Guidelines on Quality Management in Climate Services

2018 edition

WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

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EDITORIAL NOTE

METEOTERM, the WMO terminology database, may be consulted at http://public.wmo.int/en/resources/meteoterm.

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INTRODUCTION

The World Meteorological Congress, at its fourteenth session in 2003, decided that WMO should work towards a quality management framework (QMF) for National Meteorological Services (Resolution 27). The purpose of the QMF was to provide a comprehensive system of recommended procedures and practices, with regard to quality of data, products and services that should be used by WMO Members in establishing a quality management system (QMS) for the provision of meteorological and hydrological services. The Executive Council, at its fifty-sixth session in 2004, asked the Secretariat to further clarify the scope of the WMO QMF.

The World Meteorological Congress, at its sixteenth session in 2011, recognized that the special emphasis of WMO on service delivery required a renewed effort in documenting all relevant processes from physical measurements in observations to forecasts and the issue of warnings and service delivery to users. The Executive Council, at its sixty-ninth session in 2017, updated the WMO quality policy statement, which articulates that WMO, through its programmes and activities, is dedicated to ensuring the highest possible quality of all meteorological, climatological, hydrological, marine and related environmental data, products and services, in particular, those supporting the protection of life and property, safety on land, at sea and in the air, sustainable economic development and protection of the environment. To achieve this goal, WMO is committed to the adoption and implementation of an organization-wide quality management approach, associated with meeting the WMO main objectives and strategic priorities.

A QMS is an end-to-end system covering all activities from raw measurements and observations to services delivered to end users. It seeks to improve quality and performance so that customer expectations can be met or exceeded, taking into account the National Meteorological and Hydrological Service (NMHS) context as well as interested party expectations and requirements. It is an important part of the climatological practices of NMHSs and plays a key role in driving quality through the whole value chain, from the selection and installation of instrumentation, storage and quality control of data to the production of climatological products and services.

A QMS ensures that all the activities necessary to design, develop and deliver a product or service are conducted effectively and efficiently. It focuses on product and service quality, and also on the means to achieve it. It is possible to achieve consistent quality by utilizing quality assurance and quality control of functions and products. Meeting customer and applicable statutory and regulatory requirements and facilitating opportunities to enhance service delivery drive the system.

Although quality control and quality assurance have long been familiar concepts within NMHSs for ensuring data accuracy and consistency, the broader concept of a QMS, which also incorporates quality planning and quality improvement, may be less familiar and less widely exploited.

The imperatives that drive the adoption of a QMS to the delivery of products and services by NMHSs include the:

— Need for compliance with regulatory requirements
— Need for development of sound management practices
— Increasing pressure to meet stakeholder and customer requirements and expectations
— Requirements of the International Civil Aviation Organization for the delivery of aviation weather services

There is obviously a need for common understanding, as individuals and organizations hold their own perception of the definition of quality. The International Organization for Standardization (ISO), established in 1947 and based in Geneva, provides a set of international standards (the ISO 9000 series) on quality management and quality assurance. These standards were developed to help organizations effectively document QMS elements to be implemented to maintain an efficient quality system. They are not specific to any one industry and can be applied to organizations of any size. The purpose is to provide a management framework for an

organization to comply with applicable requirements, control its processes and minimize their risk, and ultimately satisfy customer needs and expectations. Standard ISO 9001:2015, *Quality Management System – Requirements* (ISO, 2015*b*), sets out the criteria for a QMS and is the only standard in the 9000 family that can be certified. It should be noted that ISO recognized WMO as an international standardization body through ISO Council Resolution 43/2007 (WMO, 2011*c*).

The provision of climate services by NMHSs can be improved by implementation of a QMS, and it is recommended that the ISO 9001 framework is used to achieve this. There is a comprehensive set of WMO Technical Regulations and guidance documents providing a sound foundation for the operation of NMHSs, and ISO 9001 gives a rigorous management framework. NMHSs will therefore be able to identify and meet the requirements of their customers, monitor and measure their own performance, identify opportunities to mitigate risk and find ways to continually improve their service delivery. In so doing, they will be able to undergo an external certification audit process (conducted by an accredited organization), to achieve certification of compliance with ISO 9001.

The *Guide to the Implementation of Quality Management Systems for National Meteorological and Hydrological Services and Other Relevant Service Providers* (WMO, 2017) gives a detailed description of the implementation of a QMS in a meteorological service. The above guide and ISO 9001 should be used in conjunction with the current publication when implementing a QMS. This publication is intended to provide NMHSs with guidelines and best practices for implementing a QMS in their climate services with respect to ISO 9001. It supplements the general documentation provided in the ISO 9000 standards and other publications, focusing on the needs and processes for the provision of climate services and products within NMHSs, including those related to climate data, climate monitoring, climate prediction and service delivery.

Chapter 1 provides a description of the process approach within the ISO 9000 family of QMS standards. Chapter 2 describes the implementation of the process approach in climate services. Chapters 3–6 provide some essential aspects, examples and best practices to be considered when implementing the process approach in climate services processes: climate data, climate monitoring, climate prediction and service delivery. Chapter 7 mentions briefly some steps in obtaining certification.

1. THE PROCESS APPROACH

The process approach is a management strategy that can assist providers of climate products and services to do so in a manner that ensures quality and consistency. It is a powerful way of organizing and managing how work activities can be developed to create value, as it organizes and manages work horizontally so that work activities create customer value. A more traditional structure organizes and manages work activities vertically by function, with quality problems frequently occurring at the boundaries of functional departments.

Using a process approach, it is possible for an organization to work on continual improvement by focusing on its processes. It is much easier to identify areas for improvement, assess the risk of implementing changes and validate that the changes have resulted in improvements to the process by breaking the overall QMS down into smaller processes. This is an important aspect of implementing the process approach because improvement is also one of the quality management principles, and one of the main reasons for implementing a QMS. The provision of climate services is suitable for adopting the process approach, thus making the process approach an effective tool for improving these services. The QMS maps the inputs and outputs with respect to the different processes, as well as the resources needed. Processes can also be monitored to see if they are providing the intended outputs needed to meet customer requirements.

1.1 Benefits

The benefits of a process approach include:

— Improved understanding, definition and integration of interdependent processes
— Integration and alignment of processes to enable achievement of desired outcomes
— Ability to focus effort on process effectiveness and efficiency
— Transparency of operations within the organization
— Help in identifying and allocating resources more effectively
— Decreased costs and creation of shorter cycle times, through the effective use of resources
— Improvement of processes and the overall QMS
— More-consistent achievement of the policies and objectives, intended results and overall performance
— Encouragement for the involvement of personnel and clarification of their responsibilities
— Provision of confidence to customers, and other interested parties, about the consistent performance of the organization
— Facilitation of the implementation of any management system

1.2 Definitions

Standard ISO 9000:2015 (ISO, 2015*a*, term 3.4.1) defines a process as "a set of interrelated or interacting activities that use inputs to deliver an intended result". These activities require allocation of resources such as people and materials. Inputs to a process are generally outputs of other processes. Processes in an organization are usually planned and carried out under controlled conditions to add value. Figure 1 is a schematic representation of a generic process and shows the interaction of its elements. The monitoring and measuring checkpoints, which are necessary for control, are specific to each process and will vary depending on the related risks.

