WMO INTERCOMPARISON OF INSTRUMENTS AND METHODS FOR THE MEASUREMENT OF SOLID PRECIPITATION AND SNOW ON THE GROUND: ORGANIZATION OF THE EXPERIMENT

Rodica Nitu [(1)], R. Rasmussen[(2)] B Baker[(3)], E Lanzinger [(4)], P. Joe[(1)] , D Yang[(7),] C Smith[(7),] Y.A. Roulet [(5)], B Goodison[(15)], H Liang[(6)], F Sabatini[(8)], J Kochendorfer [(3)], M Wolff[(9)] , J Hendrikx [(10)], E Vuerich[(11),] L Lanza[(12)], O Aulamo[(13)], V Vuglinsky[(14)]

(1) Environment Canada, 4905 Dufferin St, Toronto, Canada, Rodica.nitu@ec.gc.ca
(2) National Center for Atmospheric Research, 3450 Mitchell Lane, Boulder, CO USA
(3) NOAA Air Resources Laboratory, 456 S. Illinois Ave, Oak Ridge, TN, 37830
(4)Deutscher Wetterdienst, Frahmredder 95, 22393 Hamburg, Germany
(5)Météo Suisse, Station Aérologique, Case postale 316, CH-1530 PAYERNE, Switzerland
(6)China Meteorological Administration, No. 46 Zhongguacun, Nandajie, BEIJING 100081, China
(7)Environment Canada, 11 Innovation Boulevard, Saskatoon, SK S7N 3H5, Canada
(8) CNR-IBIMET, Institute of Biometeorology, Via Giovanni Caproni, 8, 50145 Florence, Italy
(9)Norwegian Meteorological Institute, P.O. Box 43 Blindern, Henrik Mohns plass 1, 0313 Oslo, Norway
(10)Montana State University, Bozeman, Montana, 59717-3480, U.S.A.
(11) Italian Met Service – Air Force, Centre of Meteorological Experimentations, Via Braccianese Claudia, km 20,100 00062 Vigna di Valle (Rome) Italy
(12) DICAT - Department of Civil, Environmental and Territorial Engineering, University of Genoa , GENOVA Italy
(13) Finnish Meteorological Institute, Arctic Research Centre, Sodankyla
(14) State Hydrological institute, 2nd Line 23, St.Petersburg, 199053, Russian Federation
(15) WMO, EC-PORS, GCOS, 7 bis, avenue de la Paix, CH 1211 Geneva 2, Switzerland

ABSTRACT

WMO initiated in 2010 the organization of an intercomparison of instruments and methods of observation of solid precipitation and snow on the ground, and will be delivered as a joint effort of a number of WMO Members.

The formal intercomparison is planned to commence in the fall of 2012, being organized on multiple sites in the Northern and the Southern Hemisphere, and including a wide range of instruments and systems currently used for the measurement of solid precipitation and snow on the ground, with various measuring principles, and installed in multiple configurations. The experiment is expected to take place over a minimum of two winter seasons. The organization of the intercomparison on multiple sites will allow the concurrent assessment of the same sensor models in multiple climates, and over a broad range of operational conditions.

The paper will present the organization of the experiment, an overview of the participating sites and the instruments selected for inclusion in the intercomparison. It also includes several aspects (e.g. data protocol, data quality assessment) related to the unfolding of the experiment.

OVERVIEW

The Commission for Instruments and Methods of Observation (CIMO) of the World Meteorological Organization (WMO) agreed at its Meeting in 2010 to organize, as a matter of urgency, an intercomparison to assess the impact of automation and to determine the errors in measurement of snowfall, snow depth and solid precipitation in cold climate from automatic weather stations, and in cooperation with other relevant Technical Commissions and the WMO- Executive Council for Polar Observations, Research, and Services (EC-PORS). The organization of the Solid Precipitation Intercomparison Experiment (WMO SPICE) was endorsed at the Sixteenth Congress of WMO and the work commenced in 2011.

SPICE is led by an International Organizing Committee (IOC) which brings together representatives from countries around the world with significant interest and experience in the measurement of solid precipitation: Canada, China, Germany, Italy, New Zealand, Russia, Switzerland, and the USA. Canada has assumed the leadership role in the organization and the running of the experiment.
To date, the IOC held two formal meetings in October 2011 and June 2012, with reports available on the SPICE site http://www.wmo.int/pages/prog/www/IMOP/intercomparisons/SPICE/SPICE.html.

