REQUIREMENTS FOR OBSERVATIONAL DATA IN THE FRAMEWORK OF THE WMO EARTH SYSTEM APPROACH:

THE ROLLING REVIEW OF REQUIREMENTS

1. Introduction

WMO Members require international observations to fulfil their mandates, which include monitoring and the provision of services. They endeavour to collect and share observations which address their requirements, by each cooperatively agreeing to comply with prescribed arrangements for the operation of WMO observing systems, in the framework of the WMO Integrated Global Observing System (WIGOS). This is an element of the cooperation described in Resolution 1 (Cg-Ext(2021)), WMO Policy for the International Exchange of Earth System Data. The requirements for observations are documented for each of a series of Application Areas in which the observations are directly used.

It is a challenging exercise to develop a consensus view on the design and implementation of WMO integrated observing systems, in particular where the need and implementation occur on global or regional scales. The WMO former Commission for Basic Systems (CBS) has encouraged the development of a process to accomplish this, as objectively as possible. The process is known as the Rolling Review of Requirements (RRR) and has evolved under the WMO Commission for Observation, Infrastructure and Information Systems (INFCOM) to take into account WMO's Earth System approach.

This revised description of the RRR process includes recognition of Earth System Application Categories: Space; Atmosphere, Oceans; Hydrosphere and Terrestrial; and Cryosphere; together with the overall Integrated Earth System. Interfaces are recognized as important areas for activities which have significant requirements for observations. New arrangements are included for collaboration between all the Application Areas within each category – to identify gaps in observing system capabilities and to provide guidance on the most important and achievable priorities for addressing the gaps in that Earth System Application Category.

2. Overview of the Rolling Review of Requirements (RRR) process

In brief, the RRR process compiles information about requirements for observations, about observing system capabilities, and draws on experts and impact studies to provide guidance on the most important priorities for addressing the gaps between requirements and capabilities. The main elements of the RRR process are illustrated in **Figure 1**. Ongoing management of the RRR process is undertaken by the WMO Commission for Observation, Infrastructure and Information Systems (INFCOM) through its Joint Expert Team on Earth Observing System Design and Evolution (JET-EOSDE), supported by the WMO Secretariat in the Observing Networks and Measurement Division of the Infrastructure Department.