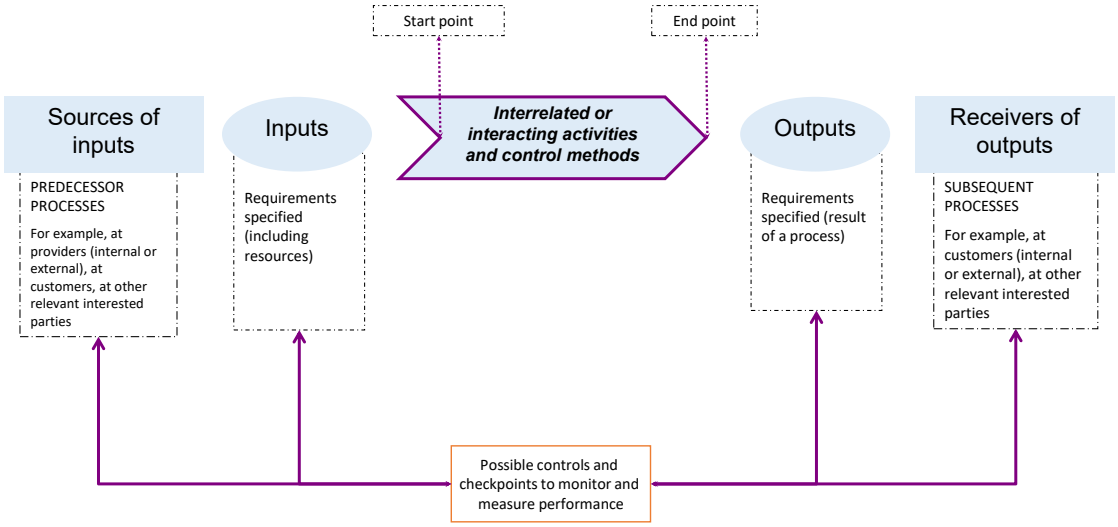


Figure 1. Schematic representation of a process

Source: ISO (2015*b*)

Standard ISO 9000:2015 (ISO, 2015*a*, term 3.7.5) defines an output as the "result of a process" and then goes on to list four general types of outputs: services, software, hardware and processed materials. However, the broad ISO definition indicates that there are many more types of outputs. If an output is the result of a process, then many kinds of outputs (results) are possible, including tangible outputs (such as products) and intangible ones (such as decisions, solutions or information). Therefore, outputs could include services, software, hardware and processed materials, and also others such as instructions, expectations, regulations, requirements, recommendations, complaints, comments or even reports. Clearly, an output could be almost anything (they can also be unintended, such as waste or pollution). Note that an output of an upstream process often becomes the input for a downstream process.

Each process has a customer or customers and other interested parties (internal or external to the organization), with needs and expectations about the process, and who define the required outputs of the process. All processes should be aligned with the objectives, scope and complexity of an organization, and should be designed to add value to the organization.

Process effectiveness and efficiency should be assessed through internal and external review processes. Ideally, a system should be used to gather data to provide information about process performance, which should then be analysed to determine if there is any need for corrective action or improvement.

Each NMHS should define the number and type of processes needed to fulfil its business objectives, and these should focus on the provision of climate services. Standard ISO 9001:2015 (ISO, 2015*b*) is no longer prescriptive in requiring certain processes. The focus has also shifted to documented information rather than records and documents as with the previous standard. This documented information is defined as meaningful data that are required to be controlled and maintained by the organization. The information can be in any format and stored in a way that is effective for running the organization.

Standard ISO 9001 employs the process approach, which incorporates the plan–do–check–act (PDCA) cycle and risk-based thinking. The PDCA methodology can be used to manage processes and systems. It operates as a cycle of continual improvement, with risk-based thinking at each stage:

— Plan: establish the objectives and processes necessary to deliver results in accordance with customer, statutory and regulatory requirements and the organization's policies ("what to do" and "how to do it")
— Do: implement the processes
— Check: monitor and measure processes and products against policies, objectives and requirements for the products and report the results
— Act: take actions to continually improve process performance

The PDCA cycle is a dynamic cycle that can be applied to each of the organization's processes, and also to the system of processes as a whole. It is intimately associated with planning, implementation, verification and improvement. Maintenance and continual improvement of QMS processes can be achieved by applying a PDCA cycle to processes (as shown in Figure 2) at all levels within the organization. These levels range from executive high-level strategic processes, such as business planning or management review, to operational processes such as product realization or calibration.

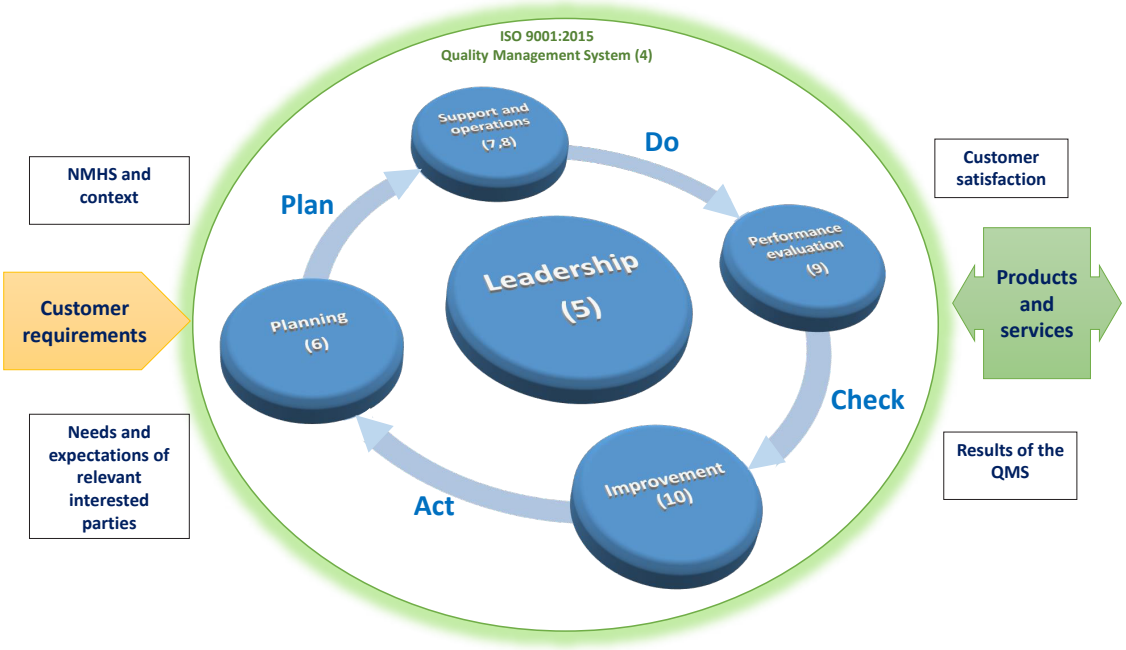


Figure 2. A single process within a QMS managed using the PDCA cycle

Source: ISO (2015*b*)

Risk analysis tools may be employed to identify potential problems in processes. The causes of these potential problems should also be established and eliminated, preventing occurrence in all processes with similarly identified risks. The multiple levels at which continual improvement occurs ensure that QMSs based on the process approach are a powerful way of managing organizations towards achieving performance excellence.

2. IMPLEMENTING THE PROCESS APPROACH IN CLIMATE SERVICES

Organizations can monitor how a process is performing, identify and implement improvements in the process, and check the improvements after changes are made, by using the process approach to define, understand and control the QMS processes.

Standard ISO 9001:2015 (ISO, 2015*b*) does not specify the structure to use for managing the processes (refer to clause 4.4.1). It simply states that an organization must determine the processes needed for the QMS and their application shall:

— Determine the inputs required and the outputs expected from these processes
— Determine the sequence and interaction of these processes
— Determine and apply the criteria and methods needed to ensure the effective operation and control of these processes
— Determine the resources needed for these processes and ensure their availability
— Assign the responsibilities and authorities for these processes
— Address the risks and opportunities as determined in accordance with the requirements of clause 6.1 of the standard
— Evaluate these processes, that is, conduct process performance monitoring and implement any changes needed to ensure that these processes achieve their intended results

The following implementation methodology of the process approach can be applied to an NMHS as a whole, with the provider of climate services within the NMHS aligning to this. Alternatively, the provider of the climate services may want to do this on their own and then link these to the overall NMHS objectives. The step sequence is only one method and is not intended to be prescriptive. Some steps may be carried out simultaneously.

2.1 Preliminary step: identify the processes

Table 1 shows the key steps for defining the processes of an organization and gives some guidance for NMHSs on how to achieve this aim.

