TT-GSRN Work Plan (2021-2024)

Deliverable 3b – GSRN Pilot Station Requirements

Summary	This document provides the station requirements for the pilot phase. Approved by TT-GSRN at its plenary meeting on 24th June 2022, the document was approved as Annex to decision 6.1(6) on "Process to nominate and implement a pilot GCOS Surface Reference Network (GSRN)" at WMO INFCOM in October 2022.

Version history:

Version	*Date*	*Status*	*Comment*
1.0	March 2022	Draft	Secretariat version
2.0	April 2022	Draft	Secretariat, Chairs and GSRN-LC version
3.0	April 2022	Draft	TT-GSRN Subgroub 4
4.2	24 June 2022	Approved	Approved by TT-GSRN-1
5.0	25 Oct 2022	Approved	Approved by INFCOM-2

Task Team – GCOS Surface Reference Network (TT-GSRN)

Pilot Network Requirements

Version 5.0 – 25 October 2022 (approved by INFCOM-2)

Measurement requirements for the GSRN

This document describes the measurement requirements for the two variables Air Temperature and Precipitation, which are to be used for a Pilot GCOS Surface Reference Network (GSRN), for which WMO members will be requested to nominate stations. In the pilot phase, these requirements will be further refined with the support of the GSRN Lead Centre and detailed requirements for the certification of GSRN stations will be developed.

1 Categories of variables

Measurements will fit into three criteria:

1.1 Mandatory variables (MV):

The mandatory variables must be measured at reference quality (s. 5.1) and must be reported together with an uncertainty budget (s. 5.2).

The two mandatory variables are air temperature and precipitation.

Note: For the pilot GSRN, and to meet the 10-year goals, the concept is to keep the list of mandatory variables limited, both for technical and cost reasons.

Note: The impracticality of measuring one of these variables in certain regions, such as precipitation in parts of Antarctica or the Sahara, will not necessarily mean that a station is excluded from the GSRN.

1.2 Recommended variables (RV):

These variables are recommended to be measured at reference level.

Some of these variables may become mandatory as GSRN evolves over time, e.g. pressure. These recommended variables are being defined.

1.3 Associated quantities of influence (AQI):

These are measurements made at the same site of the reference measurement that are needed to produce a reference measurement of a mandatory variable because they affect the result of the measurement. For example, to have reference air temperature measurements, associated values of solar radiation, relative humidity, precipitation, and wind are also necessary.

The averaging and recording time of the associated quantities of influence must be the same as for the mandatory variable.

Note: From VIM: influence quantity – quantity that, in a direct measurement, does not affect the quantity that is actually measured, but affects the relation between the indication and the measurement result.

Note: AQI is also sometimes referred to as ancillary, auxiliary measurements or simply quantities of influence.

Note: These associated quantities of influence, given they are not to be stored as reference values, do not need to be of reference quality (e.g., lower maintenance and recalibration requirements, no overall uncertainty budgets

quantified). However, a Quality Check (QC) must be constantly applied to those instruments used to generate records of AQI at a GSRN station. The QC must follow the minimum requirements prescribed for field verification[1].

Note: When an AQI is also one of the reference variables measured at the station, then the same recorded values can be used as values for the associated quantity of influence. In the above example for air temperature, the measurement of precipitation as a mandatory variable will therefore be of reference quality, but the remaining AQI do not necessarily need to be. See also section 4.2

2 Station requirements

2.1 Siting

The importance of siting characteristics and instrument exposure cannot be overstated. Siting must be classified by the Siting Classification for Surface Observing Stations on Land in GIMO, Volume I, Annex 1.D (WMO-No. 8) and should meet Class 1. If this cannot be achieved, all possible efforts should be made to improve the classification or at least to ensure that classification level does not deteriorate. See also 5.2.2 Siting measurement uncertainty.

2.2 Metadata

The third GCOS climate monitoring principles (WMO-No. 1160, Appendix 2.2) states:

The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.

Each GSRN station must record, retain and make available observational and siting metadata in accordance with the WMO standard practices as detailed in the WIGOS Metadata Standard (WMO-No. 1192, considering mandatory, conditional and optional elements) and the Guide to the WMO Integrated Global Observing System (WMO-No. 1165).

