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CHAPTER 4. TESTING, CALIBRATION AND INTERCOMPARISON**4.1 GENERAL**

One of the purposes of WMO, set forth in Article 2 (c) of the WMO Convention, is “to promote standardization of meteorological and related observations and to ensure the uniform publication of observations and statistics” (WMO, 2015). For this purpose, sets of standard procedures and recommended practices have been developed, and their essence is contained in this Guide.

Valid observational data can be obtained only when a comprehensive quality assurance programme is applied to the instruments and the network. Calibration and testing are inherent elements of a quality assurance programme. Other elements include clear definition of requirements, instrument selection deliberately based on the requirements, siting criteria, maintenance and logistics. These other elements must be considered when developing calibration and test plans. On an international scale, the extension of quality assurance programmes to include intercomparisons is important for the establishment of compatible datasets.

Because of the importance of standardization across national boundaries, WMO regional associations have set up Regional Instrument Centres (RICs)¹ to organize and assist with standardization and calibration activities. Similarly, on the recommendation of JCOMM, a network of Regional Marine Instrument Centres (RMICs)² has been set up to provide for similar functions regarding marine meteorology and related oceanographic measurements.

National and international standards and guidelines exist for many aspects of testing and evaluation, and should be used where appropriate. Some of them are referred to in this chapter.

4.1.1 Definitions

Definitions of terms in metrology are given in the *International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM)* by the Joint Committee for Guides in Metrology (JCGM, 2012). Many of them are reproduced in Volume I, Chapter 1, and some are repeated here for convenience. JCGM definitions are strongly recommended for use in meteorology, although in meteorological practice some commonly used terminology might differ from it. The JCGM document is a joint production with the International Bureau of Weights and Measures (BIPM), the International Electrotechnical Commission (IEC), the International Federation of Clinical Chemistry and Laboratory Medicine (IFCC), the International Laboratory Accreditation Cooperation (ILAC), the International Organization for Standardization (ISO), the International Union of Pure and Applied Chemistry (IUPAC), the International Union of Pure and Applied Physics (IUPAP) and the International Organization of Legal Metrology (OIML).

The VIM terminology differs from common usage in the following respects in particular:

¹ Please, see Volume I, Chapter I, Annex 1.C. for the most recent information on RIC, their ToRs, locations and capabilities, please visit: <https://www.wmo.int/pages/prog/www/IMOP/instrument-reg-centres.html>

² Please, see Volume III, Chapter 4, Annex 4.A. for the most recent information on RMICs, please visit: http://www.jcomm.info/index.php?option=com_content&view=article&id=335:rmics&catid=34:capacity-building

Accuracy (of a measurement): A qualitative term referring to the closeness of agreement between a measured quantity value and a true quantity value of a measurand. The accuracy of a measurement is sometimes understood as the closeness of agreement between measured quantity values that are being attributed to the measurand. It is possible to refer to an instrument or a measurement as having a high accuracy, but the quantitative measure of the accuracy is expressed in terms of uncertainty.

Uncertainty: A non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used.

The error of a measurement: The measured quantity value minus a reference quantity value (the deviation has the other sign). It is composed of the random and systematic errors (the term bias is commonly used for systematic error).

Repeatability: The closeness of agreement between indications or measured quantity values obtained on the same or similar objects under a set of conditions that includes the same measurement procedure, same operators, same measuring system, same operating conditions and same location, and replicate measurements over a short period of time.

Reproducibility: The closeness of agreement between indications or measured quantity values obtained on the same or similar objects under a set of conditions that includes different locations, operators and measuring systems, and replicate measurements.

4.1.2 Testing and calibration programmes

Before using atmospheric measurements taken with a particular instrument for meteorological purposes, the answers are needed to a number of questions, as follows:

- (a) What is the instrument or measuring system accuracy?
- (b) What is the variability of measurements in a network containing such measuring systems or instruments?
- (c) What change, or bias, will there be in the data provided by the instrument or measuring system if its siting location is changed?
- (d) What change or bias will there be in the data if it replaces a different instrument or measuring system measuring the same weather element(s)?

To answer these questions and to assure the validity and relevance of the measurements produced by a meteorological instrument or measuring system, some combination of calibration, laboratory testing and functional testing is needed.

Calibration and test programmes should be developed and standardized, based on the expected climatic variability, environmental and electromagnetic interference under which instruments and measuring systems are expected to operate. For example, considered factors might include the expected range of temperature, humidity and wind speed; whether or not an instrument or measuring system must operate in a marine environment, or in areas with blowing dust or sand; the expected variation in electrical voltage and phase, and signal and power line electrical transients; and the expected average and maximum electromagnetic interference. Meteorological Services may purchase calibration and test services from private laboratories and companies, or set up test organizations to provide those services.

It is most important that at least two like instruments or measuring systems be subjected to each test in any test programme. This allows for the determination of the expected variability in the instruments measuring system, and also facilitates detecting problems.

4.2 TESTING

4.2.1 The purpose of testing

Instruments and measuring systems are tested to develop information on their performance under specified conditions of use. Manufacturers typically test their instruments and measuring systems and in some cases publish operational specifications based on their test results. However, it is extremely important for the user Meteorological Service to develop and carry out its own test programme or to have access to an independent testing authority.

Testing can be broken down into environmental testing, electrical/electromagnetic interference testing and functional testing. A test programme may consist of one or more of these elements.

In general, a test programme is designed to ensure that an instrument or measuring system will meet its specified performance, maintenance and mean-time-between-failure requirements under all expected operating, storage and transportation conditions. Test programmes are also designed to develop information on the variability that can be expected in a network of like instruments, in functional reproducibility, and in the comparability of measurements between different instruments or systems.

Knowledge of both functional reproducibility and comparability is very important to climatology, where a single long-term database typically contains information from instruments and measuring systems that through time use different sensors and/or technologies to measure the same meteorological variable. In fact, for practical applications, good operational comparability between instruments is a more valuable attribute than precise absolute calibration. This information is developed in functional testing.

Even when an instrument or measuring system is delivered with a calibration report, environmental testing and possibly additional calibration should be performed. An example of this is a temperature measurement system, where at present the sensor is likely to be a resistance temperature device. Typically, several resistance temperature devices are calibrated in a temperature bath by the manufacturer and a performance specification is provided based on the results of the calibration. However, the temperature measuring system which produces the temperature value also includes power supplies and electronics, which can also be affected by temperature. Therefore, it is important to operate the electronics and sensor as a measuring system through the temperature range during the calibration. It is good practice also to replace the sensor with a resistor with a known temperature coefficient, which will produce a known temperature output and operate the electronics through the entire temperature range of interest to ensure proper temperature compensation of the measuring system electronics.

Users should also have a programme for testing randomly selected production instruments and measuring systems, even if pre-production units have been tested, because even seemingly minor changes in material, configurations or manufacturing processes may affect the operating characteristics of instruments and measuring systems.

The International Organization for Standardization has standards (ISO, 1999, 2013) which specify sampling plans and procedures for the inspection of lots of items.

4.2.2 Environmental testing

4.2.2.1 Definitions

The following definitions serve to introduce the qualities of an instrument or measuring system that should be the subject of operational testing:

Operational conditions: Those conditions or a set of conditions encountered or expected to be encountered during the time an item is performing its normal operational function in full compliance with its performance specification.