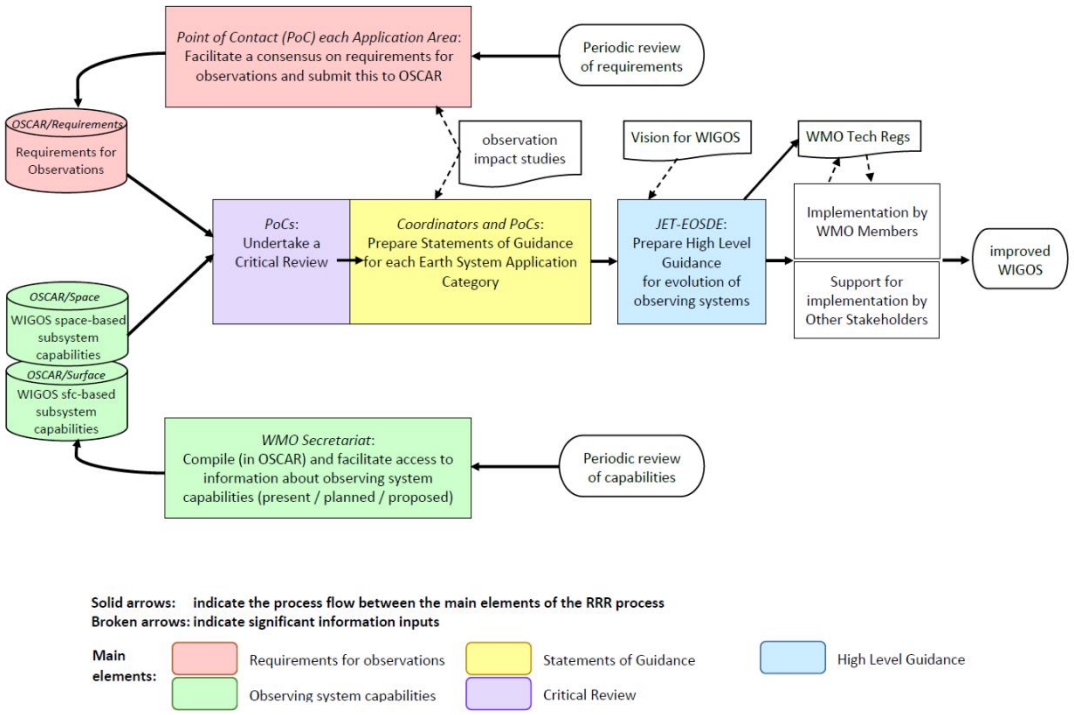

Figure 1. Elements of the RRR process.

The RRR process consists of the following elements:

(a) a review of Members' technology-free[1] requirements for observations, as compiled by the Point of Contact within each Application Area;

(b) a review of the observing capabilities of existing, planned and proposed observing systems, both surface- and space-based;

(c) a Critical Review of the extent to which the capabilities (b) meet the requirements (a);

(d) a Statement of Guidance for each Earth System Application Category based on synthesis of (c) for all Application Areas considered within the category. It is authored jointly by the relevant Points of Contact working together under a Coordinator; and

(e) the High-Level Guidance on the Evolution of Global Observing Systems in Response to the WIGOS Vision (HLG) which compiles key guidance for the next 4 to 5 years taken from all the SoGs in response to the WIGOS Vision.

The aim of the Statement of Guidance is:

(a) to inform WMO Members on the extent to which their requirements are met by present systems, will be met by planned systems, or would be met by proposed systems. The Statement of Guidance is essentially a gap analysis with recommendations on how to address the gaps based on expert judgement and Observations Impact Studies. It also provides the means

[1] Technology-free means that the requirements do not take into account the available technology for making the observations, whether it is surface-based and/or space-based; they are independent of observing system capabilities as far as is possible.

whereby Members, through the Technical Commissions, can check that their requirements have been correctly interpreted.

(b) to provide resource materials useful to WMO Members for dialogue with the agents responsible of implementing observing systems as well as the industry regarding whether existing systems should be continued or modified or discontinued, whether new systems should be planned and implemented, and whether research and development is needed to meet unfulfilled aspects of the user requirements.

The RRR process also feeds information into two key documents. Based on knowledge of:

(a) Strategic direction of WMO and priorities;

(b) Current and planned observing systems;

(c) The gaps identified by the Statements of Guidance;

(d) Which future observing systems are likely to be feasible and affordable,

guidance is provided on the component observing systems to which the WMO community should aspire in:

(a) the "Vision for the WIGOS" for the coming decade(s).

(b) the High-Level Guidance on the Evolution of Global Observing Systems in Response to the WIGOS Vision in the next 4 to 5 years.

These two documents are periodically revised and submitted to the Infrastructure Commission and the Executive Council for approval. Indeed, the whole RRR process is a rolling activity through which all data and documents are periodically reviewed and updated – more details are included in the following sections, but as a general rule all elements of the process need to be completed at least once in each 4-yearly planning cycle of the WMO.

