, like temperature, humidity, atmospheric pressure (see *Guide to Meteorological Instruments and Methods of Observation*, WMO-No. 8, Sixth ed., 1996, Vol. I, Annex 1.B)
[10] 2000 mm/h was estimated as the max. requirement and is equivalent to approximately 30 mm per minute

a) possibilities and requirements for performance tests and calibrations in laboratories,
b) possibility of performing field tests on national or regional levels, or even of a global tests,
c) requirements of comparison sites (such as which climatic conditions should be covered),
d) selection of reference conditions and instrument(s),
e) need for suitably qualified staff carrying out the test(s) at the selected comparison sites,
f) financial and organizational constraints,
g) establishment of an International Organizing Committee (IOC),
h) collection, evaluation, and analysis of data as well as presentation of results, etc.
i) feasibility of the management of the whole project and its organizational preparation, depending on the various possibilities and needs as indicated above;
j) appropriate procedures for laboratory calibrations in conjunction with reference standards.

The Expert Meeting especially based its discussion for carrying out a test on the comprehensive guidelines for organizing WMO intercomparisons, as contained in the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8, sixth edition, 1996). Details on it can be found in its Part III Chapter 5.

In referring to the proposals developed for present and future requirements related to RI measurements, as reflected in Section 6 above, it was considered that there was a particular need to compare gauges for high intensity rates, since their performance related to low intensities was tested at various national and global WMO intercomparisons, i.e. the general performance characteristics of the various types of rain gauges is already sufficiently documented for this low RI range. In considering this and noting the difficulties for getting organized a field test in climatic regions which widely have to guarantee the required high intensities during a fixed comparison period, defining suitable and well recognized reference instruments, which are currently not available, considering the enormous efforts, including provision of qualified local staff and financial implications for carrying out such an Intercomparison, it was agreed to start first with **a laboratory test period**. It considered in this context that laboratory calibrations could effectively be carried out for catchment type gauges, while non-catchment type sensors and remote sensing techniques (using radar or satellite) cannot be applied (see Section 5.1 above). The performance of these non-catchment type sensors can preferably be determined in field tests which however needs reliable and accurate reference devices which are able to cope these specific needs. It was further noted in this connection that field tests/intercomparisons may be conducted under real operating conditions not only to determine the accuracy and systematic errors of gauges, but they also provide suitable data to make procurement decisions or to determine the maintenance, long-term stability, expected lifetime, etc.

The experts proposed that such a feasible laboratory calibration and performance characteristic test should be carried out first before other, more comprehensive, field intercomparisons are considered. A decision towards a field intercomparison should then be made based on the results of the initial laboratory comparison. It is, however, essential to underline that at least two well equipped and recognized laboratories be selected for this laboratory trial.

The Expert Meeting agreed that after consideration and confirmation of this proposal by the CIMO Working Group on Surface Measurement and approval by WMO, according to the rules an International Organizing Committee (IOC) should be established by the President for the preparation and running of such a test.

Although the IOC would consider and determine the objectives of such an initial intercomparison in detail, provided the test was approved, the Expert Meeting proposed that it might be sufficient to test the same types of raingauges in at least two independent certified laboratories. It was the opinion that there is no need to check the performance at a measuring range <0.2 mm/h at all while preference should be given to the full range >2 mm/h. (see Section 6. above)

The IOC has to specify the requirements for a standardized calibration procedure, the laboratory facilities to be used, which types of catchment gauges, and how many gauges should be compared.

The main objectives of such Calibration Intercomparison should be to provide information on **the state of the art** of the equipment and on the performance of the different **measuring principles** used by catchment type gauges for measuring RI. In this report special attention should be given to new promising measuring techniques. The results should be published by WMO for the benefit of Members and manufacturers.

Depending on the decisions of the IOC it will take in preparation and running of the proposed laboratory test, the final report of the trial should provide in addition to the direct results of the test related to the performance characteristics of the tested gauges within the stated range of measurement also proposals and information on:

- a standardized procedure for laboratory calibration of rain gauges,
- definition of suitable / recommended calibration equipment and its performance as well as standard method(s) of testing, taking into account the variability of conditions including intermittence of the test facilities,
- results of an assessment on the performance of the presently existing systems / principles suitable for application under various environmental and climatic conditions (such as temperature range),
- an evaluation of the presently available technology,
- simulation of environmental conditions by dedicated laboratories,
- reference procedures for calibration and for testing,
- secondary standards suitable for field tests,
- the expected reliability, maintenance, and long-term accuracy and stability of the compared gauges,
- the influence of application of different measuring systems on the homogeneity of rainfall series as result from the data analysis,
- the need to continue the work by carrying out a WMO field intercomparison,
- the most suitable equipment for reference purposes in a field test (such as to be used in a pit

The Expert Meeting suggested that these issues might further be considered and refined before a decision towards a field intercomparison will be taken.