Withstanding conditions: Those conditions or a set of conditions outside the operational conditions which the instrument is expected to withstand. They may have only a small probability of

occurrence during an item's lifetime. The item is not expected to perform its operational function when these withstanding conditions exist. The item is, however, expected to be able to survive these conditions and return to normal performance when the operational conditions return.

Outdoor environment: Those conditions or a set of conditions encountered or expected to be encountered during the time that an item is performing its normal operational function in an unsheltered, uncontrolled natural environment.

Indoor environment: Those conditions or a set of conditions encountered or expected to be encountered during the time that an item is performing its normal operational function within an enclosed operational structure. Consideration is given to both the uncontrolled indoor environment and the artificially controlled indoor environment.

Transportation environment: Those conditions or a set of conditions encountered or expected to be encountered during the transportation portion of an item's life. Consideration is given to the major transportation modes – road, rail, ship and air transportation, and also to the complete range of environments encountered – before and during transportation, and during the unloading phase. The item is normally housed in its packaging/shipping container during exposure to the transportation environment.

Storage environment: Those conditions or a set of conditions encountered or expected to be encountered during the time an item is in its non-operational storage mode. Consideration is given to all types of storage, from the open storage situation, in which an item is stored unprotected and outdoors, to the protected indoor storage situation. The item is normally housed in its packaging/shipping container during exposure to the storage environment.

The International Electrotechnical Commission also has standards (IEC, 2002) to classify environmental conditions which are more elaborate than the above. They define ranges of meteorological, physical and biological environments that may be encountered by products being transported, stored, installed and used, which are useful for equipment specification and for planning tests.

4.2.2.2 Environmental test programme

Environmental tests in the laboratory enable rapid testing over a wide range of conditions, and can accelerate certain effects such as those of a marine environment with high atmospheric salt loading. The advantage of environmental tests over field tests is that many tests can be accelerated in a well-equipped laboratory, and equipment may be tested over a wide range of conditions specific to different climatic regions. Environmental testing in the laboratory is important; it can give insight into potential problems and generate confidence to go ahead with field tests, but it cannot replace field testing.

An environmental test programme is usually designed around a subset of the following conditions: high temperature, low temperature, temperature shock, temperature cycling, humidity, wind, rain, freezing rain, dust, sunshine (insolation), low pressure, transportation vibration and transportation shock. The ranges, or test limits, of each test are determined by the expected environments (operational, withstanding, outdoor, indoor, transportation, storage) that are expected to be encountered.

The purpose of an environmental test programme document is to establish standard environmental test criteria and corresponding test procedures for the specification, procurement, design and testing of equipment. This document should be based on the expected environmental operating conditions and extremes.

For example, the United States prepared its National Weather Service standard environmental criteria and test procedures (NWS, 1984), based on a study which surveyed and reported the expected operational and extreme ranges of the various weather elements in the United States operational area, and presented proposed test criteria (NWS, 1980). These criteria and procedures consist of three parts:

- (a) Environmental test criteria and test limits for outdoor, indoor, and transportation/storage environments;
- (b) Test procedures for evaluating equipment against the environmental test criteria;
- (c) Rationale providing background information on the various environmental conditions to which equipment may be exposed, their potential effect(s) on the equipment, and the corresponding rationale for the recommended test criteria.

4.2.3 Electrical and electromagnetic interference testing

The prevalence of instruments and automated data collection and processing systems that contain electronic components necessitates in many cases the inclusion in an overall test programme for testing performance in operational electrical environments and under electromagnetic interference.

An electrical/electromagnetic interference test programme document should be prepared. The purpose of the document is to establish standard electrical/electromagnetic interference test criteria and corresponding test procedures and to serve as a uniform guide in the specification of electrical/electromagnetic interference susceptibility requirements for the procurement and design of equipment.

The document should be based on a study that quantifies the expected power line and signal line transient levels and rise times caused by natural phenomena, such as thunderstorms. It should also include testing for expected power variations, both voltage and phase. If the equipment is expected to operate in an airport environment, or other environment with possible electromagnetic radiation interference, this should also be quantified and included in the standard. A purpose of the programme may also be to ensure that the equipment is not an electromagnetic radiation generator. Particular attention should be paid to equipment containing a microprocessor and, therefore, a crystal clock, which is critical for timing functions.

4.2.4 Functional testing

Calibration and environmental testing provide a necessary but not sufficient basis for defining the operational characteristics of an instrument or measuring system, because calibration and laboratory testing cannot completely define how the instrument or measuring system will operate in the field. It is impossible to simulate the synergistic effects of all the changing weather elements on an instrument in all of its required operating environments.

Functional testing is simply testing in the outdoor and natural environment where instruments are expected to operate over a wide variety of meteorological conditions and climatic regimes, and, in the case of surface instruments, over ground surfaces of widely varying albedo. Functional testing is required to determine the adequacy of an instrument or measuring system while it is exposed to wide variations in wind, precipitation, temperature, humidity, and direct, diffuse and reflected solar radiation. Functional testing becomes more important as electronic instruments, such as those using electro-optic, piezoelectric and capacitive elements, are placed into operational use. The readings from these instruments may be affected by adventitious conditions such as insects, spiders and their webs, and the size distribution of particles in the atmosphere, all of which must be determined by functional tests.

For many applications, comparability must be tested in the field. This is done with side-by-side testing of like and different instruments or measuring systems against a field reference standard. These concepts are presented in Hoehne (1971, 1972, 1977).

Functional testing may be planned and carried out by the laboratory, preferably accredited, of the Meteorological Service, or of other user organization, or of private company. For both the procurement and operation of equipment, the educational and skill level of the observers and technicians who will use the measuring system must be considered. Use of the equipment by these staff members should be part of the test programme. The personnel who will install, use, maintain and repair the equipment should evaluate those portions of the instrument or measuring system, including the adequacy of the instructions and manuals that they will use in their job. Their skill level should also be considered when preparing procurement specifications.

4.3 CALIBRATION

4.3.1 The purpose of calibration

Instrument or measuring system calibration is the first step in defining data validity. In general, it involves comparison against a known standard to determine how closely instrument output matches the standard over the expected range of operation. Performing laboratory calibration carries the implicit assumption that the instrument's characteristics are stable enough to retain the calibration in the field. A calibration history over successive calibrations should provide confidence in the instrument's stability.

Specifically, calibration is the operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties, and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication (JCGM, 2012). It should define an instrument/measuring system's bias or average deviation from the standard against which it is calibrated, its random errors, the range over which the calibration is valid, and the existence of any thresholds or non-linear response regions. It should also define resolution and hysteresis. Hysteresis should be identified by cycling the sensor over its operating range during calibration. The result of a calibration is often expressed as a calibration factor or as a series of calibration factors in the form of a calibration table or calibration curve. The results of a calibration must be recorded in a document called a calibration certificate or a calibration report.

The calibration certificate or report should define any bias that can then be removed through mechanical, electrical or software adjustment. The remaining random error is not repeatable and cannot be removed, but can be statistically defined through a sufficient number of measurement repetitions during calibration.

4.3.2 Standards

The calibration of instruments or measurement systems is customarily carried out by comparing them against one or more traceable measurement standards. These standards are classified according to their metrological quality. Their definitions (see also JCGM, 2012) are given in Volume I, Chapter 1 and may be summarized as follows:

Primary standard: A measurement standard established using a primary reference measurement procedure, or created as an artefact, chosen by convention.