3. Users of observations: Application Areas

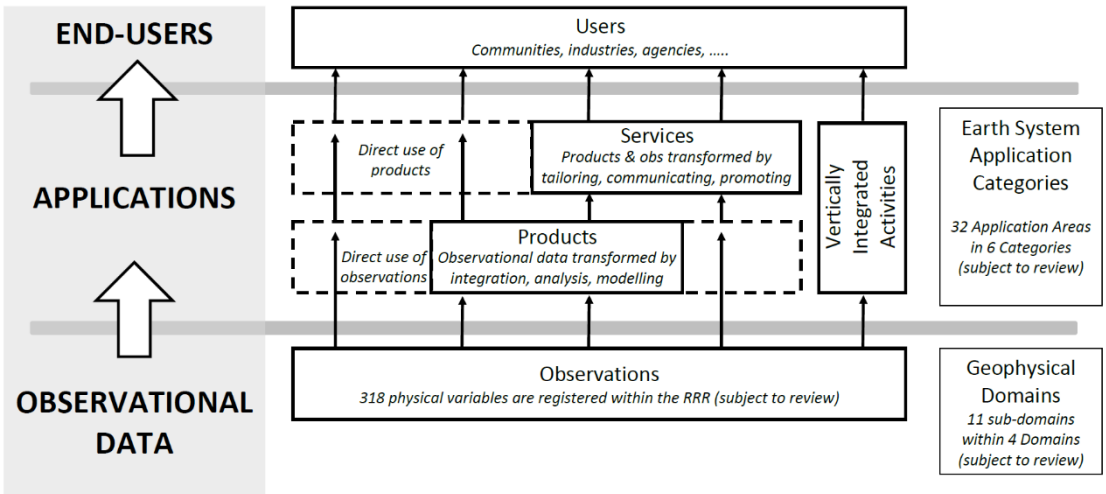

Figure 2. schematic diagram of applications in the value-chain which transform observations into the products and services seen by end-users. Some applications are primarily concerned with

generating products; some applications are primarily concerned with the usefulness of services to end-users; some applications integrate all of these concerns in their activities.

As illustrated schematically in **Figure 2**, end-users of weather, climate and water services benefit from observations but often have little awareness of the role observations play in supporting the products and services they use. To understand user requirements and priorities for observations it is more informative to seek advice from those involved in activities which directly use observations, rather than the end-users.

An Application Area is an activity involving primary use of Earth System observations which allows National Meteorological and Hydrological Services or other organizations to render services related to weather, climate and water, and other environmental events[2], contributing to public safety, socio-economic well-being and development in their respective countries. The concept of a WMO Application Area is used in the framework of the WMO RRR and describes a homogeneous activity for which it is possible to compile a consistent set of observational user requirements agreed by community experts working in this area.

Each Application Area is owned by an identified body which has the authority to (a) designate a Point of Contact, and (b) concur with the observational user requirements in Observing Systems Capability Analysis and Review (OSCAR)/Requirements, and with the gap analysis of the application area provided within a Statement of Guidance. Annex I provides a list of Application Areas and their ownership. This list is kept up-to-date online at https://community.wmo.int/rolling-review-requirements-process

Annex I also shows the groupings of Application Areas in six Earth System Application Categories, and the attributes of each Application Area indicating whether it uses observations for forecasting activities, for monitoring activities, and/or for integrated products and direct use of observations for services.

There are many ways that a list of applications could be constructed. A long list could differentiate in fine detail between numerous applications. The list used in the RRR process represents a balance between granularity/detail and keeping it short enough for the practical feasibility of maintaining the RRR process. Application Areas may be proposed for addition to or deletion from the list as required. Note however that a single Application Area can achieve substantial granularity in expressing its requirements by: (i) stating different requirements in different vertical and horizontal locations, for example across different Regions or local areas; and (ii) using the Comments field in the OSCAR/Requirements database (see Section 5 below) to indicate when a requirement is specific to a particular subset of activities within the overall Application.