Table 1. Key steps for NMHSs when defining their processes

Step	*Action to be taken*	*Guidance*[a]
Understand the NMHS and its context	NMHSs should look at external and internal issues that affect the purpose and strategic direction of either the NMHS as a whole or of the unit/department in the context of the NMHS.	NMHSs need to be aware of how these issues will affect their ability to achieve the intended result(s) of their QMS. NMHSs should consider risks and opportunities related to the context and issues of relevant interested parties (clause 6.1). When determining the scope of their QMS, NMHSs should consider external and internal issues, requirements of relevant interested parties and what products and services they are going to provide.

Step	*Action to be taken*	*Guidance*[a]
Understand the needs and expectations of interested parties	NMHSs should identify customers and other interested parties, as well as their requirements, needs and expectations, to define the intended outputs of the climate services. NMHSs should communicate frequently with customers to ensure continual understanding of their requirements, needs and expectations.	NMHS customer sectors include: media and the public, farmers, defence forces, government departments, business and industry, water and energy sectors, consumers, tourists, legal professionals, health officials, humanitarian and relief organizations, and meteorological services. NMHSs are encouraged to have regular meetings with customers to inform them about the organization's products and obtain feedback about their needs for climate services. NMHSs should consider risks and opportunities related to the relevant interested parties (clause 6.1).
Determine the scope of the QMS	NMHSs should define the scope of the QMS that they want to put in place.	Boundaries as to what is included in the scope of the QMS should be defined. Internal and external issues will provide valuable input into defining the scope.
Define the policies and objectives related to the provision of climate services	NMHSs should establish their policies and objectives with respect to climate services, based on analyses of requirements, needs and expectations.	NMHS top management should develop relevant policies then establish objectives for the intended outputs (for example, products such as forecasts, climate indicators and climate data).
Determine the processes in the provision of climate services	NMHSs should determine all the processes needed to produce the intended outputs and how they interact. Most of these processes exist in NMHSs and include management processes, realization processes and support processes. These processes should be real strategic drivers that will assist NMHSs in achieving their strategic objectives related to climate services.	NMHSs should identify key realization processes including climate data, climate prediction, climate monitoring and service delivery realization processes. All process inputs and outputs, along with suppliers, customers and other interested parties (who may be internal or external), should be identified. NMHSs should look at the sequence and interaction of processes, and how they are going to ensure effective operation and control of these processes. The resources needed to execute the processes should also be considered, with clearly assigned roles and responsibilities for these processes. NMHSs also need to be mindful of any risks or opportunities linked to operation of the processes. Ways to evaluate and improve processes should be understood. Methods and tools, such as block diagrams, matrices and flow charts, can be used to support the development of process sequences and their interactions.

Step	*Action to be taken*	*Guidance*[a]
Define process ownership	It is critical for NMHSs to have an overall process manager or process owner with end-to-end responsibility and accountability for all aspects of process performance. To manage process interactions, it may be useful for NMHSs to establish a process management team that has overview across all the processes, and which includes representatives from each of the interacting processes. The process manager needs to understand the entire process and have the authority to make changes in any part of it. It should be clearly articulated within the process manager's job description/responsibilities that they are authorized to make changes to facilitate improvements.	NMHSs should ensure QMS training is provided to the process management teams on process improvement techniques and their role within the organization. Training should also be provided on how to analyse data, investigate causes of process issues, identify risks and opportunities, and take effective corrective action. The process manager is responsible for: — Forming a cross-functional team that includes representatives from each major part of the process — Ensuring the process operates in a controlled state of predictable performance — Establishing process performance measures that adequately characterize the efficiency and effectiveness of the process in meeting the needs of all customers
Determine the need for documented information	Document management is typically the most challenging aspect of ISO 9001 compliance. However, once implemented, it provides many benefits in terms of the overall effectiveness of the QMS. Starting with a simple, versatile, structure provides the best opportunity to organize documentation and effectively orient the workforce. NMHSs should determine those processes that are to be documented and how they are to be documented, on the basis of risk-based thinking, including, for example: the complexity of the processes and their interactions, the criticality of the processes and the need for formally accountability of performance. The main purposes of documentation are to enable the consistent and stable operation of processes and for product traceability. When it is necessary to document processes, different methods can be used such as graphical representations, written instructions, checklists, flow charts, visual media or electronic methods. It is up to the organization to determine the correct amount of documented information needed to demonstrate effective planning, operation and control of its processes and the implementation and continual improvement of the effectiveness of its QMS. NMHSs should determine which processes need to be documented.	NMHSs should develop documented procedures describing how they carry out their work. They should ensure the availability of: — Documented information needed to be maintained by the organization for the purposes of establishing a QMS (high-level transversal documents) including the scope of the QMS (clause 4.3) — Documented information necessary to support the operation of processes (clause 4.4) — The quality policy (clause 5.2) — The quality objectives (clause 6.2) NMHSs should also ensure that the documented information is subject to the requirements of clause 7.5. Appendix 1 below gives a list of documented information required by ISO 9001:2015. NMHSs may not be the sole providers of climate and climate-related services in a country. The definition of roles and responsibilities of providers, agreements on standards and minimum requirements for the production of services and the identification of quality control procedures to facilitate the interface with users need special attention. For further information, refer to clause 8.4.

[a] Note that clause numbers in this column refer to those in standard ISO 9001:2015 (ISO, 2015*b*).

Once the processes needed for the QMS and their sequences and interactions have been identified, it is necessary to establish management responsibilities and accountabilities for the performance of these processes. Many methodologies are available, but all share some simple basic elements. Each individual process can be improved by applying a PDCA approach. The latest approach is a model for improvement that is sustained, which is why it is applied to the ISO 9001 standard. A simple process management and improvement methodology for climate services processes, based on PDCA (as shown in Figure 2) and organized in a series of five steps, is described below.

2.2 Steps for implementing the process approach

2.2.1 *Step 1: plan the process*

To plan the process, it is necessary to:

— Determine the interfaces, risks and activities within the process
— Define the resources needed
— Identify customers and their requirements
— Define the monitoring and measurement requirements

Table 2 provides the key steps and guidance for NMHSs when planning climate services processes.

Table 2. Key steps for NMHSs when planning climate service processes

Step	*Action to be taken*	*Guidance*
Determine the interfaces, risks and activities within the process	NMHSs should document all processes. The documents should be reviewed regularly and updated as soon as changes are made to the processes. The process manager and process management team need to carefully define the processes so everyone working within them has a good understanding of how they operate. In particular, NMHSs need to: — Define the required inputs and outputs of the processes and identify the proceeding process if the output is the input of a proceeding process — Determine the activities required to transform the inputs into the required outputs — Determine and define the sequence and interaction of the activities within the processes — Determine how each activity will be performed Note: In some cases, the customer may specify the way a process is to be performed. (Appendix 2 below gives a generic process description template.)	The following aspects should be established by NMHSs: — Process goals based on the NMHS quality objectives — Process inputs (information, materials and supplies), outputs and customers (who may be internal or external) — Interactions with sources that provide the inputs (internal processes or external suppliers) and users of the outputs (internal processes or external customers), or that provide the resources (internal support process) to perform the process activity — The nature, method, frequency and timing of interactions with other processes and where these interactions will occur (inputs, outputs, uses of resources, conversion activities and so on) — Process objectives, performance indicators and methods to monitor and measure process performance against these objectives and indicators — Formal measures of effectiveness that are reported as part of top management meetings and management review — Formal documentation of the process and its activities; many quality tools, such as block diagrams and flow charts, are available to support these activities — Identification and documentation (if needed) and process documentation (such as procedures, forms, work instructions or specifications) that may be needed to produce the output — Identification of competencies of personnel that will ensure process activities (individual roles should be defined) — Report resources such as facility, equipment, labour, materials and time needed to produce the output — Definition of controls to prevent or eliminate risk of errors, omissions or non-conformities in process activities (controls may come from the ISO standard, customer, regulatory and the organization's requirements) — Statement of what documented evidence is required to show the process is effective (See items 4–12 in Appendix 2.)