Note: When these standards are relevant to NMHS' calibration laboratories or RICs they should also be traceable to the International System of Units (SI).

Secondary standard: A measurement standard established through calibration with respect to a primary measurement standard for a quantity of the same kind.

International standard: A measurement standard recognized by signatories to an international agreement and intended to serve worldwide.

National standard: A measurement standard recognized by national authorities to serve in a State or economy as the basis for assigning quantity values to other measurement standards for the kind of quantity concerned.

Reference standard: A measurement standard designated for the calibration of other measurement standards for quantities of a given kind in a given organization or at a given location.

Working standard: A measurement standard that is used routinely to calibrate or verify measuring instruments or measuring systems.

Transfer device: A device used as an intermediary to compare measurement standards.

Travelling standard: A measurement standard, sometimes of special construction, intended for transport between different locations.

Primary standards reside within international or national metrological institutions. Units' definitions and their practical realizations are approved by the General Conference on Weights and Measures (CGPM). The practical realization of these definitions is the main task of national metrology institutes. National metrology institutes maintain primary standards either by keeping an artifact compared regularly to an international prototype, or reproduce an experiment, following a procedure which will produce a quantity.

Secondary standards often reside in major calibration laboratories and are usually not suitable for field use. These standards are generally called reference measurement standards, according to ISO/IEC 17025 (ISO/IEC, 2017). Working standards are usually laboratory instruments that have been calibrated against a secondary standard. Working standards that may be used in the field are known as travelling standards. Travelling standard instruments may also be used to compare instruments in a laboratory or in the field. All of these standards used for a meteorological purpose and relevant to NMHSs' calibration laboratories or RICs should be traceable to SI.

4.3.3 Traceability

Traceability is defined by JCGM (2012) as a: "property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty".

It is highly recommended that meteorological measurements are traceable, for example, through travelling standards, working standards and secondary standards, to national standards, and that the accumulated uncertainties are known (except for those that arise in the field, which have to be determined by field testing).

4.3.4 Calibration practices

The calibration of meteorological instruments is normally carried out in a laboratory where appropriate measurement standards and calibration devices are located. They may be Regional Instrument Centres, national laboratories, laboratories established within the NMHS or other user organization, or private laboratories. A calibration laboratory is responsible for maintaining quality of its measurement standards and for keeping records of their traceability. Such laboratories can also issue calibration certificates that must also contain the uncertainty estimation of calibration. In order to guarantee traceability, the calibration laboratory should be accredited by the appropriate national accreditation body.

Manufacturers of meteorological instruments should deliver their quality products, for example, barometers or thermometers, with calibration certificates or calibration reports issued by accredited laboratory. These documents may or may not be included in the basic price of the instrument, but may be available as options. Calibration certificates given by accredited calibration laboratories may be more expensive than factory certificates. As discussed in the previous section, environmental and functional testing, and possibly additional calibration, should be performed.

Users may also purchase calibration devices or measurement standards for their own laboratories. A good calibration device should always be combined with a proper measurement standard, for example, a liquid bath temperature calibrator with certified resistance thermometers. For the example above, further considerations, such as the use of non-conductive silicone fluid, should be applied. Thus, if a temperature-measurement device is mounted on an electronic circuit board, the entire board may be immersed in the bath so that the device can be tested in its operating configuration. Not only the calibration equipment and standards must be of high quality, but the engineers and technicians of a calibration laboratory must be well trained in basic metrology and in the use of available calibration devices and measurement standards.

Once instruments have passed initial calibration and testing and are accepted by the user, a programme of regular calibration checks and calibrations should be instituted. Fragile instruments are easily subject to breakage when transported to field sites, while others can be too bulky and heavy for easy transportation. At distant stations, these instruments should be kept stationary as

far as possible, and should be calibrated against more robust travelling standards that can be moved from one station to another by inspectors. Travelling standards must be compared frequently against a working standard or reference standard in the calibration laboratory, and before and after each inspection tour.

Details of laboratory calibration procedures of, for example, barometers, thermometers, hygrometers, anemometers and radiation instruments are given in the relevant chapters of this Guide or in specialized handbooks. These publications also contain information concerning recognized international standard instruments and calibration devices. Calibration procedures for automatic weather stations require particular attention, as discussed in Volume III, Chapter 1.

Field inspection practices

Field inspection offers the user the ability to check the instrument on site. Leaving the instrument installed at a meteorological station eliminates any downtime that would occur while removing and reinstalling the instrument in the field. Inspection is usually done at one point against the working standard by placing the working standard as close to the instrument under inspection (IUI) as possible. Stabilization time must be allowed to reach temperature equilibrium between the working standard and the IUI. Attention must be paid to the proximity of the working standard to the IUI, the temperature gradients, the airflow, the pressure differences and any other factors that could influence the inspection results. This field inspection is an effective way to verify the instrument quality. The most important disadvantage is that the inspection is usually limited to one point. The second disadvantage is that if an error is reported, the IUI should be removed and replaced by a new calibrated sensor. Then the IUI has to be calibrated and adjusted if possible in a laboratory. It should also be noted that the field inspection provides additional valuable information as it involves testing the whole instrumental set-up in the field, including cabling, etc. When performing field inspections, it is important that the metadata of the conditions at the time of the inspection be recorded, including all details on the changes made to the instrumental set-up (see additional details provided in Volume III, Chapter 1, 1.7.2).

Inter-laboratory comparisons

An inter-laboratory comparison (ILC) is defined as the organization, performance and evaluation of calibration results for the same instrument by two or more laboratories in accordance with predetermined conditions. ILCs are very effective means to demonstrate technical competence, therefore a laboratory's participation in an ILC enables the laboratory to assess and demonstrate the reliability of the resultant measurement data by comparison with results from other participating laboratories. Additionally, ILCs provide verification of different calibration methods used by participating laboratories. As participation in ILC is a requirement of accreditation body according to the ISO/IEC 17025, each accredited laboratory is expected to participate in a minimum of one proficiency test/inter-laboratory comparison at least every five years for each major sub-discipline of the main disciplines of the laboratory's scope of accreditation. Participation in at least one proficiency test/inter-laboratory comparison is required prior to the granting of accreditation. As stated in the RICs' terms of reference (Volume I, Chapter 1, Annex 1.C), a RIC must participate in and/or organize inter-laboratory comparisons of standard calibration instruments and methods.

Inter-laboratory comparisons are conducted and supervised by an ILC provider. It is desired that an ILC provider is accredited according to the ISO/IEC 17043 (ISO, 2010). General guidelines for organizing ILCs, developed in line with the requirements of ISO/IEC 17043, are available in Annex 4.A and should be followed and implemented as far as possible.

4.4 INTERCOMPARISONS OF INSTRUMENTS

Intercomparisons of instruments and observing systems, together with agreed quality-control procedures, are essential for the establishment of compatible datasets. All intercomparisons should be planned and carried out carefully in order to maintain an adequate and uniform quality level of measurements of each meteorological variable. Many meteorological quantities cannot be directly compared with metrological standards and hence to absolute references — for example,

visibility, cloud-base height and precipitation. For such quantities, intercomparisons are of primary value.