Annex B contains the minimum station metadata that is required as parts of the pilot network implementation.

2.3 Change management

Long-term (> 30 years) consistency in terms of siting and methods of measurements and observations are of critical importance. However, occasionally there are situations outside of the control of the station operators, or planned improvements that may require some changes. It is important that these are managed and documented carefully and appropriately.

The first and second GCOS climate monitoring principles, (WMO-No. 1160, Appendix 2.2):

The impact of new systems or changes to existing systems should be assessed prior to implementation; and

A suitable period of overlap for new and old observing systems is required.

The period of overlap is dependent on the different measured variable and on the climatic region.

[1] The document "Field Verification of Meteorological Instruments and Sensors - A Guide to Best Practice" being developed by SC-MINT. It includes minimum estimation of uncertainties in the field verification.

For the GSRN the overlap shall be for a period of 24 months and preferably longer. For air temperature the preferred period is 24 months and for precipitation it is 60 months. (GIMO, Volume III, Chapter 1 (WMO-No. 8)).

2.4 Traceability Assurance and Maintenance

To achieve comparability, measurements need to be traceable to recognised standards for the observed quantities.

Ensuring metrological traceability enables full confidence in the validity of measurement results.

GSRN stations are required to meet at least the "Assured traceability level" as described the *Strategy for traceability assurance* in GIMO, Volume I, Annex 1.B. (WMO-No. 8).

Field inspection should be made at regular intervals and/or at need, following for example extreme events or evidence of malfunctioning. The inspection can lead to repair / substitution of instruments.

Field verifications against travelling equipment should be performed also at regular intervals to check instruments' correct working conditions (WMO guidance under development during time of writing[1]). The verification requires a threshold limit for a pass/fail evaluation. Verification failures must be followed by an immediate recalibration.

Calibration should be repeated every year.

The recommended time regimes for field verification, calibration and maintenance are given in the measurement requirement tables in chapter 3 and 4 for the mandatory variables. Longer time intervals should only be considered if warranted by the instruments' quality, their exposure, the environmental conditions of the site, their deterioration over time, and the prescriptions from the manufacturers.

Maintenance of the instruments for the associated quantities of influence must also be undertaken at the same time as for the mandatory variables.

2.5 Measurement redundancy

Measurement redundancy, i.e., the use of multiple measuring instruments, is recommended.

Redundancy represents one way to assess aspects of both traceability and comparability. By using multiple, co-located traceable instruments to measure the same parameter, both the single instrument values, merged instrument values, and the resultant data series can be compared. Disagreement between the data series can highlight measurement problems or sensor drift which would be undetectable with a single instrument.

3 Target measurement requirements for air temperature

3.1 Mandatory Variable – Air temperature

	Air temperature
GCOS ECV Product	Air temperature near Surface
Definition (OSCAR)	Air temperature at a known height above surface, with the height specified in the metadata
Description	Temperature of the air measured between 1.25 m and 2 m from the ground (might be different for specific stations)
Unit	Degree Celsius – Symbol °C
Target system uncertainty[2] (k=2)	0.2 K
Product resolution	Minimum: 0.01 K Recommended: 0.001 K
Maximum calibration uncertainty (k=1)	0.05 K
Maximum drift (k=1)	0.02 K/year
Sampling frequency	10 s
Time constant / response time in air	20 s
Averaging and recording time	1 minute
Calibration regime	Yearly
Verification regime	6-monthly

[2] See Definition Chapter 6.2. The value of the Target system uncertainty corresponds to Class A of the Measurement Quality Classification (INFCOM 1 – WMO-No. 1251, Decision 6). Class A is aligned with OSCAR/Requirements Goal.

Maintenance regime	6-monthly
Redundancy	The threshold requirement is to employ two temperature instruments which will meet the minimum requirements for testing consistency between measurements. The recommended extended requirement is to employ three instruments for added confidence and robustness.

3.2 Associated quantities of influence for air temperature

The value of the Target system uncertainty for the associated quantities of influence correspond to Class C of the Measurement Quality Classification (INFCOM 1 – WMO-No. 1251, Decision 6).