8. PREPARATION OF RECOMMENDATIONS

Since the CIMO Working Group on Surface Measurements is dealing with these matters of concern, the Expert Meeting developed, in summarizing the results of its discussion, some recommendations for further consideration and review. They are related to the Intercomparison Project as well as to the further approach on RI measurements and data correction. These proposals might, as far as appropriate, be submitted to CIMO-XIII for discussion and decision, or could already be provided for information and consideration to other technical commissions concerned.

Recommendation 1: Carrying out a WMO Laboratory Intercomparison(s)
(which includes the establishment of an International Organizing Committee (IOC))

The Expert Meting proposed that due to the defined objectives a comparison of various methods of rainfall intensity measurements (state of the art) should be carried out with the objective to determine their performance characteristics. Only catchment type gauges should be considered for the calibration and they must be capable of measuring rainfall intensities >2 mm/h. It is recommended to carry out at the earliest convenience an initial laboratory calibration test first. Depending on its result, it might be considered to organize a field test. Resulting from the Laboratory Test, the development of a secondary standard suitable for field test should be proposed, if available or developed.

The establishment of an International Organizing Committee (IOC) should be done as usual by the President of CIMO according to the guidelines contained in the CIMO-Guide (/WMO-No. 8).

It was proposed to carry out the Laboratory Test at least in two well equipped and recognized laboratories under the supervision of experienced staff[11].

Recommendation 2: Methods of calibrations

The Expert Meeting proposed that a standardized procedure for generating consistent and repeatable laboratory flow rates be developed and designated for use as the laboratory standard for RI calibration of catchment type gauges. This should include definitions on accuracy and range requirements; the recommended calibration equipment and its proper configuration; and the expected performance as well as standard method(s) of testing, taking into account the variability of conditions including intermittence of the test facilities.

Recommendation 3: Measuring range and uncertainty requirements

The Expert Meeting recommended that the following measuring range and uncertainty requirements should be considered for adoption:

(a) Minimum time resolution: Δt = 1 min (data transmission all 10 min)

(b) Required measuring range(s) and related uncertainties (ΔRI)[12]
(referred to the above measuring period of 1 minute)

Total range: 0.02 to 2000 mm/h with the following distinction in uncertainty:

0.02 to 0.2 mm/h (trace – see *CIMO Guide* (WMO-No. 8))
yes/no information (for RI > 0) as precipitation indication
(mainly used for present weather observations, such as for road meteorology)

0.2 to 2 mm/h ΔRI = 0.1 mm/h
2 to 2000 mm/h ΔRI = 5 %

The certainty if these accuracy requirements are fulfilled is based primarily to laboratory calibrations. Due to additionally induced errors in the field, such as related to siting and exposure (representativity) and environment induced instrumental errors, will reduce the accuracy of measurement. In practice such issues are not very well defined or well known quantitatively and "operational achievable accuracy" will be a common measure for uncertainty of measurement.

Recommendation 4: Correction of long-term data series

Taking into consideration the results of the laboratory test in expecting that any new correction and calibration factors of gauges might be derived which have not been considered earlier, the Expert Meeting recommended that appropriate correction procedures and instrument specific factors should be developed by the user community for the application on long-term data series to maintain temporal homogeneity. Special consideration should be given to extreme values.

Recommendation 5: Collection of information on the results of national tests of rain gauges*[13]*

Since several Services carried out national tests of rain gauges already (see evaluation of the WMO Inquiry) for which the results could partly be made available, the Co-rapporteurs are invited to collect related information, evaluate them and make the results available, at least as supplementary information, for a decision on carrying out a field test after the laboratory test was finished. After having collected the available national reports, the Co-rapporteurs are invited to prepare them in a manner so that they could be made accessible through WMO/CIMO's Web-site.

---

[11] METEO-France; University of Genoa, Italy; SHMU, Slovakia; KNMI Netherlands; etc. might be considered.

[12] Note, SI Units are used, such as mm/h and not mm/min!