Comparisons or evaluations of instruments and observing systems may be organized and carried out at the following levels:

- (a) International comparisons, in which participants from all interested countries may attend in response to a general invitation;
- (b) Regional intercomparisons, in which participants from countries of a certain region (for example, WMO Regions) may attend in response to a general invitation;
- (c) Multilateral and bilateral intercomparisons, in which participants from two or more countries may agree to attend without a general invitation;
- (d) National intercomparisons, within a country.

Because of the importance of international comparability of measurements, WMO, through one of its constituent bodies, from time to time arranges for international and regional comparisons of instruments. Such intercomparisons or evaluations of instruments and observing systems may be very lengthy and expensive. Rules have therefore been established so that coordination will be effective and assured. These rules are reproduced in Annexes 4.B and 4.C.³ They contain general guidelines and should, when necessary, be supplemented by specific working rules for each intercomparison (see the relevant chapters of this Guide).

Reports of particular WMO international comparisons are referenced in other chapters in this Guide (see, for instance, Volume I, Chapters 3, 4, 9, 12, 14 and 15). Annex 4.D provides a list of the international comparisons which have been supported by the Commission for Instruments and Methods of Observation and which have been published in the WMO technical document series.

Reports of comparisons at any level should be made known and available to the meteorological community at large.

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ANNEX 4.A. GUIDELINES FOR ORGANIZING INTER-LABORATORY COMPARISONS**1. INTRODUCTION**

An inter-laboratory comparison (ILC) is defined by the standard ISO/IEC 17043 (ISO/IEC, 2010) as the organization, performance, and evaluation of calibration/test results for the same or similar item by two or more laboratories in accordance with predetermined conditions. ILCs offer to laboratories the additional means to assess their ability of competent performance either for the purpose of the assessment by accreditation bodies or for their internal quality assurance process. ILC techniques vary depending on the nature of the test item, the method in use and the number of laboratories participating. Usually ILCs involve a test item to be measured or calibrated being circulated successively among participating laboratories.

³ Recommendations adopted by the Commission for Instruments and Methods of Observation at its eleventh session (1994), through the annex to Recommendation 14 (CIMO-XI) and Annex IX.

Following definitions of standard ISO/IEC 17043 (ISO/IEC, 2010) the ILC provider is an organization which takes responsibility for all tasks in development and operation of an inter-laboratory comparison. ILC coordinator is one or more individuals with responsibility for organizing and managing all of the activities involved in the operation of an inter-laboratory comparison.

2. PROCEDURE FOR ORGANIZING OF AN INTER-LABORATORY COMPARISON

2.1 Personnel involved in the organizing and conducting ILC

2.1.1 Measurement of the properties of interest and statistical treatment of participants' results are performed by the technically competent and experienced personnel of the ILC provider, who all should have relevant work experience, training and suitable qualifications.

2.1.2 Responsibilities of the ILC provider that need to be met in the ILC are: initiation, planning, appropriate instrument selection, operation of specific equipment, handling and distribution of ILC items, operation of data processing system, conducting statistical analysis, performance evaluation of ILC participants, opinions and interpretations, issuance and authorisation of ILC report.

2.2 Organization and design logistics

2.2.1 ILC protocol

2.2.1.1 An ILC protocol should be agreed upon by participants and must be documented before commencement of the ILC. It should include at least the following information:

- a) name and address of the ILC provider;
- b) name, address and affiliation of the ILC coordinator and other personnel involved in the design and operation of the ILC scheme;
- c) activities to be subcontracted and the names of subcontractors involved in the operation of the ILC scheme;
- d) criteria to be met for participation;
- e) number and type of expected participants in the ILC scheme;
- f) selection of the measurand(s) or characteristic(s) of interest;
- g) description of the range of values or characteristics, or both, to be expected for the ILC items;
- h) requirements for the production, quality control, storage and distribution of ILC items;
- i) reasonable precautions to prevent collusion between participants or falsification of results, and procedures to be employed if collusion or falsification of results is suspected;
- j) description of the information, which is to be supplied to participants and the time schedule for the various phases of the ILC scheme;
- k) dates upon which ILC items are to be distributed to participants, the deadlines for the return of results by participants and, where appropriate, the dates on which testing or measurement is to be carried out by participants;
- l) any information on methods or procedures which participants need to use to prepare the test materials and perform the tests or measurements;
- m) procedures for the test or measurement methods to be used for the homogeneity and stability testing of ILC items;
- n) preparation of any standardized reporting formats to be used by participants;
- o) detailed statistical analysis to be used;
- p) the origin, metrological traceability and measurement uncertainty of any assigned values;
- q) criteria for the evaluation of performance of participants;
- r) description of the data, interim reports or information to be returned to participants;
- s) description of the extent to which participant results, and the conclusions that will be based on the outcome of the ILC scheme, are to be made public.

2.2.1.2 The ILC provider must ensure access to the necessary technical expertise and experience. This may be achieved by establishing an advisory group, whose responsibilities include, but are not limited to, the following: supervising the selection and preparation of test item, supervising the drawing of the protocol, supervising the choice of method and procedure, supervising all the communication with participants, taking care that time schedule is met, informing participants about delays, informing participant about next participant of the scheme, supervising issuing of the invoice, supervising issuing of interim and final report, etc.

2.2.2 Preparation of test items

2.2.2.1 Test items have to match needs of ILC participants. Test item preparation includes its selection. Initially, it is necessary to specify characteristics of the test item, such as stability, range, resolution, uncertainty, etc. Then a suitable test item is acquired, either chosen from existing equipment on stock or purchased. After that, the chosen test item is tested (measured several times, put under the conditions that can be expected during the transport and measurements at the participating laboratories) in order to confirm specified characteristics. If tests are successful, the item is used for the ILC.

2.2.2.2 Test items with stability worse than uncertainty of any of the participating laboratories are not used for the ILC scheme, unless otherwise agreed in advance with participants.

2.2.3 Stability testing

Preliminary stability checks must be made and periodic checks of assigned property values should be carried out throughout the course of the ILC. Where appropriate, the property values to be determined in the ILC must be measured periodically, preferably over a range of conditions under which the test item is to be stored prior to distribution. Test items must demonstrate sufficient stability to ensure that they will not undergo any significant change throughout the conduct of the ILC.

2.2.4 Choice of method or procedure

ILC participants are expected to use a test method, calibration or measurement procedure of their choice, which is consistent with routine procedures used in their laboratories. Under certain circumstances, the ILC provider may instruct participants to use a specified method. When participants are allowed to use a method of their choice, the ILC provider can, whenever appropriate, request details of the chosen method, in order to properly interpret the results obtained by different test methods.

2.3 Conduct of inter-laboratory comparison

2.3.1 Instructions to participants

The ILC provider should give detailed documented instructions to all participants which are usually included as an integral part of the ILC protocol. Instructions to participants must include details of factors which could influence the testing of the test items, the nature of the test items, the test procedure employed, and the timing of the testing. Specific instructions related to recording and reporting test results must include, but are not necessarily limited to, the units of measurement, the number of significant figures, reporting basis, and the latest date for receipt of test results.

2.3.2 Handling and storage of ILC items

2.3.2.1 In order to avoid any damage of the ILC items, the ILC provider should identify, preserve and segregate all ILC items, for example, from any potential damaging influence of humidity, temperature, electricity and magnetic field, prior to their distribution to ILC participants. For each ILC, the items must be identified in terms of specifications related to environmental conditions which could occur during transport.