Variable	**Precipitation (liquid and solid)**
Motivation	Precipitation can cause cooling of thermometer solar shields. This results in a negative bias to the temperature records. The effect can last for hours after the end of the precipitation event, due to the cooling effect from water evaporation. Aspirated (fan ventilated) shields can also generate droplets or spray on the temperature sensors lowering the temperature readings. Solid precipitation can accumulate over solar shields causing false readings and significant errors.
Target system uncertainty	Greater of 5 mm or 10% (amount) Greater of 2 mm/h or 15% (intensity)

Note: Given that precipitation is a mandatory variable, the reference requirements take priority, unless the station operator decides to use an extra instrument for AQI. In this case the requirements of the table above can be used.

Variable	**Relative humidity**
Motivation	Water content in air can cause condensation or evaporation forcing heat transfers to and from the sensing element, resulting in errors in temperature measurements.
Target system uncertainty	10 % RH

Variable	**Global solar radiation (upward looking pyranometer)**
Motivation	Incoming solar radiation causes extra heat to the thermometer's solar shields, resulting in positive biases in temperature records.
Target system uncertainty	8% + 55 W/m^2

Variable	**Reflected solar radiation (downward looking pyranometer)**

Motivation	Reflected radiation can cause extra heating to the thermometers. Solar shields should be optimized to protect temperature sensor from direct radiation.
Target system uncertainty	8% + 55 W/m^2

Variable	**Wind (speed and direction)**
Motivation	Wind reduces biases in temperature records due to solar radiation, depending on the relative speed with respect to the thermometer. It also reduces the effect of shield ageing. Conversely, wind can cause cooling if the radiation shield is wet. Wind direction is also required to improve knowledge of siting representativeness, in case of obstacles also at a wider distance than the ones prescribed by the siting classification. Wind speed and direction are fundamental in evaluating local conditions and better understanding temperature extremes. Instruments can be mounted at the same height as temperature instruments.
Target system uncertainty	Greater of 5 m/s or 15% (speed) 15° (direction)

4 Target measurement requirements for precipitation

4.1 Mandatory Variable – Precipitation

	Precipitation
GCOS ECV Product	Accumulated precipitation
OSCAR Variable	Precipitation intensity at surface (liquid or solid)
Definition	Integration of solid and liquid precipitation rate reaching the ground over a time period defined in the metadata.
Definition	Intensity of precipitation reaching the ground.
Description	Integration of solid and liquid precipitation rate reaching the ground over several time intervals.
Description	The measurement unit of rainfall intensity is linear depth per hour, usually in millimeters per hour. Rainfall intensity is normally measured or derived over one-minute time intervals due to the high variability of intensity from minute to minute
Unit	mm
Unit	mm/h

Target system uncertainty (k=2) Target system uncertainty (k=2)	The greater of 1 mm or 2% (liquid) The greater of 0.2 mm/h or 5% (liquid)
Product resolution Variable resolution	0.1 mm 0.1 mm/h
Maximum calibration uncertainty (k=1) Maximum calibration uncertainty (k=1)	1% 0.1 mm/h
Maximum drift (k=1)	1% / year
Sampling frequency	1 s
Starting threshold	0.1 mm/h for liquid precipitation intensity only
Maximum time constant / response time	1 s at event start (for liquid)
Accumulation and recording time	Integrating data at 1 minute Total daily precipitation recorded
Calibration regime	Yearly
Verification regime	6-monthly
Maintenance regime	Monthly
Redundancy	At least two instruments are recommended. However, the instruments used do not necessarily need to be the same type but data management

	practices within the NMHS must enable storing of each instrument's data.

Note: The resolution, starting threshold, and time constant values above are required for measurements in most climates. However, for example it is recognized that in certain tropical/monsoon climates that a tipping bucket gauge with 0.2mm, or even 0.5mm resolution might be more appropriate and will be looked at on a case-by-case basis. Stations within Group A of the Köppen climate classification might fit this criteria. Solid precipitation measurements is another example to be looked at on a case-by-case basis.

4.2 Associated quantities of influence for precipitation

The value of the Target system uncertainty for the associated quantities of influence correspond to Class C of the Measurement Quality Classification (INFCOM 1 – WMO-No. 1251, Decision 6).