Regional aspects of the RRR process are discussed further in Annex II where it is noted that a WMO Region in total is not regarded as an application area because it includes a diversity of activities associated with a range of application areas. Regional experts liaise with the Point of Contact for each relevant application area to collaborate in documenting

[2] In the context of WMO Strategic Plan 2020-2023, the term "weather" refers to short-term variations in the state of the atmosphere and their phenomena or effects, including wind, cloud, rain, snow, fog, cold spells, heat waves, drought, sand and dust storms and atmospheric composition, as well as tropical and extratropical cyclones, storms, gales, the state of the sea (e.g. wind-generated waves), sea ice, coastal storm surges etc. "Climate" refers to longer-term aspects of the atmosphere-ocean-land surface systems. "Water" includes freshwater above and below the land surfaces of the Earth, their occurrence, circulation and distribution, both in time and space. Related "environmental" issues refer to surrounding conditions affecting human beings and living resources, for example the quality of air, soil and water, as well as "space weather" - the physical and phenomenological state of the natural space environment, including the Sun and the interplanetary and planetary environments.

Region-specific requirements, gaps, and priorities for the evolution of observing system capabilities.

Requirements defining which geophysical observations are needed for a certain application, and their associated attributes, are meant to provide information from experts (as compiled by the Points of Contact (PoCs) in each Application Area) to provide guidance to observing systems designers and networks architects to optimize their designs and networks. However, these requirements are currently not prioritized. To provide such information, the concept of prioritization in the RRR process has been developed which can be found in Annex XI.

Note also that, as illustrated in **Figure 2**, Application Areas have many relationships and data flows with each other. Requirements for observations are only to be expressed where there is direct use of the observation in the application activity, otherwise it is left to the upstream activity to express the requirement for the observation.

4. Points of Contact (POC) and Earth System Application Category Coordinators

The RRR process depends on input from each Application Area regarding its requirements and priorities for observations. To obtain this input, an expert in each Application Area is identified to be the PoC. That expert has a very important role as the conduit to the RRR for input and feedback from the entire stakeholder community for that Application Area, through that Application Area owner. Hence it is important for the PoC to provide information on input and feedback processes to their stakeholder community, including Members, Regional Associations, and Technical Commissions and their expert teams. As well as documenting requirements for observations, PoCs are also co-authors of the Statement of Guidance (SoG) for the Earth System Application Category in which their Application Area is active.

The authority for selecting each PoC is with the owner of the relevant Application Area (see Annex I). A list of PoCs is maintained online at https://community.wmo.int/rolling-review-requirements-process

See Attachment 3 for further details on the role of the Points of Contact.

Additionally, in the framework of the WMO Earth System approach, just one SoG is prepared for each Earth System Application Category. The PoCs within each Earth System Application Category must work together as a team of experts to prepare the SoG, under the guidance of an Earth System Application Category Coordinator. The role of an Earth System Application Category Coordinator is to coordinate with the PoCs of the relevant Application Areas to develop the SoG (gap analysis with recommendations on how to address the gaps) of an Earth System Application Category. They are the lead author of the SoG.

A Coordinator is selected from within the team of PoCs in each Earth System Application Category.

See Attachment 3 for further details on the role of the Coordinators.

5. Requirements for observations

One of the main elements of the RRR process, as shown in **Figure 1**, is the compilation of requirements for observations in the Requirements component of the OSCAR tool, known as OSCAR/Requirements. Each PoC consults widely with the community of experts in their Application Area, considers any relevant guidance from Observations Impact Studies, and applies their own expert assessment, in order to establish a consensus view of the requirements for observations, in particular with the body which has been identified as the owner of the Application Area. The PoC then enters into the OSCAR/Requirements database their proposed updates to existing requirements and/or additions of new requirements.

The user requirements are not system-dependent; they are intended to be technology-free. No consideration is given to what type of measurement characteristics, observing platforms or data processing systems are necessary (or even possible) to meet them. The requirements are aimed at the WIGOS Vision time frame.

The basic structure used to record each individual requirement is shown in **Figure 3**. There are three basic elements needed to express a requirement:

(a) the first element is to specify who wants the observation, this is one of the Application Areas together with a comment which may elaborate further, for example to identify a specific activity within the overall Application;

(b) the second element is to specify what the observation is, importantly this combines a geophysical variable with the place/s where it is to be observed within[3] a defined list of 31 vertical layers and 8 types of horizontal coverage;

(c) then the third element is to specify the performance level required for this observation for this user.