2.3.2.2 The ILC item should be prevented from any adjustment (either as password protected part of the test item, or by single usage seal).

2.3.2.3 The ILC provider should ensure adequate packaging of all ILC items and provide secure storage areas and/or stock rooms which prevent damage or deterioration of any item prior to distribution. When appropriate, the conditions of all stored or stocked items should be assessed at specified intervals during their storage life in order to detect possible deterioration. The ILC provider should control packaging and marking processes to the extent necessary to ensure conformity with relevant regional, national and/or international safety and transport requirements.

2.4 Data analysis and interpretation of scheme results

2.4.1 Data analysis and records

2.4.1.1 Results received from participants must be promptly recorded and analyzed by appropriately documented statistical procedures. In case of doubtful results after data analysis, the ILC provider must promptly ask the participant with suspicious results to check those results. Before the final report is issued to the participants, all the participants should check their data and confirm their consistency. Every participant of the ILC scheme, in accordance with the protocol, should report all the relevant results and their uncertainties in a dedicated spreadsheet table. Data analysis should include at least summary of measurement, performance statistics and associated information consistent with the ILC statistical model and objectives. Two steps are common to all ILC:

a) Determination of the assigned values:

There are various procedures available for establishment of the assigned values:

1. Reference values - as determined by the ILC provider, based on analysis, measurement or comparison of a test item alongside a standard, traceable to a national or international standard.
2. Consensus values from expert laboratories - expert laboratories should have demonstrable competence.

The assigned value(s) must not be disclosed to participants until after the results have been collated. The uncertainty of assigned values should be determined using procedures described in the Guide to the Expression of Uncertainty in Measurement (ISO/IEC, 2008).

b) Calculation of performance statistics:

ILC results often need to be transformed into performance statistics for interpretation and comparison purposes. The objective is to measure the deviation from the assigned value in a manner that allows evaluation of performance. Commonly used statistics for quantitative results in measurement comparison schemes is E_n number:

$$E_n = \frac{x_{\text{lab}} - x_{\text{ref}}}{\sqrt{U_{\text{lab}}^2 + U_{\text{ref}}^2}}$$

where x_{lab} is the participant's result, x_{ref} is the assigned value, U_{lab} is the expanded ($k=2$) uncertainty of the participant's result and U_{ref} is the expanded ($k=2$) uncertainty of the reference laboratory's assigned value.

In addition to E_n number, also z score can be implemented. z score is calculated as:

$$z = \frac{x - X}{\hat{\sigma}}$$

where x is participant's result, X is the assigned value and $\hat{\sigma}$ is the "standard deviation for ILC" that can be calculated from the following:

- fitness for purpose goal for performance as determined by expert judgement;
- estimate from previous rounds of ILC or expectations based on experience;
- estimate from a statistical model;
- results of a precision experiment; or
- participant results, for example a traditional or robust standard deviation based on participant results.

2.4.2 Evaluation of performance

2.4.2.1 The ILC provider is responsible for ensuring that the method of evaluation is appropriate for maintenance of the credibility of the ILC. Such a method must be documented in the ILC protocol and must include a description of the basis upon which the evaluation is made. Criteria for performance evaluation is based on statistical determination of E_n number:

$$E_n \leq 1 = \text{satisfactory}$$

$$E_n > 1 = \text{unsatisfactory}$$

or z score:

$$z \leq 2.0 = \text{satisfactory performance and generates no signal};$$

$$2.0 < z \leq 3.0 = \text{questionable performance and generates warning signal};$$

$$z > 3 = \text{unsatisfactory performance and generates an action signal}.$$

2.4.2.2 Graphs should be used whenever possible to show performance. They should show distributions of participant values, relationship between results on multiple test items and comparative distributions for different methods.

2.4.3 Inter-laboratory comparison reports

The content of ILC reports can vary, depending on the purpose of a particular scheme, but each report must be clear and comprehensive and must include data on the distribution of results of all participants, together with an indication of the performance of individual participant. The following information must usually be included in reports of ILC schemes:

- a) name and contact details of the ILC provider;
- b) names and contact details of the ILC coordinator;
- c) date of issue of the report;
- d) report number and clear identification of the ILC;
- e) clear description of the items used;
- f) laboratory participation codes and test results;
- g) statistical data and summaries, including assigned values and range of acceptable results and graphical displays;
- h) procedures used to establish assigned value;
- i) details of the traceability and uncertainty of assigned values, where applicable;
- j) assigned values and summary statistics for test methods/procedures used by other participants (if different methods are used by different participants);
- k) comments on participants' performance by the ILC provider and technical advisers;
- l) procedures used to design and implement the scheme (what may include reference to a scheme protocol);

- m) procedures used for statistical analysis of the data;
- n) advice, where appropriate, on the interpretation of the statistical analysis.

2.5 Confidentiality

2.5.1 The identity of participants in an ILC is usually confidential and known only to the minimum number of persons involved in the provision and evaluation of the ILC. All information supplied by a participant to the ILC provider must be treated as confidential.

2.5.2 Participants may agree on waived confidentiality of their identity in the ILC protocol and/or in the ILC report.

2.5.3 Chosen option must be confirmed by unanimous agreement of all participants based on a written confirmation when they agree on participation in an ILC.

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ANNEX 4.B. PROCEDURES OF WMO GLOBAL AND REGIONAL INTERCOMPARISONS OF INSTRUMENTS

1. A WMO intercomparison of instruments and methods of observation shall be agreed upon by the WMO constituent body concerned so that it is recognized as a WMO intercomparison.
2. The Executive Council will consider the approval of the intercomparison and its inclusion in the programme and budget of WMO.
3. When there is an urgent need to carry out a specific intercomparison that was not considered at the session of a constituent body, the president of the relevant body may submit a corresponding proposal to the President of WMO for approval.
4. In good time before each intercomparison, the Secretary-General, in cooperation with the president of CIMO and possibly with presidents of other technical commissions or regional associations, or heads of programmes concerned, should make inquiries as to the willingness of one or more Members to act as a host country and as to the interest of Members in participating in the intercomparison.
5. When at least one Member has agreed to act as host country and a reasonable number of Members have expressed their interest in participating, an international organizing committee should be established by the president of CIMO in consultation with the heads of the constituent bodies concerned, if appropriate.
6. Before the intercomparison begins, the organizing committee should agree on its organization, for example, at least on the main objectives, place, date and duration of the intercomparison, conditions for participation, data acquisition, processing and analysis methodology, plans for the publication of results, intercomparison rules, and the responsibilities of the host(s) and the participants.
7. The host should nominate a project leader who will be responsible for the proper conduct of the intercomparison, the data analysis, and the preparation of a final report of the intercomparison as agreed upon by the organizing committee. The project leader will be a member ex officio of the organizing committee.

8. When the organizing committee has decided to carry out the intercomparison at sites in different host countries, each of these countries should designate a site manager. The responsibilities of the site managers and the overall project management will be specified by the organizing committee.
9. The Secretary-General is invited to announce the planned intercomparison to Members as soon as possible after the establishment of the organizing committee. The invitation should include information on the organization and rules of the intercomparison as agreed upon by the organizing committee. Participating Members should observe these rules.
10. All further communication between the host(s) and the participants concerning organizational matters will be handled by the project leader and possibly by the site managers unless other arrangements are specified by the organizing committee.
11. Meetings of the organizing committee during the period of the intercomparison could be arranged, if necessary.
12. After completion of the intercomparison, the organizing committee shall discuss and approve the main results of the data analysis of the intercomparison and shall make proposals for the utilization of the results within the meteorological community.
13. The final report of the intercomparison, prepared by the project leader and approved by the organizing committee, should be published in the WMO Instruments and Observing Methods Report series.