Step	*Action to be taken*	*Guidance*
Define the resources needed	NMHSs should determine the resources needed for effective operation of each process. Examples of resources include: — Human resources — Infrastructure — Environment for the implementation of processes — Information and communication technologies — Information and knowledge — Materials — Financial resources Human resources are most important and should be given attention. Staff should be trained to implement the process procedures, which need to be reviewed continuously, and to contribute to the implementation and improvement of the QMS. A staff training programme should be in place to ensure competencies.	NMHSs should ensure that all employees have ready access to and become familiar with the QMS. Climate service providers should seek to partner with other organizations to acquire the requisite training for their personnel (for example, WMO Regional Climate Centres). Exchange of personnel among NMHSs and other organizations involved in the provision or delivery of climate services could assist in capacity development. Refresher training should be ongoing within any NMHS providing climate services. Professional and technical staff should be trained and certified according to the relevant WMO standards (covered by item 7.1 in Appendix 2).
Identify customers and their requirements	NMHSs should carefully gather, analyse and document customer needs, including how customers use outputs of the process. Understanding how the outputs are used can lead to their improvement. Equally important is the ability to identify an output that is not required. For example, if a report is an output of the process, and this report is not used or not needed as a record of the process effectiveness, then the effort to create this report is wasted and the resources can be used more efficiently elsewhere. NMHSs should also identify which elements are contributing to customer satisfaction, including: services other than the product itself, documentation, a hotline, commercial contacts, assistance, delivery time, product accessibility and training.	NMHSs should ensure that user requirements feed into the development of climate services to make them appropriate and demand driven. Customer requirements should be the focus of the development of climate services (WMO, 2018). This is best achieved through constant interaction with all stakeholders. These interactions should give the provider a clear understanding of the present and future requirements of users and give the users a knowledge of what can be provided. Users also need to be made aware of the meaning and usefulness of products. Management should ensure that customer requirements are determined and met, with the aim of enhancing customer satisfaction (covered by item 8 in Appendix 2). Feedback mechanisms such as surveys and consultations should be put in place to monitor user satisfaction.

Step	*Action to be taken*	*Guidance*
Define the monitoring and measurement requirements	NMHSs should directly link process performance measures with customer needs – this is one of the most powerful aspects of process management. There is a need to translate customer needs and requirements into measures of process performance and include customer satisfaction, in-process measures and measures of supplier performance. NMHSs should determine where and how monitoring and measuring should be applied. This should be for control and improvement of the processes and the intended process outputs. Monitoring is always applicable, but measurement may not be practicable or even possible. Nevertheless, measurement gives objective data on the performance of the process, and it is a powerful management and improvement tool. Performance indicators may relate to the process output as well as the process activity. Performance indicators for process outputs must focus on meeting customer and regulatory requirements.	NMHSs should ensure, as far as possible, that versions of the same product emanating from different sources are identical. Performance indicators for process activity should focus on measuring process effectiveness and efficiency. They can include the following: — Conformity with requirements — Defect or error rates — Reviews of performance — Satisfaction of interested parties — On-time delivery and lead times — Failure rates and waste — Incident frequency — Supplier performance The process approach is one of the strongest approaches for integrating management system standards because each process must be managed and improved simultaneously for all process performance measures (covered by item 13 in Appendix 2).

2.2.2 ***Step 2: implement and measure the process***

Once the process is planned, the next step is implementation. The organization may develop a project for implementation that includes:

— Communication
— Awareness
— Training
— Change management
— Management involvement
— Applicable review activities

Then, controls should be applied, and monitoring and measurements performed as planned.

2.2.3 ***Step 3: monitor and analyse the process***

At this stage, analysis and evaluation of process information obtained from monitoring and measuring data are crucial for quantifying process performance. The results of process performance information should be compared with the defined requirements of the process, to confirm process effectiveness and efficiency and to identify any need for corrective actions.

This step is also an opportunity to identify critical process improvement opportunities based on results of the analysis of process information and gaps in process performance, especially through performance of process reviews. Decisions resulting from management review, top management meetings, and internal and external audit reviews should be considered as inputs for process review. Then, the performance of the process should be reported to top management and other relevant people in the organization, as appropriate.

2.2.4 ***Step 4: improve the process – corrective actions***

NMHSs should establish corrective action systems to prevent problems from recurring, as well as a system to measure customer satisfaction, process effectiveness and product conformity. It

is recommended that climate service providers conduct regular self-audits (internal audits) and undertake corrective actions as soon as possible to address the non-conformities that may arise out of these audits. A significant benefit of process management is its natural fit with process improvement. Once process performance has been compared with customer requirements, process improvement is the natural next step through using gaps in process performance versus customer needs to determine critical process improvement opportunities.

Process effectiveness and efficiency can increase as a result of process improvement activities. Once process improvement opportunities are identified, any of the many quality improvement methods can be used to improve process performance by selecting the process improvement opportunity to pursue. This selection should take into account attributes such as:

— Criticality of certain improvement needs
— Difficulty of improvement opportunities
— Availability of resources and expertise

Whenever corrective actions are needed, the method for implementing them should be defined. This should include identification and elimination of the causes of the problems (for example, errors, defects or lack of adequate process controls). The effectiveness of the actions taken should be reviewed. Once the corrective actions have been implemented, the changes should be documented and their effectiveness verified.

The method for improvement should be defined and implemented. Examples of improvements include: process simplification, enhancement of efficiency, improvement of effectiveness, automation and reduction of process cycle time.

Even when planned process outputs are being achieved and requirements fulfilled, NMHSs should still seek to improve process performance, customer satisfaction and reputation. They should focus efforts on actions to improve process performance to higher levels, on a continual basis. This can be achieved, for example, by small continuous improvements, breakthrough improvements and/or by innovation.

2.2.5 *Step 5: assess and address risk*

When planning a QMS, it is important that an organization determines the risks and opportunities that need to be addressed, to:

— Give assurance that the QMS can achieve its intended result(s)
— Enhance desirable outcomes
— Prevent, or reduce, undesired effects
— Achieve improvements

This is in accordance with ISO 9001:2015 (ISO, 2015*b*), clause 6.1. NMHSs also need to action plans to address these risks and opportunities and to evaluate the effectiveness of these actions. Risk analysis tools may be employed to identify potential problems. The cause(s) of these potential problems should also be identified, documented and eliminated, preventing occurrence in all processes with similarly identified risks. The PDCA methodology can be a useful tool to define, implement and control corrective actions and improvements.

Risk is commonly understood to be negative. Opportunity can also be found in risk-based thinking – this is sometimes seen as the positive side of risk. Risk-based thinking is already part of the process approach. It can be set up through the following actions (as shown in Figure 3):

1. Identify the process risks and opportunities;
2. Analyse and prioritize the risks and opportunities;
3. Plan and schedule actions to address the risks and implement them, then take action;
4. Implement the plan, then take action;
5. Control and check the effectiveness of the action;
6. Learn from experience.