Variable	**Air temperature**
Motivation	Air temperature is a useful indicator in determining the likely state (liquid/solid) of precipitation.
Target system uncertainty	1.0 K
QC & Maintenance	Yearly

Note: Given that air temperature is a mandatory variable, the reference requirements take priority, unless the station operator decides to use an extra instrument for AQI. In this case the requirements of the table above can be used.

Variable	**Relative humidity**
Motivation	Low humidity can cause evaporation in the gauge prior to measurement resulting in underestimation of the precipitation amount and/or intensity. The magnitude of the effect is instrument specific.
Target system uncertainty	10 % RH

Variable	**Global solar radiation (upward looking pyranometer)**
Motivation	Incoming solar radiation is useful in determining any biases in timing of precipitation events due to frost melt or melting of solid precipitation.
Target system uncertainty	8% + 55 W/m^2
QC & Maintenance	Yearly

Variable	**Wind (speed and direction)**
Motivation	Wind speed and its direction can introduce positive and negative biases in precipitation records due to turbulences associated with the presence of the instrument structures. The anemometer should be mounted at same height as orifice of gauge, and sited carefully to be unaffected by the wind shadow of the gauge or other obstructions.
Target system uncertainty	Greater of 5 m/s or 15% (speed)

	15° (direction)
QC & Maintenance	Yearly

5 Definitions

5.1 Reference measurements

The result of a reference measurement is a value of an observed quantity that is traceable back to a recognized international standard (SI where possible) and where at a minimum, the uncertainty of the measurement (including corrections) has been determined and the entire measurement procedure and set of processing algorithms are properly documented and accessible.

Note: Reference data can be produced from a single reference measurement, by averaging multiple reference measurements over a specified time period, or by processing reference measurements from multiple instruments (identical or different and also involving different measuring principles).

5.2 Measurement uncertainty

The measurement uncertainty is evaluated according to the GUM (Guide on the expression of uncertainty in measurement, JCGM 100:2008). This describes the current best knowledge of instrument performance under the conditions encountered during an observation and it describes the factors impacting a measurement as a result of operational procedures.

The measurement uncertainty budget includes the contributions from the calibration, site characteristics and quantities of influence. The quantities of influence may be other reference observables at the station or may need to be additionally measured (with standard quality). Corrections can be applied, if documented studies give indications about how to evaluate the correction coefficients/curves and associated uncertainties. Uncorrected and uncalibrated data (direct instrument reading without applying any calibration curves and the corrections from quantities of influence) must be kept.

The three primary steps for managing measurement uncertainty in GSRN are:

1. Describe/Analyse all sources of measurement uncertainty to the extent possible.
2. Quantify/Synthesize the contribution of each source of uncertainty to the total measurement uncertainty.
3. Verify that the derived net uncertainty is a faithful representation of the true uncertainty.

5.2.1 Target System Uncertainty

The target system uncertainty is the maximum uncertainty for a measurand to meet GSRN requirements. The calculation of the uncertainty shall be done according to the WMO Measurement Quality Classification (INFCOM 1 – WMO-No. 1251, Decision 6).

5.2.2 Siting Measurement Uncertainty

The siting measurement uncertainty is defined in the WMO Measurement Quality Classification (INFCOM 1 – WMO-No. 1251, Decision 6) as “The siting measurement uncertainty is the uncertainty associated with instrument exposure, as described in the Siting Classification for Surface Observing Stations on Land (GIMO, Volume I, Annex 1.D, (WMO-No. 8)).”

For the initial GSRN these generalised uncertainties as described in GIMO cannot be applied, because they lack a robust metrological basis. Instead they would have to be calculated site specifically and account for seasonal and diurnal effects. This would require very substantial and in-depth further research which could be carried out in future.

Note: This represents the effects from nearby objects on the environment of the measurement (for example, trees, walls, fences, large areas of water or pavement).

Note: The measurements of the associated quantities of influence might help to support research activities so that these uncertainties can be considered in future re-analysis.

6 Related publications and further reading

The development of these requirements used many existing resources and guidance. Many of these have also been referenced with hyperlinks within the document.