Further illustration of the detailed structure of requirements, as they are expressed in the OSCAR/Requirements database, is provided together with some examples in Annex III.

[3] We only expect requirements to be expressed where it makes sense to do so.

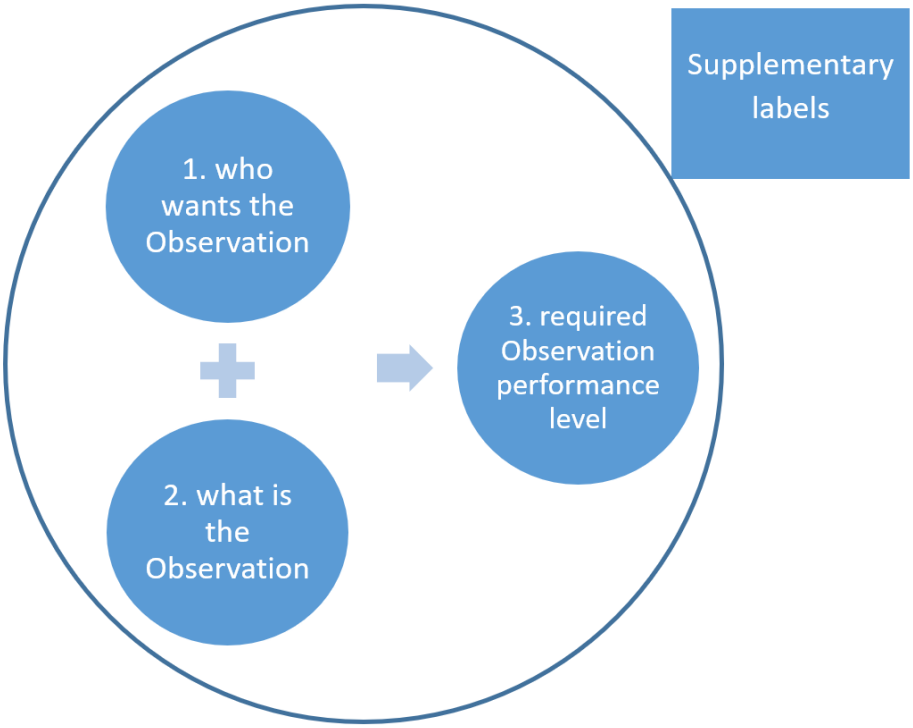

Figure 3. Schematic diagram of the basic structure used to express an observation requirement in the OSCAR/Requirements database.

The required performance levels are stated quantitatively in terms of six criteria, which are :

(a) Horizontal resolution;

(b) Vertical resolution;

(c) Frequency (observation cycle);

(d) Timeliness (delay in availability);

(e) Uncertainty[4] (acceptable RMS error and any limitations on bias), and

(f) Stability (the maximum permissible cumulative effect of systematic changes of the measurement system, to allow long-term climate records compiled from assorted measurement systems – percentage change per decade).

A further two criteria are to be included in the future:

[4] Within the context of WMO Guide No. 8 Guide to Instruments and Methods of Observation and other INFCOM documentation the term uncertainty is aligned to the JCGM_200_2012_VIM: International vocabulary of metrology and JCGM_100_2008_e_GUM: Guide to the Estimation of Uncertainty. These definite of Expanded Uncertainty as a quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand, at a typical 95% confidence level. Within INFCOM this is the definition used when referring generally to uncertainty, rather than the RMS (69% confidence level) quoted here. It is important to take this difference of meaning into account when comparing similar information between OSCAR and INFCOM. It is also noted that most reputable manufactures of instruments, also comply with the GUM, however this needs to be checked on a case-by-case basis.