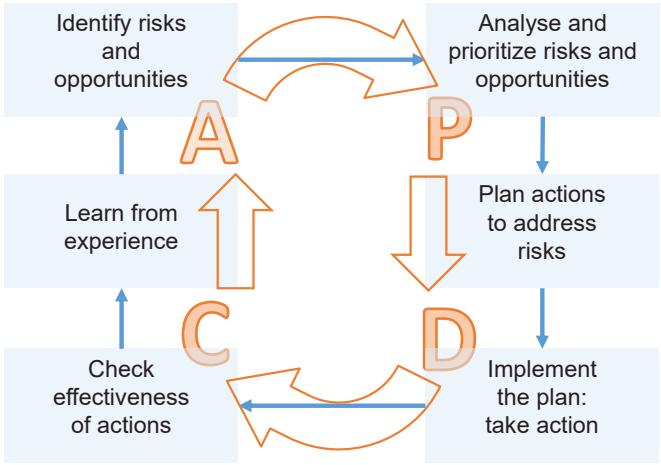


Figure 3. Process risk management steps

Source: Bureau Veritas (2015)

The next four chapters provide guidance on how to adopt the process approach in the following climate service processes:

— Climate data
— Climate monitoring
— Climate prediction
— Service delivery

3. QUALITY MANAGEMENT IN CLIMATE DATA

The climate data process is one of the key realization processes in NMHSs. Reliable climate data and products are key inputs to many economic sectors, stakeholders and government institutions, who increasingly rely on them for their decision-making. It is imperative that accurate and reliable data be accessible in a timely manner. The value of such data and information (WMO, 2010*b*, 2014*b*) increases when they are provided by organizations that have established and adhere to quality management principles.

The need for more-accurate and timely information continues to increase rapidly as the diversity of user requirements carries on expanding. It is in the interest of every NMHS to adopt and apply consistent practices in performing climate observations, in handling and managing climate records and in maintaining the necessary quality and utility of the climate services provided.

The product realization processes must be planned, implemented, analysed and improved, taking into account many aspects such as: customer requirements, quality objectives for the products, activities to create the products, product documentation, provision of verification and validation for product design and development, and provision of monitoring activities specific to the products. As with the processes of a QMS, it is important to understand the suppliers, inputs, activities, outputs and customers for each process. Each realization process should be monitored, measured and analysed.

Following the step methodology described in the previous chapter, the subsections below provide best practices for implementing quality management in a climate data process and also guidance on the process activities.

Define process ownership

It is advisable that the owner of the process be a member of the NMHS management team. It is also recommended to designate a cross-functional team to work with the process manager to oversee the process on an ongoing basis with members from NMHS observing programmes, regions and head office. It would be also beneficial to have a representative from interrelated processes that provide inputs and use outputs. NMHSs are also encouraged to have a process manager from the regional level on the team if any processes are to be performed at a regional level within their countries.

3.1 Plan the process

3.1.1 *Define and describe process activities*

NMHSs should ensure that the procedures, manuals, work instructions and external documents related to the climate data process are legible, and are quickly and easily retrievable for all climate service staff. The Internet is one of the most important tools for accessing updated documents when changes occur. It is advisable to record contact details of all stakeholders involved in the process so that they can be informed about any changes.

The internal documents of an NMHS should follow the correct procedures applicable for the control of documents for the QMS. Every process should be documented, and the documents should be reviewed regularly and updated as soon as changes are made to the process.

NMHSs should address the important aspects related to data management in accordance with WMO standards, regulations and best practices for climate services, when describing the climate data process. Careful attention should be given to allocating adequate resources, to ensuring that the process is effective in meeting its objectives and to delivering the intended outputs.

The generic flow chart in Figure 4 shows the main activities to be undertaken by an NMHS in the climate data process. Each NMHS should provide specific detail for each activity, in a manual or work instruction, taking into account NMHS practices and local specifications.

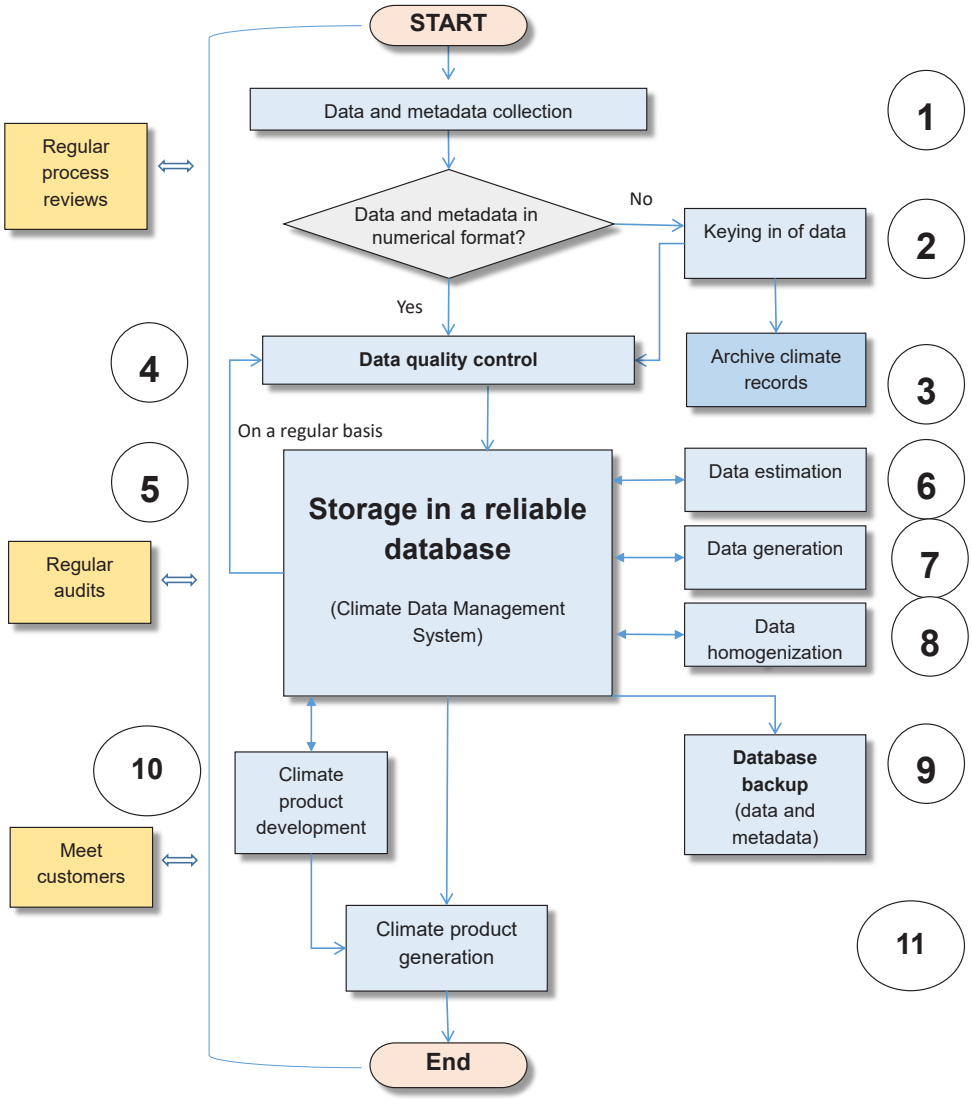


Figure 4. Main activities in the climate data process

Source: Based on activities at the National Meteorological Office of Morocco

Note: The *Guide to Climatological Practices* (WMO, 2011*a*) gives detailed guidance regarding the collection, processing and publication of climatological data. The same guide (WMO, 2011*a*), the *Guide to Meteorological Instruments and Methods of Observation* (WMO, 2014*c*), and the *Guide to the Global Observing System* (WMO, 2010*a*) give detailed guidance regarding the establishment, maintenance and update of metadata (metadata are of crucial importance in interpreting measurements and observations). WMO *Technical Regulations* comprise standard and recommended practices and procedures that NMHSs need to follow or implement, and which should be adhered to when developing a process.

3.1.2 *Collect climate data*

Climate data include observations of a variety of meteorological and other relevant phenomena, and also details of how and where observations were made and the conditions that they were made under. Once observational data are acquired, they must be managed and a process outlining how this is to be done should be mapped.

NMHSs should establish, maintain and update explanatory metadata and ensure data homogeneity. Data homogeneity is very important for the calculation of climate normals and averages (see Chapter 4 on climate monitoring). An adequate set of metadata must be available to inform future users about the nature of the data in the system, how the various datasets were collected and any inherent problems. Researchers and other expert users of climate products are also keenly interested in metadata to help interpret and analyse data homogeneity and quality. The *Guidelines on Climate Metadata and Homogenization* (WMO, 2003) provide a detailed treatment of station-specific metadata.