In consultation with a broad range of stakeholders representing the Commission for Hydrology, Commission for Agriculture Meteorology, World Climate Research Program – Working Group on Nowcasting, the Remote Sensing community, GCOS, EC-PORS, as well as some of national Meteorological Services, the IOC defined the objectives of SPICE, planning to focus on:

- recommending appropriate automated field reference system(s) for the unattended measurement of solid precipitation and to provide guidance on the performance of modern automated systems for measuring: (i) total precipitation amount for all seasons, especially when the precipitation is solid, (ii) snowfall (height of newly fallen snow), and (iii) snow depth (snow on the ground).

- understanding and documenting the differences between a field reference system using an automatic gauge and different automatic systems, and between automatic and manual measurements of solid precipitation using equally exposed/shielded gauges, including their siting and configuration.

MOTIVATION

The results of the 2008 CIMO Survey on instruments and methods for measuring solid precipitation, published as the 2010, WMO/TD-No. 1544, IOM No. 102, indicated that manual observations are still the primary method for measuring solid precipitation, snowfall, and snow on the ground, worldwide. Since the completion of the survey there is indication that the transition from manual to automatic instruments has accelerated including in large networks, as are those of Russia, China, the Himalayan countries.

The CIMO Survey report indicates that a large variety of automatic precipitation gauges are currently used for the measurements of solid precipitation, worldwide, including in the same country. The gauges vary in terms of their measuring system, orifice area, capacity, sensitivity, height, whether or not using a wind shield. This variety exceeds by far the variety of manual standard precipitation gauges (Goodison et. al, 1998). The use of a broad range of instruments and configurations significantly impacts the ability to derive results at large scale, and has serious consequences for the accuracy and consistency of local and global precipitation time series. (B Sevruk , 1994).

As the wind induced gauge undercatch is the largest source of measurement errors (Goodison et al, 1998), the final report of the 1987-1993 WMO intercomparison of solid precipitation measurement recommended wind adjustments developed using observations available at the time, mainly daily precipitation and synoptic observations, which are taken 6 hrs apart. Today's automatic stations provide precipitation values hourly, and in many cases, at 15 minute intervals. At this time scales, the dynamics and the climatology of precipitation is different and the availability of wind adjustment functions using short interval observations of both wind and precipitation is an imperative.

The 1987-1993 WMO intercomparison recommended the use of a Double Fence Intercomparison Reference (DRIF), a double fence with the outside diameter of 12 m, surrounding a manual Tretyakov gauge, as a secondary field reference standard (Goodison et all, 1998). Since then, in many applications, the manual gauge has been replaced with automatic gauges as a result of the need for higher temporal resolution reference data or due to various limitations, e.g. unavailability of local human observers, remote locations, etc. A thorough characterization of a field reference using automatic gauges remains a key objective of the scientific community.

ORGANIZATION OF WMO SPICE

In the fall of 2011, the WMO Members and the manufacturers of automatic instruments have been invited to join the efforts of organizing the coordinated solid precipitation experiment focusing on the automatic instruments currently operational, as well as the new and emerging technologies.
Following the Second Letter of Invitation issued by WMO in January 2012, twelve Members indicated interest in participating in the experiment with at least one site, while three Members and nineteen manufacturers indicated interest in contributing instruments.
Most of the participating manufacturers are members of the Association of the Hydro-Meteorological Equipment Industry (HMEI).

A total of seventeen sites have been proposed as hosts for SPICE in both the Northern and Southern Hemispheres, by Australia, Canada, Chile, Finland, Japan, Norway, New Zealand, Russia, Switzerland, Poland, United States of America, and Uzbekistan. The IOC reviewed the submissions and accepted the participation in SPICE of fifteen sites. All the hosting sites also proposed the inclusion in the experiment of instruments and configurations representative for their national measurement programs.

The instruments proposed by manufacturers and other WMO Members, also known as Instrument Providers, complement the suite of instruments proposed by the site hosts. Overall, all major types of instruments used for the measurement of solid precipitation, snowfall, and snow on the ground are well represented in SPICE, and are representative of the current configuration of national networks measuring precipitation.