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ANNEX 4.C. GUIDELINES FOR ORGANIZING WMO INTERCOMPARISONS OF INSTRUMENTS

1. INTRODUCTION

1.1 These guidelines are complementary to the procedures of WMO global and regional intercomparisons of meteorological instruments. They assume that an international organizing committee has been set up for the intercomparison and provide guidance to the organizing committee for its conduct. In particular, see Volume I, Chapter 12, Annex 12.D.

1.2 However, since all intercomparisons differ to some extent from each other, these guidelines should be considered as a generalized checklist of tasks. They should be modified as situations so warrant, keeping in mind the fact that fairness and scientific validity should be the criteria that govern the conduct of WMO intercomparisons and evaluations.

1.3 Final reports of other WMO intercomparisons and the reports of meetings of organizing committees may serve as examples of the conduct of intercomparisons. These are available from the World Weather Watch Department of the WMO Secretariat.

2. OBJECTIVES OF THE INTERCOMPARISON

The organizing committee should examine the achievements to be expected from the intercomparison and identify the particular problems that may be expected. It should prepare a clear and detailed statement of the main objectives of the intercomparison and agree on any criteria to be used in the evaluation of results. The organizing committee should also investigate how best to guarantee the success of the intercomparison, making use of the accumulated experience of former intercomparisons, as appropriate.

3. PLACE, DATE AND DURATION

3.1 The host country should be requested by the Secretariat to provide the organizing committee with a description of the proposed intercomparison site and facilities (location(s), environmental and climatological conditions, major topographic features, and so forth). It should also nominate a project leader.⁴

3.2 The organizing committee should examine the suitability of the proposed site and facilities, propose any necessary changes, and agree on the site and facilities to be used. A full site and environmental description should then be prepared by the project leader. The organizing committee, in consultation with the project leader, should decide on the date for the start and the duration of the intercomparison.

3.3 The project leader should propose a date by which the site and its facilities will be available for the installation of equipment and its connection to the data-acquisition system. The schedule should include a period of time to check and test equipment and to familiarize operators with operational and routine procedures.

4. PARTICIPATION IN THE INTERCOMPARISON

4.1 The organizing committee should consider technical and operational aspects, desirable features and preferences, restrictions, priorities, and descriptions of different instrument types for the intercomparison.

4.2 Normally, only instruments in operational use or instruments that are considered for operational use in the near future by Members should be admitted. It is the responsibility of the participating Members to calibrate their instruments against recognized standards before shipment and to provide appropriate calibration certificates. Participants may be requested to provide two identical instruments of each type in order to achieve more confidence in the data. However, this should not be a condition for participation.

4.3 The organizing committee should draft a detailed questionnaire in order to obtain the required information on each instrument proposed for the intercomparison. The project leader shall provide further details and complete this questionnaire as soon as possible. Participants will be requested to specify very clearly the hardware connections and software characteristics in their reply and to supply adequate documentation (a questionnaire checklist is available from the WMO Secretariat).

4.4 The chairperson of the organizing committee should then request:

- (a) The Secretary-General to invite officially Members (who have expressed an interest) to participate in the intercomparison. The invitation shall include all necessary information on the rules of the intercomparison as prepared by the organizing committee and the project leader;
- (b) The project leader to handle all further contact with participants.

5. DATA ACQUISITION

5.1 Equipment set-up

5.1.1 The organizing committee should evaluate a proposed layout of the instrument installation prepared by the project leader and agree on a layout of instruments for the

⁴ When more than one site is involved, site managers shall be appointed, as required. Some tasks of the project leader, as outlined in this annex, shall be delegated to the site managers.

intercomparison. Special attention should be paid to fair and proper siting and exposure of instruments, taking into account criteria and standards of WMO and other international organizations. The adopted siting and exposure criteria shall be documented.

5.1.2 Specific requests made by participants for equipment installation should be considered and approved, if acceptable, by the project leader on behalf of the organizing committee.

5.2 Standards and references

The host country should make every effort to include at least one reference instrument in the intercomparison. The calibration of this instrument should be traceable to national or international standards. A description and specification of the standard should be provided to the organizing committee. If no recognized standard or reference exists for the variable(s) to be measured, the organizing committee should agree on a method to determine a reference for the intercomparison.

5.3 Related observations and measurements

The organizing committee should agree on a list of meteorological and environmental variables that should be measured or observed at the intercomparison site during the whole intercomparison period. It should prepare a measuring programme for these and request the host country to execute this programme. The results of this programme should be recorded in a format suitable for the intercomparison analysis.

5.4 Data-acquisition system

5.4.1 Normally the host country should provide the necessary data-acquisition system capable of recording the required analogue, pulse and digital (serial and parallel) signals from all participating instruments. A description and a block diagram of the full measuring chain should be provided by the host country to the organizing committee. The organizing committee, in consultation with the project leader, should decide whether analogue chart records and visual readings from displays will be accepted in the intercomparison for analysis purposes or only for checking the operation.

5.4.2 The data-acquisition system hardware and software should be well tested before the comparison is started and measures should be taken to prevent gaps in the data record during the intercomparison period.

5.5 Data-acquisition methodology

The organizing committee should agree on appropriate data-acquisition procedures, such as frequency of measurement, data sampling, averaging, data reduction, data formats, real-time quality control, and so on. When data reports have to be made by participants during the time of the intercomparison or when data are available as chart records or visual observations, the organizing committee should agree on the responsibility for checking these data, on the period within which the data should be submitted to the project leader, and on the formats and media that would allow storage of these data in the database of the host. When possible, direct comparisons should be made against the reference instrument.

5.6 Schedule of the intercomparison

The organizing committee should agree on an outline of a time schedule for the intercomparison, including normal and specific tasks, and prepare a time chart. Details should be further worked out by the project leader and the project staff.

6. DATA PROCESSING AND ANALYSIS

6.1 Database and data availability

6.1.1 All essential data of the intercomparison, including related meteorological and environmental data, should be stored in a database for further analysis under the supervision of

the project leader. The organizing committee, in collaboration with the project leader, should propose a common format for all data, including those reported by participants during the intercomparison. The organizing committee should agree on near-real-time monitoring and quality-control checks to ensure a valid database.

6.1.2 After completion of the intercomparison, the host country should, on request, provide each participating Member with a dataset from its submitted instrument(s). This set should also contain related meteorological, environmental and reference data.

6.2 Data analysis

6.2.1 The organizing committee should propose a framework for data analysis and processing and for the presentation of results. It should agree on data conversion, calibration and correction algorithms, and prepare a list of terms, definitions, abbreviations and relationships (where these differ from commonly accepted and documented practice). It should elaborate and prepare a comprehensive description of statistical methods to be used that correspond to the intercomparison objectives.