Manuals

I. Manual on the WMO Integrated Global Observing System (WMO-No. 1160)

Guides

I. Guide to Instruments and Methods of Observation (WMO-No. 8), Volumes I, II, III and V

II. Guide to Climatological Practices (WMO-No. 100)

III. Guide to the Global Observing System (WMO-No. 488)

IV. Guide to the expression of uncertainty in measurement (JCGM 100:2008)

Technical documents/technical notes

I. Guidelines on climate metadata and homogenization (WMO/TD-No. 1186; WCDMP-No. 53)

II. Baseline Surface Radiation Network (BSRN), Operations Manual, World Climate Research Programme Publication Series No. 121 (WMO/TD-No. 1274)

III. Guidelines for managing changes in climate observation programmes (WMO/TD-No. 1378; WCDMP-No. 62)

IV. Guide to the GCOS Surface Network (GSN) and GCOS Upper-air Network (GUAN), GCOS Report No. 144 (WMO/TD-No. 1558; 2010 update of GCOS-73)

Guidelines and other publications

I. Climatological Reference Stations: definitions and requirements (to be published)

II. Measurement Quality Classification (INFCOM 1 – WMO 1251, Decision 6) (to be added to WMO-No. 8)

III. U.S. Surface Climate Observing Reference Networks

IV. WIGOS Metadata Standard (WMO-No. 1192)

V. Challenges in the Transition from Conventional to Automatic Meteorological Observing Networks for Long-term Climate Records (WMO-No. 1202)

VI. Guidelines on Surface Station Data Quality Control and Quality Assurance for Climate Applications (WMO-No. 1269)

VII. GCOS Essential Climate Variables and Product Definitions

VIII. The GCOS Reference Upper-Air Network (GRUAN) - Manual (GCOS Report No. 170)

IX. The GCOS Reference Upper-Air Network (GRUAN) - Guide (GCOS Report No. 171)

X. GCOS Surface Reference Network (GSRN): Justification, requirements, siting and instrumentation options (GCOS Report No. 226)

Annex B –GSRN Pilot station nomination form

Please complete the following form for each nominated station separately.

General information					
WMO Member:		Supervising Organisation:		WMO Region of the station:	
Contact person:			E-Mail:		
Address of the Organisation					
Station details					
Station Name:		WIGOS Station Identifier(s):		Alternative Identifier(s):	
Country/territory of the site		Date established:		WMO Program/ Network Affiliation*	
Longitude		Latitude		Altitude amsl. (m)	
Köppen Climate Classification		Terrain feature of the site		Vegetation cover of the site	
Are there any special considerations why the station should be included in the GSRN pilot network?					

Measurement details (s. Annex A)					
GSRN mandatory variable:	**Air Temperature**			**Precipitation**	
Will you provide data of this mandatory variable?	Yes ☐ No ☐			Yes ☐ No ☐	
Describe the type of instrument(s) and its shielding					
Class of the WMO Siting Classification:					
Will you provide data of the **associated quantities of influence** (**AQI**) for the mandatory variable?	Precipitation	Yes ☐ No ☐		Air temperature	Yes ☐ No ☐
	Relative humidity	Yes ☐ No ☐		Relative humidity	Yes ☐ No ☐
	Global solar radiation	Yes ☐ No ☐		Global solar radiation	Yes ☐ No ☐
	Reflected solar radiation	Yes ☐ No ☐		Wind at the height of the precipitation gauge	Yes ☐ No ☐
	Wind	Yes ☐ No ☐		(Wind at another height)	Yes ☐ No ☐
	Comment:			Comment:	
Do you already fulfil the requirements from Annex A for the GSRN mandatory variable and the AQIs?	Yes ☐ No ☐			Yes ☐ No ☐	
	Comment:			Comment:	
If you choose “no” in the above question: Will you be able to fulfil them in future? If not, please explain the reasons.	Yes ☐ No ☐			Yes ☐ No ☐	
	Comment:			Comment:	

Additional Information for the station	
Historical observing records	

Long term assurance of measurements at the station	
Condition for the maintenance of the site and equipment	
Photos of the station looking towards N, E, S, W	
360° panorama photo from the centre of the site*	
Satellite image of the station surrounding (15 km radius) *	