(a) Layer/s quality (how well the specified vertical layer/s is/are delivered),

(b) Coverage quality (how well the specified horizontal coverage is delivered).

For each Application, there is usually no abrupt transition in the utility of an observation as its quality changes; improved observations (in terms of resolution, frequency, accuracy, etc.) are usually more useful while degraded observations, although less useful, are usually not useless. Moreover, the range of utility varies from one application to another. Therefore, for each of these criteria, the requirement includes three values determined by experts: the "goal", the "threshold", and the "breakthrough".

The "goal" or "maximum requirement" is the value above which further improvement of the observation would not cause any significant improvement in performance for the application in question. The cost of improving the observations beyond the goal would not be matched by a corresponding benefit. The goals are likely to evolve as applications progress and develop a capacity to make use of better observations.

The "threshold" or "minimum requirement" is the value that has to be met to ensure that data are useful. Below this minimum, the benefit derived does not compensate for the additional cost involved in using the observation. Threshold requirements for any given observing system cannot be stated in an absolute sense; assumptions have to be made concerning which other observing systems are likely to be available.

Within the range between threshold and goal requirements, the observations become progressively more useful. The "breakthrough" is an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. Note also that the concept of a "breakthrough" level is different to the concept of the optimum cost-benefit level (see Annex V) since it refers to a significant increase in the value or benefit of an observation without reference to the costs involved.

6. Capabilities of WIGOS observing systems

Another one of the main elements of the RRR process, as shown in **Figure 1**, is the compilation of information about WIGOS observing system capabilities. The ideal situation would be to integrate the capabilities of all component systems in a single database using the same technology-free structure as the requirements database – that is to document which observations are being made by WIGOS (which variables at what vertical locations and horizontal coverage) with what performance level (eight criteria: horizontal resolution, vertical resolution, frequency, timeliness, uncertainty[5], stability, layer/s quality, coverage quality). It is a very complex challenge to derive such information from available information about the various observing technologies being used at many different stations and platforms and facilities, and how they are deployed and operated in many different networks and systems and missions and constellations and fleets. The ideal situation remains an aspiration for the future; for now the relevant

[5] Within the context of WMO Guide No. 8 Guide to Instruments and Methods of Observation and other INFCOM documentation the term uncertainty is aligned to the JCGM_200_2012_VIM: International vocabulary of metrology and JCGM_100_2008_e_GUM: Guide to the Estimation of Uncertainty. These definite of Expanded Uncertainty as a quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand, at a typical 95% confidence level. Within INFCOM this is the definition used when referring generally to uncertainty, rather than the RMS (69% confidence level) quoted here. It is important to take this difference of meaning into account when comparing similar information between OSCAR and INFCOM. It is also noted that most reputable manufactures of instruments, also comply with the GUM, however this needs to be checked on a case-by-case basis.

information is found in several sources and with data structures reflecting the specific technologies, platforms and/or networks.

The Infrastructure Department of the WMO Secretariat coordinates the compilation of observing capabilities data in the two databases shown in **Figure 1**: capabilities of the WIGOS space-based subsystem are stored in OSCAR/Space and capabilities of the WIGOS surface-based subsystem are stored in OSCAR/Surface, keeping track as much as practicable with the addition of Earth System components and interface observations as WMO's Earth System approach is applied. Additional information about WIGOS observing capabilities may also be obtained from other sources.

For the capabilities of space-based observing systems, each of the contributing space agencies has provided a summary of the potential performances of their instruments, expressed in the same terms as the user requirements, together with sufficiently detailed descriptions of the instruments and missions to support evaluation of the performances. Assessment of service continuity is based on the programmatic information supplied. Particular care has been taken to establish a common language, in the form of agreed definitions for the geophysical variables for which observations are required / provided and agreed terminology to characterize requirements and performances.