NMHSs should collect, conduct quality control on and process data from a selection of representative high-quality stations for climatological purposes on at least a monthly basis (WMO, 2015*c*). Members should carry out collection, maintenance and transfer of climatological data and records (WMO, 2010*c*).

3.1.3 *Perform quality control of climate data*

Product quality control is an integral component of the ISO 9001 framework. Quality control procedures are applied to detect and identify errors made in the processes of recording, formatting, transmitting and archiving data. Knowledge of the applied procedures will allow assessment of the validity of the observations and improve data usage.

NMHSs are responsible for performing quality control on their climate data. Quality control is a concept that is very familiar to NMHSs as a tool for improving data accuracy and reliability. The purpose of the control of data quality should be error detection, possible error correction and error prevention, to ensure that the data meet and/or exceed the stated standards of accuracy and precision for their optimum use by as many users as possible. Error detection should also lead to investigations of the cause and what actions can be taken to prevent it from occurring again.

NMHSs should implement minimum standards of quality assurance/quality control at all levels on a regular and systematic basis (WMO, 2003, 2011*a*). In particular, NMHSs should have on-site quality control for climate data where possible, such as at synoptic stations (WMO, 2010*a*, 2015*c*). Delayed quality control can be implemented at an NMHS archiving centre.

If manuscript records constitute the source document, trained personnel should, upon receipt at the archiving centre, scrutinize them before any digitization takes place. Methods and procedures must be documented and applied so that all manuscripts of a certain type are treated in the same manner. When observed data are available in digital form, the archiving centre should subject them to full, elaborate quality control procedures on a regular and systematic basis.

All observations should be appropriately flagged to indicate the level of quality control applied to the data. The quality flag should indicate the different stages of quality control that a given value went through. This includes differentiating whether it went through extended quality control procedures or only basic ones, or no quality control at all. Corrections or estimations should be clearly flagged before being entered into the database. However, the original data must also be retained in a database. Quality control procedures and algorithms should be documented in detail for each stage of data processing, from observation through to archiving.

3.1.4 *Manage, generate and back up data*

NMHSs should manage their climate data in accordance with WMO best practices (see *Climate Data Management System Specifications* (WMO, 2014*b*) for comprehensive details). Data management includes metadata maintenance, keying or ingestion of data and metadata, data storage, data estimation, data quality control, data processing, data homogenization, handling of missing values, computation of climate normals and derived fields such as relative humidity.

NMHSs need to have a climate database management system (CDMS) that is compliant as far as possible with the requirements of the *Climate Data Management System Specifications* (WMO, 2014*b*). This is a required tool for managing climate data and facilitating data retrieval and analysis.

NMHSs should set up and implement a backup procedure for all climatological data (including metadata) to secure the climate dataset. All aspects of the CDMS should be archived, including the data values and also catalogues, inventories, histories, dictionaries and other similar information. Such a data backup strategy should include regular off-site backups.

NMHSs should ensure that climate document archives are secured and protected against physical hazards such as fire and excess humidity. Electronic databases should be protected against cyber hazards such as virus attacks, unauthorized access or editing. Data management, data generation and backup/restore procedures should be documented.

3.1.5 *Homogenize data*

Many homogenization methods are widely used by various international research institutions. Recommendations for homogenization of monthly, seasonal and annual data are summarized in the *Guidelines on Climate Metadata and Homogenization* (WMO, 2003), which describe the requirements for station metadata and homogeneity and the recommended methodologies. NMHSs should ensure that the processes for the availability of updated, homogenized climate datasets with complete and relevant metadata are documented and that staff who are tasked with conducting such work are well aware of the procedures.

3.1.6 *Archive and rescue data*

Each NMHS should establish and maintain a data rescue programme if all records are not in digital format. A maintenance programme should then be established to rescue deteriorating documents and particularly the data they contain. The data rescue objective should be clearly communicated to all relevant staff involved in those activities. The *Guidelines on Best Practices for Climate Data Rescue* (WMO, 2016*b*) provide valuable information for NMHSs drawing up data rescue programmes.

NMHSs should maintain an archive of all climate records, ensuring that documents and records can be accessed and retrieved with ease, and processes linked to this work should be established.

3.1.7 *Ensure traceability of products*

It is a requirement for nearly all products produced by NMHSs that each product must be traceable to the version of the data from which it was created, along with details of items such as station location and time of data receipt/product issuance. This also means keeping detailed records of the product history. A product can be identified by providing a serial number, but effective traceability means that it would be possible to provide the history of that product and how it was produced.

3.1.8 *Improve personnel competency and develop capacity*

Competent and experienced staff should be identified with respect to WMO categories of personnel and competencies (WMO, 2015*d*), for each activity of the process. Staff should be trained to implement the process procedures.

Professional and technical staff should also be trained and certified according to the relevant WMO standards. Support staff should be suitably qualified for the tasks they may be required to perform. It is important that a schedule be implemented for re-evaluation of the competencies of all professional/technical staff, and deficiencies identified should be corrected as soon as possible. The entire re-evaluation process of each officer should be properly documented.

Training and certification of staff at all levels should be an ongoing process in order to maintain a pool of competent personnel at all times and to allow seamless succession planning. Refresher training should be ongoing within any organization or section providing climate services. NMHSs in climate-vulnerable developing countries should give priority to developing capacity. NMHSs have to determine the necessary competencies for such staff. The *Guidelines for the Education and Training of Personnel in Meteorology and Operational Hydrology, Volume I: Meteorology* (WMO, 2002) give high-level guidance on the training needs of managers and key staff in meteorological offices.

NMHSs should maintain records of the education and training of their personnel as part of their QMS, for their human resource development activities and for auditing purposes, where appropriate, in accordance with the *Guide to the Implementation of Education and Training Standards in Meteorology and Hydrology, Volume I – Meteorology* (WMO, 2015*b*).

3.1.9 *Identify customers and their requirements*

Standard ISO 9001:2015 (ISO, 2015*b*) does not include any product requirements. Customers, WMO standards and regulations, and NMHSs specify these requirements.

User requirements should be the focus of development and operation of climate services. This is best achieved through constant interactions with all stakeholders (WMO, 2018). These interactions should give NMHSs a clear understanding of the present and future requirements of users, and the users a knowledge of what can be provided. The users also need to be made aware of the meaning and usefulness of the products. NMHSs are encouraged to maintain inventories of the data contained in their CDMS, and they should update them routinely because customers often want access to this type of information.

For WMO Members, the obligation to share data and metadata with other Members, and the conditions under which these may be passed to third parties, are covered under Resolution 40 of the Twelfth World Meteorological Congress (WMO, 1995) and Resolution 60 of the Seventeenth World Meteorological Congress (WMO, 2015*a*). Among the climatological data that should be shared by NMHSs are CLIMAT messages. These reports should be available not later than the fifth day of the following month to which the data refer. The *Handbook on CLIMAT* and *CLIMAT TEMP Reporting* (WMO, 2009) describes the coding and reporting procedures. Use of agreed-upon international standard formats for data exchange is critical. NMHSs should document how they will meet these obligations in a data policy as well as the state that station data will be supplied to WMO in terms of CLIMAT messages.

In addition, NMHSs should establish normals (including climatological standard normals) and periodically revise them as appropriate, for stations whose climatological data are distributed on the Global Telecommunication System in accordance with the provisions of the *Manual on Codes* (WMO, 2011*b*), and forward those normals to the WMO Secretariat.

Consideration of the needs for environmental and climate monitoring products and assessments, such as assessments by the Intergovernmental Panel on Climate Change, should be integrated into national, regional and global observing priorities.

3.1.10 *Define monitoring and measurement requirements*

NMHSs should define performance indicators for the following aspects of the process:

— Process cycle
— Timeliness (if climate data are available on time, which is dependent upon user requirements)
— Customer satisfaction (for example, using feedback by email); it is very important that products include NMHS contact information
— Quality of data
— Gaps in data

An example of performance indicators that an NMHS can consider is the mean of the timeliness of availability of daily observations in the climate database. The timeliness is calculated as the difference between the time of reception of daily data and the time of observation.