* information is voluntary

General information:

WMO Member:	Member of WMO to which the station belongs
Supervising Organisation:	Organisation responsible for the operation of the station
WMO Region of the station:	Region of the station location
Contact person	Contact person for the GSRN LC to gather additional information about the station
E-Mail	E-Mail of the contact person
Organisational Address	Address of the supervising organisation

Station details

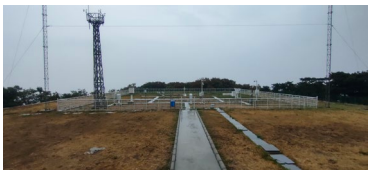
Station Name:	Name of the Station (as used in OSCAR)
WIGOS Station Identifier(s):	WIGOS Station Identifier according to the Guide to the WMO Integrated Global Observing System (WMO-No. 1165), if assigned.
Alternative Identifier(s):	Alternative international or national identifier, if assigned.
Country/territory of the site:	Country or territory in which the station is located.
Date established:	Date since when the station was established to observe meteorological data
WMO Program/Network Affiliation*	Is the station already participating to another WMO Program or network (e.g. GRUAN, BSRN, GCW, GSN, …)
Longitude/ Latitude	Provide the latitude and longitude at the temperature measurement of the nominated station in the form of degree decimal with a resolution of at least 0.001, with the datum specified in GIMO Vol. I, Chapter I, 1.3.3.2.
Altitude amsl (m)	Provide the altitude of the station at ground level in meter above mean sea level with the datum specified in GIMO Vol. I, Chapter I, 1.3.3.2.
Köppen Climate Classification	Provide the abbreviation and name of the climate zone where the nominated station is located, e.g., Cfa: Humid subtropical climate.
Terrain feature of the site	Please describe the surrounding terrain e.g.: "Plain", "plateau", "basin", "hill", "mountain", "coastal", "island", etc. Multiple features can be used, for example, island, coastal.

Surface type of the site	Please describe the main surface type of the station area, e.g. grass, sand, rock
Are there any special considerations why the station should be included in the GSRN pilot network?	GSRN would like to cover all areas around the world, especially stations in data sparse regions are of great value. Please indicate if the nominated station has some unique characteristics (e.g. arctic station, specialised instrumentation)

Measurement details

Type of the instrument and description:	Please describe the instruments you are using to measure the mandatory variable.
Class of the WMO Siting Classification:	Describe, which class the mandatory variable according to the Siting Classification for Surface Observing Stations on Land in GIMO, Volume I, Annex 1.D (WMO-No. 8) has (1 – 5). If it is not class 1, please explain what are the reasons that is not yet achieved or cannot be achieved?
Will you provide data of the associated quantities of influence for the mandatory variable?	Please indicate which AQIs you measure at the station? If you are using the mandatory measurements as the AQIs (Temp, Prec.), please note this as well.
Do you already fulfil the requirements from Annex A for the GSRN mandatory variable and the AQIs?	Please check carefully and indicate whether you are able to fulfil all the requirements for the mandatory variables and the AQIs (e.g. on uncertainties, maintenance and calibration regimes) according to Annex A.
If you choose “no” in the above question: Will you be able to fulfil them in future? If not, please explain the reasons.	If you choose “no” in the above question. Please explain, which requirements

Additional Information for the station

Historical observing records	Explain, since when you gather automatic meteorological measurements that might be useful for GSRN purposes.
Long term assurance of measurements at the station	In order to achieve the objectives of the GSRN a site should be able to ensure sustained operations and preferably provide accurate long-term records (> 10 years) of reference variables. Please explain, if you expect to fulfil this with the nominated station. Do you expect any significant changes to the nearby surrounding of the station that might affect the measurements or their representativity for GSRN.
Condition for the maintenance of the site and equipment	Explain your process to repair or replace the equipment at fault.
Photos of the station looking towards N, E, S, W	The photos should show the whole station equipment as well. Please indicate on the photos the cardinal direction. e.g. East  South  West  North 
360° panorama photo from the centre of the site*	e.g.: 
Satellite image of the station surrounding	e.g.:

(15 km radius) *