The organization of the intercomparison, including the collection and the sharing of data in preparation of the final report is governed by the SPICE Data Protocol, which is intended to recognize the need to actively share the data among the participants, while protecting the integrity of the SPICE data set and of the results published in the Final Report.

Participating Instruments: Measurement of Precipitation Amount

The instruments accepted for the intercomparison, contributed by either the host sites or the manufacturers, cover all the principles of operation known to be used worldwide for the measurement of precipitation. Three types of automatic instruments have been included in SPICE; tipping bucket rain gauge (TBRG), weighing gauge (WG), and optical sensors.

Tipping Buckets Type Gauges

The TBRG measures the amount of liquid precipitation by recording the number of tips which correspond to a fixed amount of precipitation, which is the nominal value of each of the two tipping buckets. The TBRGs vary in size and shape and only heated TBRGs are being used for the measurement of solid precipitation. Overall, TBRG provide a large percentage of the precipitation amount measurements, in all climate regimes, estimated at about 80% of the total of observations by automatic instruments (IOM 102/2010).

The report of the 2008 CIMO Survey indicates that 28 different models of TBRGs, produced by 22 manufacturers, were used by the participating NMHSs.

The TBRGs participating in SPICE cover a subset of the TBRG models noted in the 2008 survey, and are all heated.

The following TBRGs have been accepted for participation in SPICE:

Adolf Thies GmbH&Co KG	Precipitation transmitter, model 5.4032.35.008
CAE S.p.A.	Tipping Bucket (heated) model PMB25R
Environment Meas. Limited	Universal Precipitation Gauge UPG1000
E.T.G.srl	Heated Rain Gauge, model R102R
Hydrlogical Services Pty. Ltd	Heated Tipping Bucket , model TBH/TBH-LP
Meteoservis v.o.s.	MR3H-FC Rain Gauge, model AH-01 with heating
MTX s.r.l.	TB Precipitation sensor , model FAK015AA
ZAMG (Austria)	TB MR3H-FC ZAMG-version

Weighing Gauges

A weighing gauge (WG) weighs the precipitation collected in a large bucket and derives the precipitation amounts based on the detected mass or load. Heating of the WGs is a feature increasingly used to address the ice buildup and snow capping of gauges.

The report of the 2008 CIMO Survey indicates that WGs in use operationally apply three different principles of measurement: the vibrating wire load , the single point electronic load, the strain gauge. The collecting capacity of the WGs in use varied from 240 mm to 1000 mm, while the collecting area is between 200 cm^2 and 1000 cm^2.

The WG proposed for SPICE are representing well the current operational configurations, most of the manufacturers producing WGs being represented in SPICE . The following instruments have been included in SPICE:

Belfort Instrument Company	All Environment Precipitation Gauge, model 36000-1DDH
Geonor AS	WG model T-200B3/T-200BM3, capacity600mm, 1000mm, 1500 mm
Meteoservis v.o.s.	Weighing Rain Gauge model MRW500

MPS System	Total Rain Weighing sensor, model TRwS 204
OTT Hydromet GmbH	OTT Pluvio^2 model 200_RH
Sutron (USA)	TPG model TPG-0001-1

Use of wind shields

The results of the CIMO 2008 survey indicate that, overall, 72% of the automatic instruments (WGs and TBRGs) are not configured with wind shields. Of the automatic gauges that have wind shields, the WGs are used in a much larger proportion with shields, than the TBRGs. Specifically, 82% of the total of WGs were configured using single wind shields. The wind shields in use at the time of the survey were the Alter, Nipher, Tretyakov, or of a special design (e.g. Japan Meteorological Administration).

The report on the 1987-1993 Solid Precipitation Intercomparison (Goodison et al, 1998) indicates that the Nipher shield was the most effective in minimizing the wind undercatch. However, windshields that are typically good for manual observations are responsible for other issues with snow measurements at automatic stations, such as the snow capping. Therefore, alterative shield configurations have to be considered for gauges operating at automatic stations, in particular those unattended.

As part of its objectives, SPICE will investigate and report on various shield configurations, by conducting relevant field experiments and theoretical studies of the airflow/snowflake trajectory around shields.