NMHSs should produce monitoring reports. Typical monitoring reports include the number and type of stations in the database, the quantity of data in the database grouped by station and by observation element type, and information about missing data. Reports on data ingestion may be made automatically, perhaps every day. Monthly reports on the quantity and quality of data usually match the monthly cycle of many CLIMAT products.

3.2 Implement and measure the process

The process manager should oversee, on a quasi-daily basis, implementation and control of the process and its activities as planned, and perform the agreed performance monitoring and measurements as planned. The quality and homogeneity of data should be regularly assessed as part of routine operations.

NMHSs should establish monitoring procedures to ensure that, as far as possible, the CDMSs under their control are kept updated (including metadata) and that the data they contain are easily retrievable. NMHSs should guarantee that all employees have ready access to and become familiar with the latest quality objectives and that they have access to all the necessary documentation of the process.

NMHSs should warrant, as far as possible, that the same products produced by different sources within the organization are consistent. For example, products that link to providing information on a drought for a set period for a set region should not give conflicting information. Management should ensure that customer requirements are determined and met to the best of the ability of the NMHS, with the aim of enhancing customer satisfaction. Feedback mechanisms such as surveys and consultations should be put in place to monitor user satisfaction. There should be appropriate documented evidence related to processes and their ability to achieve desired results or outcomes. Appendix 1 lists mandatory documents and records required by ISO 9001.

3.3 Monitor and analyse the process

In addition to daily monitoring, it is recommended that climate service providers conduct frequent process reviews, regular self-audits (one or two per year) and, as soon as possible, undertake corrective actions to address non-conformities that may arise out of these audits through focus groups or task teams, for example. It is also recommended that the following are produced and kept:

— Daily/weekly reports of inconsistencies, or trouble/error detection
— Monthly reports covering non-conformities
— Quality control errors and false positives
— Key entry/digitization performance statistics and inventories
— Biannual internal and external audits

— Requests for and action on corrective actions and meeting outcomes of a high-level quality committee

The process performance indicators should be calculated on a regular basis: daily, weekly, monthly and annually. They should be shared with process staff, and key indicators should be reported to the management review.

All products should include contact information to receive feedback from customers. Given that NMHSs want their end users to be happy with their products and services, it makes sense to measure customer satisfaction. While measuring customer satisfaction is subjective, it will inform NMHSs as to what end users like and dislike about the products and services that they receive. The process manager should maintain and follow customer requests and feedback.

Regular process reviews should be performed to analyse process performance, to ensure the necessary outputs are provided. The process manager should then report to top management and other relevant people in the organization on the performance of the process, as appropriate. The process manager should also consider top management feedback during the process review.

3.4 Improve the process – corrective actions

All NMHSs should have a plan to deal with non-conformities. This plan should be widely communicated and understood. Whenever a non-conformity is detected, corrective actions should be taken, and any consequences resulting from the non-conformity should be dealt with and documented. The effectiveness of the actions taken should be reviewed, corrective actions implemented and their effectiveness verified according to the plan. NMHSs should determine if a similar non-conformity exists or could potentially occur, and implement appropriate actions to correct these or prevent them from occurring.

Identification of non-conformities and implementation of corrective actions help to look at risks and opportunities that may have arisen and allow response to these. Any potential risks and/or opportunities should be addressed when processes are reviewed and updated.

The climate data process manager should maintain all the corrective action documents. The method for improvement should be defined and implemented as mentioned in section 2.2.4. Analysis of the results of non-conformities should be conducted periodically to ensure that non-conformities are not reoccurring. NMHSs should seek to create and sustain employee awareness and motivation by involving staff in developing and improving the system, especially when it comes to raising and closing non-conformities.

4. QUALITY MANAGEMENT IN CLIMATE MONITORING

Climate monitoring is one of the main realization processes in NMHSs. Best practices for implementing quality management in the climate monitoring process and guidance on the process activities are given below, following the step methodology described in Chapter 2. It is advisable that the ownership of the process be selected from a climate service section, department or unit. It is also advisable to designate a cross-functional team to work with the process manager to oversee the process on an ongoing basis.

4.1 Plan the process

4.1.1 *Define and describe process activities*

NMHSs should ensure that the procedures, manuals, work instructions and external documents related to the climate monitoring process are legible, and are quickly and easily retrievable for all climate service staff. The Internet is one of the most important tools for accessing updated documents when changes occur.

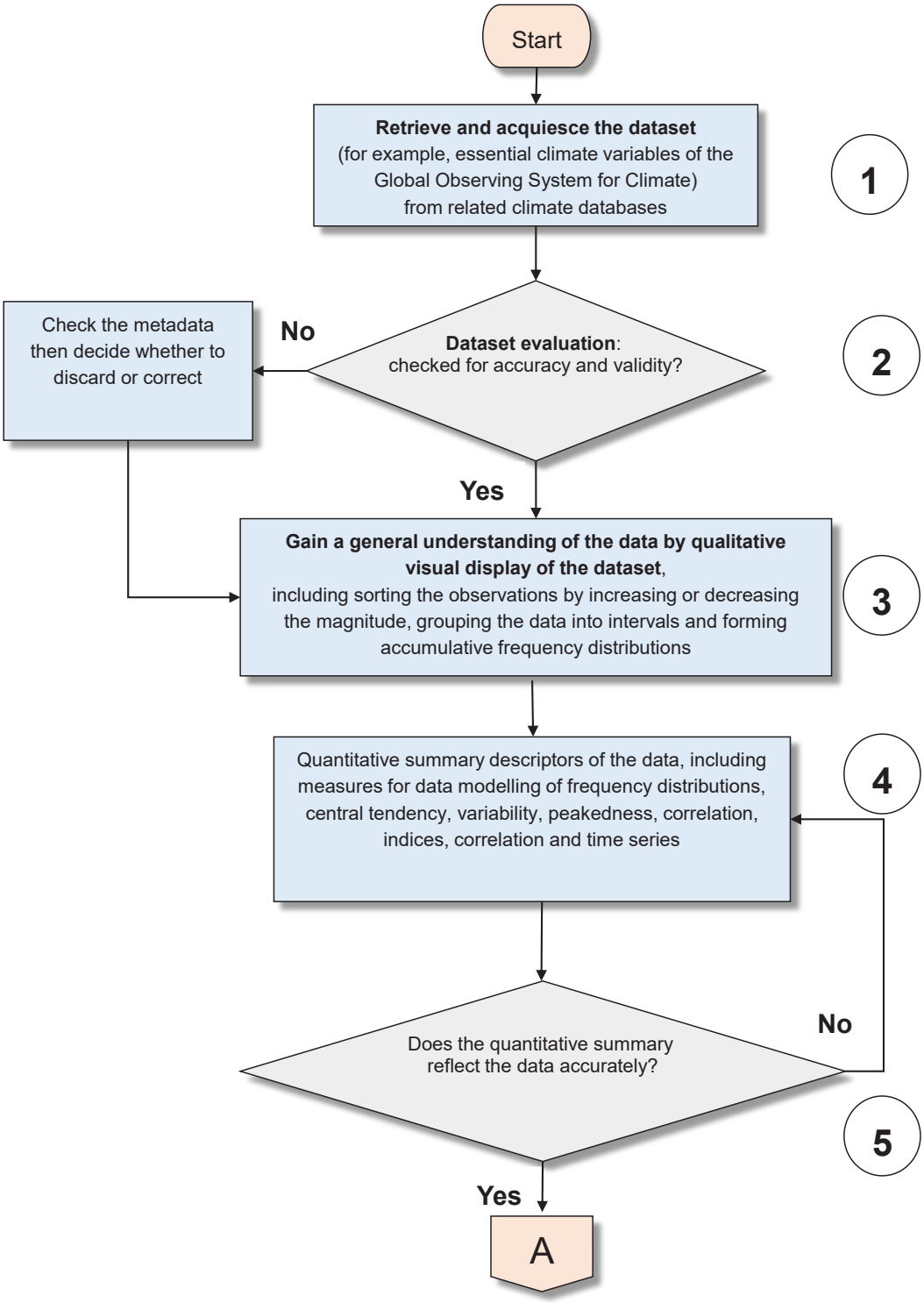
When describing the climate monitoring process, NMHSs should address the important aspects related to climate monitoring in accordance with WMO standards, regulations and best practices. As stated in the *Guide to Climatological Practices* (WMO, 2011*a*), it is appropriate that each NMHS processes its own data and analysis results and, where possible, compiles them together with the material of other agencies (such as agriculture) into a set of products that can be promptly disseminated with each agency's views on current climate conditions. If the necessary data are not available within a given country, the relevant NMHS should obtain regional or global data and analyses from foreign or international agencies, such as WMO Regional Climate Centres (RCCs), Global Climate Observing System Surface Network Monitoring Centres and Global Producing Centres (GPCs), and process the information into a form suitable for local to national use.