Additional comment: One may also note the related information contained in general summary of CBS-XII, 6.1.45: "As regarded the recommendation to use the physical units mm h^{-1} and kg m^{-2} s^{-1} to express the intensity of all type of precipitation, the Commission was pleased to note that the appropriate proposal was already included for adoption in the proposals submitted under agenda item 6.2" (i.e. BUFR code proposal)

[13] For further consideration at the forthcoming session of the CIMO Working Group on Surface Measurements

9. ANY OTHER BUSINESS

The participants particularly appreciated the opportunity to visit the Research and Test Station in Jaslovske Bohunice at which an intercomparison on the subject of consideration has recently been started. The information provided by the experts involved on the preliminary results obtained at the short period of its implementation has been received by the experts with great interest. This tour demonstrated the capabilities and high performance of SHMU for the benefit of Slovakia as well as for the surrounding region.

The Expert Meeting was informed by Mr Schulze (WMO) that the thirteenth session of the Commission for Instruments and Methods of Observation (CIMO-XIII) will be held conjointly with the WMO technical conference (TECO-2002) and the exhibition of meteorological and related equipment (METEOREX-2002) in Bratislava, Slovakia, from 23 September to 3 October 2002.

10. CLOSURE OF THE SESSION

All participants were unanimous in their gratitude to SHMU for the excellent hospitality provided and for making arrangements to ensure the Expert Meeting was a success.

Dr Sevruk thanked the participants for their active work and their valuable contributions provided at the session. He highly appreciated the interest shown in the matter of concern by all experts and especially the interest shown and assistance given by the experts from Slovakia who attended the meeting.

Mr Schulze thanked all experts for their lively discussions and their dedicated work. On behalf of the participants, he especially thanked Dr Sevruk for his engaged chairmanship. He underlined the importance for continuing this important work as proposed by the Expert Meeting. He finally wished the participants every success in their work as well as a safe trip home.

The Expert Meeting was closed on Wednesday, 25 April 2001, at 4.00 p.m.

****

APPENDIX A

LIST OF ATTENDANCE

Name		From	Function
Invited Experts			
1	B. Sevruk	Switzerland	Chairman
2	P.Y.T. Louie	Canada	
3	F. Vidal Jara	Chile	(CHy)
4	M. Leroy	France	
5	J.P. van der Meulen	Netherlands	
6	B. Chvila	Slovak Republic	
7	M. Gifford	USA	
Experts and Observers			
8	E. Rudel[14]	Austria	(CCl)
9	L.G. Lanza	Italy	
10	L. Stagi	Italy	
11	M. Lapin[1]	Slovak Republic	
12	I. Zahumensky	Slovak Republic	
13	S. Handzak	Slovak Republic	
14	J. Schwarz	Slovak Republic	
WMO Secretariat			
15	K. Schulze	WMO, WWW-B	

****

[14] Part-time participation

APPENDIX B

LIST OF ADDRESSES

Invited Experts

Dr Boris Sevruk
Swiss Federal Institute of Technology
Department of Geography
Winterthurerstr. 190
CH-8057 ZURICH
Switzerland
Tel.: (+41 1) 635 5235 (or -5211 or 5231)
Fax: (+41 1) 362 5197
E-mail: sevruk@geo.umnw.ethz.ch

Mr Paul Y.T. Louie
Meteorological Service of Canada
Senior Research Meteorologist
Climate Processes & Earth Observation Division
Climate Research Branch
4905 Dufferin Street
Downsview, Ontario M3H 5T4
Canada
Tel.: (+1 416) 739 4351
Fax: (+1 416) 739 5700
E-mail: Paul.Louie@ec.gc.ca

Mr Fernando Vidal Jara
Dirección General de Aguas
Jefe, Subdepto Hydrometria
Morande 59, Piso 8
Santiago de Chile
Chile
Tel.: (+56 2) 361-2390, or -2391
Fax: (+56 2) 361-2387
E-mail: fernando.vidal@moptt.gov.cl

Mr Michel Leroy
Meteo-France
Direction des systèms d'observation
Chef du Département de l'Observation au sol, DSO/DOS/D
BP 202
F-78 195 TRAPPES CEDEX
France
Tel.: (+33) 1 3013-6405
Fax: (+33) 1 3013 6020
E-mail: michel.leroy@meteo.fr

Dr Jitze P. van der Meulen
Royal Netherlands Meteorological Institute
R & D Observations
Wilhelminalaan 10
P.O. Box 201
NL-3730 AE de BILT
Netherlands
Tel.: (+31 30) 2206 432
Fax: (+31 30) 2210 407
E-mail: meulenvd@knmi.nl