Optical Sensors

An optical sensor uses the scattering or obscuration by hydrometeors, in some cases together with information gathered by other sensors such as rain sensor and temperature, to determine the type of precipitation and to estimate its intensity and accumulation.

The following optical instruments have been accepted for inclusion in SPICE:

Adolf Thies GmbH&Co KG	Laser precipitation monitor model 5.4110.01.200
Campbell Scientific Ltd	Present Weather Sensor model PWS100
Droplet Measurement Technologies	Meteorological particle sensor
OTT Hydromet GmbH	OTT Parsivel

Given the increasing use of optical sensors for deriving precipitation amount, SPICE will focus on assessing the ability of these instruments to provide representative reports of the amount of precipitation over various time scales. With a lower priority, SPICE will assess the ability of these instruments to report precipitation rate, for solid and mixed precipitation events.

Participating Instruments: Measurement of Snow on the Ground and Snowfall

The 2008 CIMO survey results indicate that only eleven of the fifty-five participating countries were operating automatic instruments measuring depth of snow on the ground and snowfall amount, obtained mostly on the basis of snow depth measurements. In Slovenia, at the time of the survey, the snowfall amount was obtained using forward scattering present weather sensors.

The majority of instruments measuring snow depth are ultrasonic or sonic ranging depth sensors. The sonic ranging sensors measure the elapsed time between emission and return of an ultrasonic pulse sent vertically down to the ground surface covered with snow. Other snow depth instruments operate on the principle of phase variation of visible laser when it bounces off the snow surface.

The following snow depth sensors have been accepted for inclusion in SPICE:

Campbell Scientific Canada	Snow depth sensors model SR50ATH-316SS
ESW GmbH	Snow Depth Sensor, model SHM30/012840-642-22
E.T.G srl	Snow Depth Sensor, model SENULSNIV
Felix Technology Inc.	Snow Depth Sensor, model SL300
Sommer	Snow Depth Sensor, model USH-8

Of these, the sensors manufactured by Campbell Scientific Canada, ESW GmbH, and Sommer have been reported as operational, as part of the 2008 CIMO survey.

Participating Instrument: Measurement of Snow Water Equivalent

One sensor reporting primarily the Snow Water Equivalent has been accepted for inclusion in SPICE. This is the CS725 Gamma Ray Snow Water Equivalent Sensor (previously known as GMON3), manufactured by Campbell Scientific. The CS725 obtains a measurement by monitoring gamma rays, naturally emitted from the ground. As snow accumulates on top of the ground the CS725 measures a decrease in the normal background radiation levels. The higher the water content the higher the attenuation of the gamma radiation.

Configuration of Working Field Reference Systems

The term DFIR (Double Fence Intercomparison Reference) as defined during the previous WMO Solid Precipitation Intercomparison (1989-1993, WMO/TD-No. 872 (1998)) refers to the complete system comprising the octagonal double-fence as well as the Tretyakov gauge placed in its centre. In order to clearly differentiate the octagonal double fence from the complete system, the IOC decided to use the term DFIR-fence when referring to the octagonal double fence only. Furthermore, in order to clearly differentiate the DFIR system from a similar configuration using an automatic gauge in the centre of the octagonal double-fence, the IOC decided to refer to the latter as Double Fence Automatic Reference (DFAR).

For the purpose of the experiment, the IOC defined 3 levels of reference configurations, taking into account the limitations on some of the sites.

The Working Field Reference type R1

It comprises a DFIR-fence with a manual Tretyakov gauge and a Tretyakov shield, adopted as the secondary field reference at the end of the WMO Intercomparison of Solid Precipitation 1989-1993 (WMO/TD-872 /1998). A site with a R1 reference is designated as a S1 type Intercomparison site.

The Working Field Reference type R2

It comprises a heated automatic weighing gauge equipped with a single Alter windshield within a DFIR-fence, together with a capacitive precipitation detector. A site hosting a R2 reference is designated as a S2 type intercomparison site.

The Working Field Reference System type R3

It consists of a pair of identical automatic weighing gauges heated in the same manner, one being unshielded and the second installed with a single Alter shield, together with a capacitive precipitation detector. The configuration of the Alter shield is specified by the SPICE IOC. A site operating only a R3 reference is designated as a S3 type site.