6.2.2 Whenever a direct, time-synchronized, one-on-one comparison would be inappropriate (for example, in the case of spatial separation of the instruments under test), methods of analysis based on statistical distributions should be considered. Where no reference instrument exists (as for cloud base, meteorological optical range, and so on), instruments should be compared against a relative reference selected from the instruments under test, based on median or modal values, with care being taken to exclude unrepresentative values from the selected subset of data.

6.2.3 Whenever a second intercomparison is established some time after the first, or in a subsequent phase of an ongoing intercomparison, the methods of analysis and the presentation should include those used in the original study. This should not preclude the addition of new methods.

6.2.4 Normally the project leader should be responsible for the data-processing and analysis. The project leader should, as early as possible, verify the appropriateness of the selected analysis procedures and, as necessary, prepare interim reports for comment by the members of the organizing committee. Changes should be considered, as necessary, on the basis of these reviews.

6.2.5 After completion of the intercomparison, the organizing committee should review the results and analysis prepared by the project leader. It should pay special attention to recommendations for the utilization of the intercomparison results and to the content of the final report.

7. FINAL REPORT OF THE INTERCOMPARISON

7.1 The organizing committee should draft an outline of the final report and request the project leader to prepare a provisional report based on it.

7.2 The final report of the intercomparison should contain, for each instrument, a summary of key performance characteristics and operational factors. Statistical analysis results should be presented in tables and graphs, as appropriate. Time-series plots should be considered for selected periods containing events of particular significance. The host country should be invited to prepare a chapter describing the database and facilities used for data-processing, analysis and storage.

7.3 The organizing committee should agree on the procedures to be followed for approval of the final report, such as:

- (a) The draft final report will be prepared by the project leader and submitted to all organizing committee members and, if appropriate, also to participating Members;
- (b) Comments and amendments should be sent back to the project leader within a specified time limit, with a copy to the chairperson of the organizing committee;

- (c) When there are only minor amendments proposed, the report can be completed by the project leader and sent to the WMO Secretariat for publication;
- (d) In the case of major amendments or if serious problems arise that cannot be resolved by correspondence, an additional meeting of the organizing committee should be considered (the president of CIMO should be informed of this situation immediately).

7.4 The organizing committee may agree that intermediate and final results may be presented only by the project leader and the project staff at technical conferences.

8. RESPONSIBILITIES

8.1 Responsibilities of participants

8.1.1 Participants shall be fully responsible for the transportation of all submitted equipment, all import and export arrangements, and any costs arising from these. Correct import/export procedures shall be followed to ensure that no delays are attributable to this process.

8.1.2 Participants shall generally install and remove any equipment under the supervision of the project leader, unless the host country has agreed to do this.

8.1.3 Each participant shall provide all necessary accessories, mounting hardware, signal and power cables and connectors (compatible with the standards of the host country), spare parts and consumables for its equipment. Participants requiring a special or non-standard power supply shall provide their own converter or adapter. Participants shall provide all detailed instructions and manuals needed for installation, operation, calibration and routine maintenance.

8.2 Host country support

8.2.1 The host country should provide, if asked, the necessary information to participating Members on temporary and permanent (in the case of consumables) import and export procedures. It should assist with the unpacking and installation of the participants' equipment and provide rooms or cabinets to house equipment that requires protection from the weather and for the storage of spare parts, manuals, consumables, and so forth.

8.2.2 A reasonable amount of auxiliary equipment or structures, such as towers, shelters, bases or foundations, should be provided by the host country.

8.2.3 The necessary electrical power for all instruments shall be provided. Participants should be informed of the network voltage and frequency and their stability. The connection of instruments to the data-acquisition system and the power supply will be carried out in collaboration with the participants. The project leader should agree with each participant on the provision, by the participant or the host country, of power and signal cables of adequate length (and with appropriate connectors).

8.2.4 The host country should be responsible for obtaining legal authorization related to measurements in the atmosphere, such as the use of frequencies, the transmission of laser radiation, compliance with civil and aeronautical laws, and so forth. Each participant shall submit the necessary documents at the request of the project leader.

8.2.5 The host country may provide information on accommodation, travel, local transport, daily logistic support, and so forth.

8.3 Host country servicing

8.3.1 Routine operator servicing by the host country will be performed only for long-term intercomparisons for which absence of participants or their representatives can be justified.

8.3.2 When responsible for operator servicing, the host country should:

- (a) Provide normal operator servicing for each instrument, such as cleaning, chart changing, and routine adjustments as specified in the participant's operating instructions;
- (b) Check each instrument every day of the intercomparison and inform the nominated contact person representing the participant immediately of any fault that cannot be corrected by routine maintenance;
- (c) Do its utmost to carry out routine calibration checks according to the participant's specific instructions.

8.3.3 The project leader should maintain in a log regular records of the performance of all equipment participating in the intercomparison. This log should contain notes on everything at the site that may have an effect on the intercomparison, all events concerning participating equipment, and all events concerning equipment and facilities provided by the host country.

9. RULES DURING THE INTERCOMPARISON

9.1 The project leader shall exercise general control of the intercomparison on behalf of the organizing committee.

9.2 No changes to the equipment hardware or software shall be permitted without the concurrence of the project leader.

9.3 Minor repairs, such as the replacement of fuses, will be allowed with the concurrence of the project leader.

9.4 Calibration checks and equipment servicing by participants, which requires specialist knowledge or specific equipment, will be permitted according to predefined procedures.

9.5 Any problems that arise concerning the participants' equipment shall be addressed to the project leader.

9.6 The project leader may select a period during the intercomparison in which equipment will be operated with extended intervals between normal routine maintenance in order to assess its susceptibility to environmental conditions. The same extended intervals will be applied to all equipment.

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ANNEX 4.D. REPORTS OF INTERNATIONAL COMPARISONS CONDUCTED UNDER THE AUSPICES OF THE COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATION^{5,6,7}

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TABLE: Table horizontal lines

Topic	Instruments and Observing Report No.	Title of report
Ceilmeters	32	<i>WMO International Ceilometer Intercomparison</i> (United Kingdom, 1986), D.W. Jones, M. Ouldrige and D.J. Painting, WMO/TD-No. 217 (1988).
Humidity instruments	106	<i>WMO Field Intercomparison of Thermometer Screens/Shields and Humidity Measuring Instruments</i> (Ghardaïa, Algeria, November 2008–October 2009) Final Report, M. Lacombe, D. Bousri, M. Leroy, M. Mezred, WMO/TD-No. 1579 (2011).
Humidity instruments	38	<i>WMO International Hygrometer Intercomparison</i> (Oslo, Norway, 1989), J. Skaar, K. Hegg, T. Moe and K. Smedstud, WMO/TD-No. 316 (1989).
Humidity instruments	34	<i>WMO Assmann Aspiration Psychrometer Intercomparison</i> (Potsdam, German Democratic Republic, 1987), D. Sonntag, WMO/TD-No. 289 (1989).
Precipitation gauges	67	<i>WMO Solid Precipitation Measurement Intercomparison – Final Report</i> , B.E. Goodison, P.Y.T. Louie and D. Yang, WMO/TD-No. 872 (1998).
Precipitation gauges	17	<i>International Comparison of National Precipitation Gauges with a Reference Pit Gauge</i> (1984), B. Sevruck and W.R. Hamon, WMO/TD-No. 38 (1984).
Present weather instruments	73	<i>WMO Intercomparison of Present Weather Instruments/Systems – Final Report</i> (Canada and France, 1993–1995), M. Leroy,

⁵ For the most recent reports see: <http://www.wmo.int/pages/prog/www/IMOP/publications-IOM-series.html>.