For the capabilities of surface-based observing systems, observing system operators provide station-by-station metadata in accordance with the WIGOS metadata standard and reporting obligations. The OSCAR/Surface database also obtains some station information indirectly from other databases such as the WMO Radar Database and the Global Atmosphere Watch Station Information System.

A complementary approach for assessing the WIGOS observing capabilities is provided by the monitoring and evaluation components of the WIGOS Data Quality Monitoring System (WDQMS). This provides an in-practice confirmation of the observations that are actually made available to the global NWP centres providing monitoring information for WDQMS (known in this context as WIGOS Monitoring Centres), however careful interpretation is needed since it also reflects the performance of the data communications pathways.

Annex IV provides further information about OSCAR/Space, OSCAR/Surface and the WDQMS.

7. The Critical Review

A further element of the RRR process, as shown in **Figure 1**, is the Critical Review. This represents the first step in comparing WIGOS observing capabilities to the requirements in an objective fashion to identify gaps. If observing capabilities were documented in the ideal manner described earlier, this step could be undertaken as a simple and direct comparison between the databases. In practice, some effort is needed to investigate and understand the observing capabilities in an integrated view and to assess how well they address the requirements.

Some tools are available which provide a more limited but still helpful scope of comparisons. OSCAR/Space is supplemented with a gap analysis tool which assesses the capabilities of various satellite instruments against requirements. The monitoring and evaluation components of the WDQMS provide ongoing assessments of how well actual surface observations meet the planned performance levels.

Currently, each PoC undertakes this Critical Review effort in some form as an initial step in analysing the gaps and priorities for action relevant to their Application Area before drafting their input to the SoG.

8. Statements of Guidance (SoG)

A key element of the RRR process, as shown in **Figure 1**, is the SoG. Each of the six Earth System Application Categories prepares an SoG under the leadership of its Coordinator as the lead author. All the PoCs for Application Areas within each Earth System Application Category contribute as co-authors.

The role of a SoG is to provide a synthesis and interpretation of the outputs of the critical reviews as gap analyses for the relevant application areas, to draw conclusions, and to identify priorities for action. The process of preparing such a statement is necessarily more subjective than that of the critical review. Moreover, whilst a review attempts to provide a comprehensive summary, a SoG is more selective, drawing out key issues. It is at this stage that judgements are required concerning, for example, the relative importance of observations of different variables. These judgements can be enhanced by taking into account the results of observation impact studies (see Annex VI) and considering cost-benefit aspects (see Annex V). The SoG template provides informative guidance on what is required to be included in the document. The template is available online at: [editorial note: hyperlink to be provided once approved and available online; it is available in Attachment 1 for the time being]

The following terminology has been adopted in the SoGs:

(a) "Marginal" indicates minimum user requirements are being met,

(b) "Acceptable" indicates greater than minimum but less than maximum requirements (in the useful range) are being met, and

(c) "Good" means close to maximum requirements are being met.

Since the preliminary SoG were published in 1998, several updates and additions have been completed in order to extend the process to new application areas, to take into account the evolving nature of requirements, and to include the capabilities of surface-based sensors. Also, during 2022, the RRR process has evolved to take into account the WMO's Earth System approach. The latest SoG can be found on the WMO website at: https://community.wmo.int/rolling-review-requirements-process

When reviewing the existing versions, keep in mind that the new Earth System Application Category approach is significantly different from the previous approach in which each Application Area drafted its own SoG.

9. High-Level Guidance for the Evolution of Global Observing Systems

The High-Level Guidance for the Evolution of Global Observing Systems in Response to the WIGOS Vision (HLG), which responds to the Vision for WIGOS (see Annex VII), is a key document providing Members with clear and focused guidelines and recommended actions, in order to stimulate cost-effective evolution of the observing systems and to address the requirements of WMO programmes and co-sponsored programmes in an integrated way.

The HLG is produced by the Infrastructure Commission following wide expert review through the RRR process, looking at SoG for all Earth System Application Categories and their component Applications Areas, taking overall cost-effectiveness into account, as well as WMO priorities.