Mr Branislav Chvila
Slovak Hydrometeorological Institute
Meteorological Service Division
Department of Meteorological Networks
Jeséniova 17
SK-833 15 Bratislava
Slovak Republic
Tel.: (+421 2) 5941 5162
Fax: (+421 2) 5477 3620
E-mail: Branislav.Chvila@shmu.sk

Mr Malcolm Gifford
ASOS Development Manager
National Weather Service W/OST32
1325 East-West Highway, Room 12110
Silver Spring, MD 20910
USA
Tel.: (+1) 301-713-0304 Extension 156
Fax: (+1) 301-713-9395
E-mail: Malcolm.Gifford@noaa.gov

Experts and Observers

Dr Ernest Rudel
Zentralanstalt für Meteorologie und Geodynamik
Hohe Warte 38
A-1190 Wien
Austria
Tel.: (+43 1) 360 26-2201
Fax: (+43 1) 360 26 72
E-mail: ernest.rudel@zamg.ac.at

Prof. Luca G. Lanza
Department of Environmental Engineering
University of Genoa
1, Montallegro
I-16145 Genova
Italy
Tel.: (+39 010) 3532-123 (direct) or -496 (Secret.)
Fax: (+39 010) 3532 481
E-mail: luca@diam.unige.it

Dr Luigi Stagi
Department of Environmental Engineering
University of Genoa
1, Montallegro
I-16145 Genova
Italy
Tel.: (+39 010) 3532 480
Fax: (+39 010) 3532 481
E-mail: luigi@diam.unige.it

Dr Milan Lapin
Department of Meteorology and Climatology
Faculty of Mathematics, Physics and Informatics
Comenius University
SK-842 48 Bratislava
Slovak Republic
Tel.: (+421 2) 6542 6820
Fax: (+421 2) 6542 5882
E-mail: lapin@fmph.uniba.sk

Dr Igor Zahumensky
Slovak Hydrometeorological Institute
Jeséniova 17
P.O. Box 15
SK-833 15 Bratislava
Slovak Republic
Tel.: (+421 46) 5413 624
Fax: (+421 2) 5477 3620
E-mail: Igor.Zahumensky@shmu.sk

Mr Stefan Handzak
Slovak Hydrometeorological Institute
Branch Kosice
Jeséniova 17
SK-833 15 Bratislava
Slovak Republic
Tel.: (+421 55) 6339 271 Ext. 44
Fax: (+421 55) 6320 591
E-mail: Stefan.Handzak@shmu.sk

Ing. Juraj Schwarz
MPS system s.r.o.
Pri vinohradoch 326
SK-831 06 Bratislava
Slovak Republic
Tel.: (+421 2) 4488 9486
Fax: (+421 2) 4488 9486
E-mail: schwarz@mps-system.sk

WMO Secretariat

Mr Klaus Schulze
World Meteorological Organization
World Weather Watch, Basic Systems Department
7 bis, Avenue de la Paix
P.O. Box 2300
CH-1211 Geneva 2
Switzerland
Tel.: (+41 22) 7308-409 (direct)
Fax: (+41 22) 7308 021 (direct)
E-mail: schulze@wmo.ch (*or*
Schulze_K@gateway.wmo.ch)

****

LIST OF DOCUMENTS[15]

Doc.	Item	Title	Submitted by
INF. 1	1.3	Arrangements for the Session	WMO Secretariat
INF. 2	4	Summary of the Requirements and Needs for the Use and the Management of Data of Rainfall Intensity Measurements for Climatological Purposes	E. Rudel (Austria)
No number (for info)	5	Tipping Bucket Mechanical Errors and their Influence on Rainfall Statistics and Extremes	P. La Barbera, L.G. Lanza, and L. Stagi (all Italy)
Doc. 1	1.3	Provisional Agenda	WMO Secretariat
Doc. 2	1.3	Explanatory Memorandum to the Provisional Agenda	WMO Secretariat
Doc. 3	3	Information on the Evaluation of the WMO Questionnaire on Recording Precipitation Gauges	B. Sevruk (Switzerland) and J. Michaeli (Israel)
Doc. 4	4	Information on Results Related to Rain Intensity Measurements	M. Leroy (France)
Doc. 5	6	Canadian Requirements and Specifications for Rate of Rainfall Measurements	P.Y.T. Louie (Canada)
Doc. 6	7	Summary of Requirements Related to Precipitation Intensity Measurements	M. Douglas Gifford (USA)
Doc. 7	5 & 6	Some Considerations Related to Precipitation Intensity Measurements	J.P. van der Meulen (Netherlands)

****

[15] All documents can be made available on request addressed to Mr. Klaus Schulze c/o WMO, E-mail: wwwmail@wmo.int