⁶ The reports of the WMO International Pyrheliometer Intercomparisons, conducted by the World Radiation Centre at Davos (Switzerland) and carried out at five-yearly intervals, are also distributed by WMO.

⁷ This table is sorted by topic/instrument, in alphabetical order, and the reports for each topic are listed in reverse chronological order.

		C. Bellevaux, J.P. Jacob, WMO/TD-No. 887 (1998).
Barometers	46	The WMO Automatic Digital Barometer Intercomparison (de Bilt, Netherlands, 1989–1991), J.P. van der Meulen, WMO/TD-No. 474 (1992).
Pyranometers	98	Sub-Regional Pyranometer Intercomparison of the RA VI members from South-Eastern Europe (Split, Croatia, 22 July–6 August 2007), K. Premec, WMO/TD-No. 1501 (2009).
Pyranometers	16	Radiation and Sunshine Duration Measurements: Comparison of Pyranometers and Electronic Sunshine Duration Recorders of RA VI (Budapest, Hungary, July–December 1984), G. Major, WMO/TD-No. 146 (1986).
Pyrgeometers	124	Second International Pyrgeometer Intercomparison – Final Report, Davos, Switzerland, 27 September to 15 October 2015, J. Gröbner and c. Thomann (2018).
Pyrheliometers	124	WMO International Pyrheliometer Comparison – Final Report, Davos, Switzerland, 28 September to 16 October 2015, W. Finsterle (2016).
Pyrheliometers	113	Third WMO Regional Pyrheliometer Comparison of RA II, (Tokyo, 23 January to 3 February 2012), N. Ohkawara, H. Tatsumi, O. Ljima, H. Koide, S. Yamada (2013).
Pyrheliometers	112	Baltic Region Pyrheliometer Comparison, 21 May–1 June 2012, Norrköping, Sweden, T. Carlund (2013).
Pyrheliometers	108	WMO International Pyrheliometer Comparison – Final Report, Davos, Switzerland, 27 September to 15 October 2010, W. Finsterle (2011).
Pyrheliometers	97	Second WMO Regional Pyrheliometer Comparison of RA II (Tokyo, 22 January–2 February 2007), H. Sasaki, WMO/TD-No. 1494 (2009).
Pyrheliometers	91	International Pyrheliometer Comparison – Final Report, Davos, Switzerland, 26 September–14 October 2005, W. Finsterle, WMO/TD-No. 1320 (2006).
Pyrheliometers	64	Tercera Comparación Regional de la OMM de Pirheliómetros Patrones Nacionales AR III – Informe Final (Santiago, Chile, 24 February–7 March 1997), M.V. Muñoz, WMO/TD-No. 861 (1997).
Pyrheliometers	53	Segunda Comparación de la OMM de Pirheliómetros Patrones Nacionales AR III (Buenos Aires, Argentina, 25 November–13 December 1991), M. Ginzburg, WMO/TD-No. 572 (1992).
Pyrheliometers	44	First WMO Regional Pyrheliometer Comparison of RA IV (Ensenada, Mexico, 20–27 April 1989), I. Galindo, WMO/TD-No. 345 (1989).
Pyrheliometers	43	First WMO Regional Pyrheliometer Comparison of RA II and RA V (Tokyo, Japan, 23 January–4 February 1989), Y. Sano, WMO/TD-No. 308 (1989).
Radiosondes	107	WMO Intercomparison of High Quality Radiosonde Systems, Yangjiang, China, 12 July–3 August 2010, J. Nash, T. Oakley, H. Vömel, LI Wei, WMO/TD-No. 1580 (2011). (Clarification note)
Radiosondes	90	WMO Intercomparison of GPS Radiosondes – Final Report, Alcantâra, Brazil, 20 May to 10 June 2001, R. da Silveira, G. F. Fisc, L.A. Machado, A.M. Dall’Antonia Jr., L.F. Sapucci, D. Fernandes, R. Marques, J. Nash, WMO/TD-No. 1314 (2006).
Radiosondes	85	WMO Radiosonde Humidity Sensor Intercomparison – Final Report of Phase I and Phase II, Phase I: Russian Federation, 1995–1997, Phase II: USA, 8–26 September 1995, Phase I: A. Balagurov, A. Kats, N. Krestyannikova, Phase II: F. Schmidlin,

		WMO/TD-No. 1305 (2006).
Radiosondes	83	WMO Intercomparison of Radiosonde Systems, Vacoas, Mauritius, 2–25 February 2005, J. Nash, R. Smout, T. Oakley, B. Pathack and S. Kurnosenko, WMO/TD-No. 1303 (2006).
Radiosondes	76	Executive Summary of the WMO Intercomparison of GPS Radiosondes (Alcantara, Maranhão, Brazil, 20 May–10 June 2001), R.B. da Silveira, G. Fisch, L.A.T. Machado, A.M. Dall’Antonia Jr., L.F. Sapucci, D. Fernandes and J. Nash, WMO/TD-No. 1153 (2003).
Radiosondes	59	WMO International Radiosonde Comparison, Phase IV (Tsukuba, Japan, 15 February–12 March 1993), S. Yagi, A. Mita and N. Inoue, WMO/TD-No. 742 (1996).
Radiosondes	40	WMO International Radiosonde Comparison, Phase III (Dzhambul, USSR, 1989), A. Ivanov, A. Kats, S. Kurnosenko, J. Nash and N. Zaitseva, WMO/TD-No. 451 (1991).
Radiosondes	30	WMO International Radiosonde Comparison (United Kingdom, 1984/United States, 1985), J. Nash and F.J. Schmidlin, WMO/TD-No. 195 (1987).
Radiosondes	29	WMO International Radiosonde Intercomparison, Phase II (Wallops Island, United States, 4 February–15 March 1985), F.J. Schmidlin, WMO/TD-No. 312 (1988).
Radiosondes	28	WMO International Radiosonde Comparison, Phase I (Beaufort Park, United Kingdom, 1984), A.H. Hooper, WMO/TD-No. 174 (1986).
Rainfall intensity gauges	99	WMO Field Intercomparison of Rainfall Intensity Gauges (Vigna di Valle, Italy, October 2007–April 2009), E. Vuerich, C. Monesi, L. Lanza, L. Stagi, E. Lanzinger, WMO/TD-No. 1504 (2009).
Rainfall intensity gauges	84	WMO Laboratory Intercomparison of Rainfall Intensity Gauges – Final Report, France, The Netherlands, Italy, September 2004–September 2005, L. Lanza, L. Stagi, M. Leroy, C. Alexandropoulos, W. Wauben, WMO/TD-No. 1304 (2006).
Sunshine duration recorders	16	Radiation and Sunshine Duration Measurements: Comparison of Pyranometers and Electronic Sunshine Duration Recorders of RA VI (Budapest, Hungary, July–December 1984), G. Major, WMO/TD-No. 146 (1986).
Thermometer screens	106	WMO Field Intercomparison of Thermometer Screens/Shields and Humidity Measuring Instruments, Ghardaia, Algeria, November 2008–October 2009 Final Report, M. Lacombe, D. Bousri, M. Leroy, M. Mezred, WMO/TD-No. 1579 (2011).
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