The decision to configure the R3 reference as a combination of a gauge in a single Alter shield and an unshielded gauge is based on the fact that, globally, the operational configurations of instruments for the measurement of precipitation amount are typically either unshielded or have a single shield. These results have been documented in the WMO-CIMO survey conducted in 2008. The same rationale was applied during the first WMO Solid Precipitation intercomparison.

Weighing Gauge used as part of the field reference system

The IOC has approved for inclusion in the working field reference system of SPICE two gauges with wide operational use, and which have demonstrated consistent performance during the tests preceding the formal experiment. These are the Geonor T200-B3, with 3 transducers and capacities of 600 mm or 1000 mm and Pluvio^2, 200 cm^2 inlet opening, with 1500 mm capacity, which is manufactured by OTT Hydromet GmbH.

Reference for the measurement of Snow on Ground and Snowfall

The recommended reference for the measurement of Snow on Ground and Snowfall are manual measurements taken in a predefined configuration (i.e. using snowboards) and supported by an array of ancillary measurements. Additionally, function of the time scale of the observations, a composite reference derived using instruments available would be explored. Additional work is being conducted to refine this reference.

Participating Sites

The fifteen sites designated by the IOC as SPICE sites are located in twelve countries, in the Northern and the Southern hemispheres. The activities on each site will be lead by a Site Manager, who becomes an ex-officio member of the IOC. The participating sites are:

WMO SPICE MAP

Australia

The Snowy Hydro Limited of Australia participates in SPICE with the site Guthega Dam weather station, Kosciuszko National Park, New South Wales, Australia.
The site reference is type R3, using Geonor T200B3 gauges.

Canada

Environment Canada will organize SPICE on 3 sites:

- Centre for Atmospheric Research and Experiments (CARE), Egbert, Ontario; which will operate references type R1 with Tretyakov collector and R2, R3, using Geonor T200B3, 600 mm, gauges.
- Bratt's Lake, Saskatchewan; operating references type R2 and R3, using Geonor T200B3, 600 mm gauges.
- Caribou Creek (Smeaton), Saskatchewan, operating references type R2 and R3, using Geonor T200B3, 600 mm gauges.

Chile

The Centro de Estudios Avanzados en Zonas Áridas of Chile will participate in SPICE with the site Tapado AWS, Valle de Elqui, Región de Coquimbo, Chile.
Given its location, at over 4500 m elevation, the site will focus on the assessment of instruments operating in remote locations. The feasibility of a R3 type field reference is being investigated.

Finland

The Finnish Meteorological Institute will organize SPICE at the Sodankylä Arctic Research Centre (ARC) . The site will operate references type R2, R3, using Pluvio^2, 200 cm2, weighing gauges.

Additionally, the site is a primary location for the assessment of snowfall and snow on the ground, and will operate field references, relevant to these measurements.

Japan

Two sites are being planned to join SPICE in 2013, from Japan:

- The National Agriculture and Food Research Organization (NARO), Agricultural Research Center, with the site Joetsu;
- The National Institute of Polar Research (NIPR), 10-3, Midoricho, Tachikawa, Tokyo with the site Rikubetsu, Ashorogun, Hokkaido.

The details of the configuration of the two sites will be finalised in 2013.

New Zealand

The National Institute of Water and Atmospheric Research Ltd of New Zealand will participate in SPICE with Mueller Hut Electronic Weather Station site, which is part of the National Climate Network. The site will operate a field reference type R3, using Geonor T200B3 gauges.

Norway

The Norwegian Meteorological Institute will participate in SPICE with the site Haukeliseter, Vinjeveien, Telemark, Norway. The site will operate field references type R2 and R3, using Geonor T200B3, weighing gauges, 1000 mm.

Poland

The Institute of Meteorology and Water Management, National Research Institute of Poland proposed two operational synoptic stations for participation in SPICE, Hala Grasienicowa and Zakopane. The two sites are located close together but at different elevations.
The IOC accepted for participation in SPICE the site Hala Gasienicowa, with a focus on the measurement of snow on the ground and snowfall, and operating an appropriate reference.