Progress against actions in the HLG is regularly reviewed and, when necessary, recommended actions are revised or added.

The current version of the HLG is available from the WMO website at: [editorial note: hyperlink to be provided once approved and available online; for the time being it is available as INFCOM-2 INF 6.1(1)]

10. Other RRR outputs and uses

The key outputs resulting from the RRR process are the Statements of Guidance, the High-Level Guidance that builds on them, and less directly the Vision for WIGOS which takes into account the SoGs. These outputs aim to influence the actions of observing system owners, operators, planners and sponsors in all Member countries and other supportive entities as they evolve their observing systems for greater capabilities. Once a new capability is widely implemented – once a strong majority of Member countries have the capability and agree – then it may be added to the Technical Regulations, elevating the capability to a standard practice which all Members are required to adopt or, if the capability and agreement is less widespread, then it may be added as a recommended practice which all Members are urged (but not required) to adopt.

Other products of the RRR – the OSCAR/Requirements, OSCAR/Space, and OSCAR/Surface databases – are also directly useful. For example, the OSCAR/Requirements database provides a direct source of information to surface observing system planners, designers and operators regarding their contributions to the Global and Regional Basic Observing Networks (GBON and RBONs). For RBON, the following standard practices form part of the WIGOS Technical Regulations in the *Manual on the WMO Integrated Global Observing System* (WMO-No. 1160), 2019 edition as updated in 2021:

> *3.2.3.3 Members shall nominate an observing station/platform for inclusion in RBON only if it meets one or more requirements of one or more WMO application areas.*
>
> *3.2.3.6 Members shall design RBONs in response to user observational requirements as compiled in the OSCAR/Requirements database, in consideration of regional needs.*
>
> *3.2.3.7 Members shall each nominate a set of stations/platforms to enable RBONs to meet, at threshold levels or better, the observational requirements of all WMO application areas.*

OSCAR/Requirements is freely available to all for read-only access and there are several tables with filtering, sorting and export options to enhance the useability of the data. Access is available at: https://space.oscar.wmo.int/observingrequirements.

11. Involvement of stakeholders

Success of the RRR process is extremely dependent on the productive involvement of stakeholders. It critically depends on the willingness of Member countries to contribute information about their observing system capabilities and to nominate volunteer experts to fulfil roles, particularly the role of PoC for an Application Area or the role of Coordinator for an Earth System Application Category. It also depends on the willingness of Member countries to consider and act on the published HLG and SoGs, and to report on their actions taken.

The PoC for each Application Area can only carry out the role effectively if the community of experts (applications experts and observing technology experts, including with WMO programmes and co-sponsored programmes) for that application contribute to the compilation of their requirements for observations as well as providing input to the drafting of the SoG. This includes the active involvement of relevant experts from each of the WMO Regional Associations, as is urged in Annex II.

The Infrastructure Commission encourages feedback to the Coordinators from Members, Regions, other Technical Commissions and other stakeholders.

The RRR process is intended to be comprehensive, covering all observation-using activities of WMO programmes and co-sponsored programmes across all WMO Regions and the Antarctic. It should broadly cover all applications, whether global, regional or national, which require international observations. It is important that any deficiencies in this respect are reported back to the Infrastructure Commission so that they can be considered and corrected. More generally, all stakeholders are invited to share feedback regarding any aspect of the RRR process. The following email address may be used for this purpose:

obs-rrr@wmo.int [editorial note: this email address is not functional yet; it will be implemented in due course]

Members and Regions are also encouraged to adopt the concepts of the RRR process when considering observing system developments specific to their own country or region.

Finally, it may be noted that the design, implementation and evolution of WIGOS as a total integrated system depends on the combined efforts of all observing system owners, operators, planners and sponsors. It will not be achieved by relying on the RRR process alone, as discussed further in Annex VIII.