Switzerland

MeteoSwiss will participate in SPICE with the site Weissfluhjoch (Davos). The site is a partnership between MeteoSwiss and the Swiss Institute for Snow and Avalanche Research (who owns the site).
The site references are type R2 and R3, using a Pluvio^2, 200 cm^2 weighing gauge.

Russian Federation

The IOC accepted the participation in SPICE of Roshydromet with two sites, Valdai, State Hydrological Institute, Valdai Branch, and Voljskaya Hydro Meteorological Observatory (Volga), Gorodec, Nijny Novgorod Reg, Russia.
Confirmation regarding the configuration of site references is expected from the proponent.

United States of America

The National Oceanographic and Atmospheric Administration (NOAA)/Atmospheric Turbulence and Diffusion Division proposed for its participation in SPICE the NOAA/FAA/NCAR Winter Precipitation Testbed (Marshall) site in Boulder, CO.
The site will operate references type R1 with a Tretyakov collector, and R2, and R3 using Geonor T200-B3, 600 mm.

Uzbekistan

The Scientific-Research Hydrometeorological Institute of Uzhydromet proposed for participation in SPICE the site located at the Mountain Kumbel, hole Beldersay, Bostalik district, Tashkent region, Republic of Uzbekistan.

The IOC recognized that installing a SPICE site at this location would require major construction work, time and significant costs. Based on the assessment of the site conditions, the IOC recommended that the proponent cooperates with the proponent from the Russian Federation and enable capacity building in the Scientific-Research Hydrometeorological Institute of Uzhydromet regarding the measurement of solid precipitation and the use of automatic instruments. The recommendation is based on the sharing of a common language and the proximity of the sites.

CHINA

The China Meteorological Administration Committed to participate in SPICE with at least one site. The CMA proposal has not been received at the time of this paper.

Running the Experiment

At http://www.wmo.int/pages/prog/www/IMOP/intercomparisons/SPICE/SPICE.html, WMO hosts on its website a SPICE site, which enables the active communication among all participants and the sharing of information regarding the unfolding of the experiment and the project progress with the entire community.

The first season of the SPICE experiment is the winter of 2013 in both hemispheres, and will run for two consecutive winter seasons, at least.
The project will conclude with the publication by WMO of the Final Report, which will include the results addressing the project objectives based on the results from each of the participating sites and the relative assessment of results for similar configurations in various climate conditions.

Given the duration of the experiment, the broad engagements, and the need to actively engage the community in the validation of the experiment results, the IOC has decided that publications prior to the publishing of the final report are encouraged within the terms of the SPICE Data Protocol.

In the spirit of engaging all SPICE participants in the effective running of the experiment, the IOC has decided to encourage each site host to share with the Instrument Providers the data from the instruments they contribute to the experiment. These datasets will be complemented by a minimum set of ancillary measurements. It is expected that the Instrument Providers will provide feedback on the instrument performance and will work with each site team to ensure the availability of data.

The successful completion of SPICE relies entirely on the coordination of efforts across many time zones and languages. The dedication and engagement of project teams at national and international level will remain the key to achieving the desired outcomes.

REFERENCES:

R. Nitu, K. Wong, 2010, WMO/TD-No. 1544, IOM No. 102: CIMO Survey on national summaries of methods and instruments for solid precipitation measurement at AWS, WMO/TD-No. 1544, IOM No. 102, World Meteorological Organization, 57 p.

B. Goodison, P. Y. T. Louie, and D. Yang, 1998: WMO solid precipitation measurement intercomparison final report. WMO/TD-No. 872, IOM No. 67, World Meteorological Organization, 212 pp.

Sevruk, B.: Spatial and temporal inhomogeneity of global precipitation data. In: M. Desbois and F. Desalmand (eds.). Global Precipitation and Climate Change, NATO ASI Series, **I 26**, 219-230, 1994, Springer Verlag, Berlin.

Report of Meeting, International Organizing Committee (IOC) for the WMO Solid Precipitation Intercomparison Experiment (SPICE), First Session, 5-7 October 2011, Geneva, Switzerland http://www.wmo.int/pages/prog/www/IMOP/reports/2011/Joint_ET-II_IOC-SPICE.pdf

Report of Meeting, International Organizing Committee (IOC) for the WMO Solid Precipitation Intercomparison Experiment (SPICE), Second Session, 11-15 June 2012, Boulder, CO, USA