However, the NMHS should add its own views to these global analyses about the connections between the local climate conditions and the large-scale climatic fields. Monitoring activities require that the climate service develops expertise in analysing the state of past and current climate and global to regional teleconnections, and provide summarized information to public and private sector users.

NMHSs should ensure the generation of good monitoring products, because they are inputs for the climate prediction process (WMO, 2016*a*). NMHSs are encouraged to compute climate indices routinely and share them with WMO Members and the climate community. Climate indices are widely used to characterize features of the climate for climate prediction and to detect climate change. Indices usually combine several elements into characteristics of, for example, droughts, continentality, phenological plant phases, heating degree-days, large-scale circulation patterns and teleconnections.

The construction and evaluation of indices specific to climate change detection, climate variability and climate extremes are ongoing processes, as discussed in the *Report on the Activities of the Working Group on Climate Change Detection and Related Rapporteurs* (WMO, 2001). The process of how the NMHS computes climate indices should thus be developed with additional work instructions or standard operating processes that are easily retrievable by staff tasked with this work. It is important that consideration be given to what resources, including human resources, would be needed to produce this information in a regular and timely manner. It is often necessary for the climate service to interpret the meaning of an index value, changes in values over time and sometimes calculation procedures, when providing information to users. Users and their needs should help to determine the way this is done.

The generic flow chart in Figure 5 represents the main activities to be undertaken by NMHSs during implementation of the climate monitoring process. Each activity should be documented in detail, taking into account NMHS practices and specifications. Some organizations like to number the steps in a process and expand these in a work instruction or standard operating procedure; hence the numbers in circles in the figure.


Start
Retrieve and acquiesce the dataset
(for example, essential climate variables of the Global Observing System for Climate)
from related climate databases
1
Dataset evaluation:
checked for accuracy and validity?
2
No
Check the metadata then decide whether to discard or correct
Yes
Gain a general understanding of the data by qualitative visual display of the dataset,
including sorting the observations by increasing or decreasing the magnitude, grouping the data into intervals and forming accumulative frequency distributions
3
Quantitative summary descriptors of the data, including measures for data modelling of frequency distributions, central tendency, variability, peakedness, correlation, indices, correlation and time series
4
Does the quantitative summary reflect the data accurately?
No
5
Yes
A

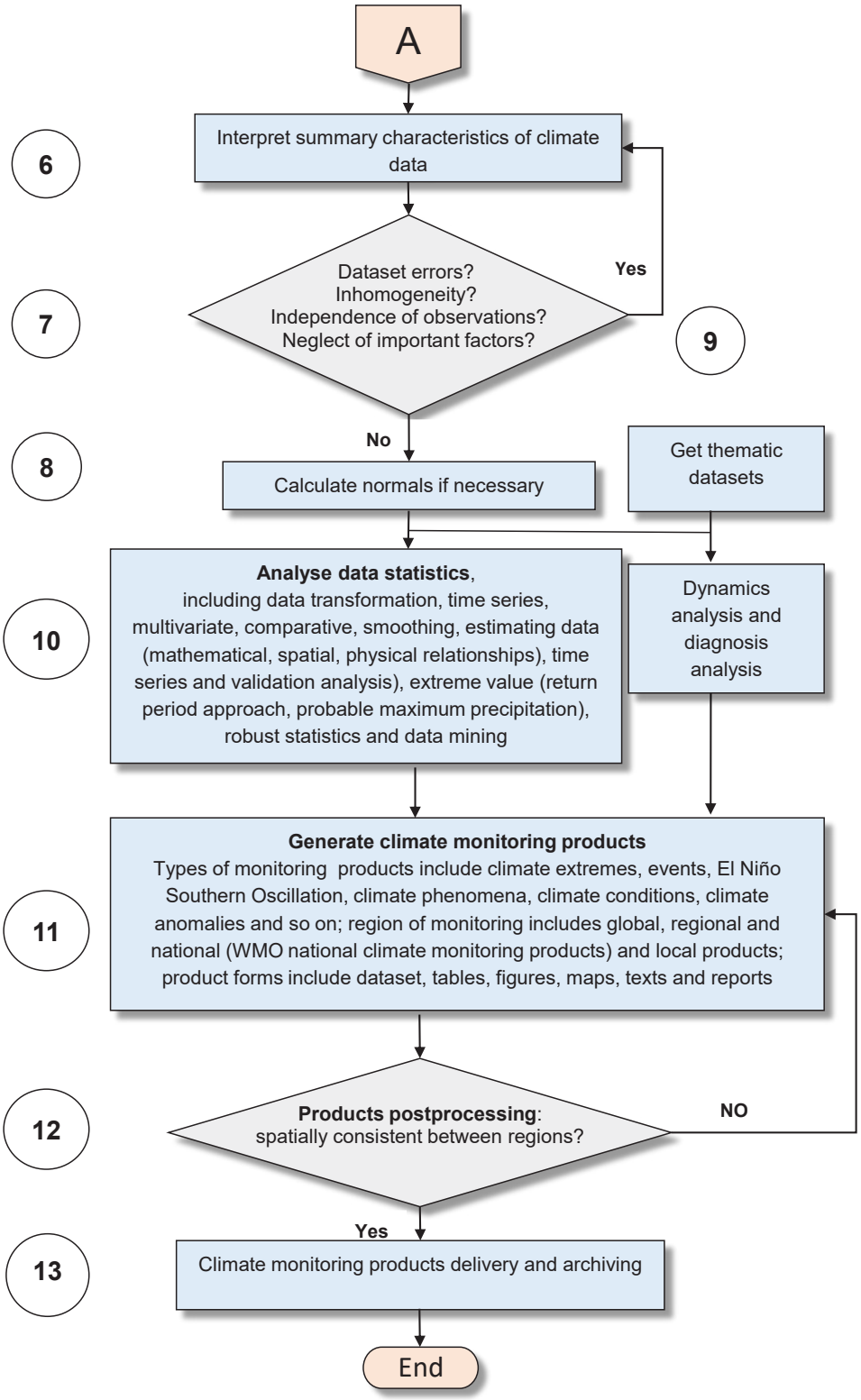


Figure 5. Main activities in the climate monitoring process

4.1.2 *Improve personnel competency and develop capacity*

Staff training and competency were mentioned in the climate data process section above (section 3.1.8). The level of competency required for the climate monitoring process is high. NMHSs should ensure refresher training on an ongoing basis. This is particularly important due to the continuous progress made at the international level in the area of climate monitoring. Staff should also be involved and participate in national and international meetings and workshops dealing with this subject.

4.1.3 *Identify customer requirements*

Standard ISO 9001:2015 (ISO, 2015*b*) does not include any product requirements, as stated in the previous chapter. Customers, WMO standards and NMHSs specify these requirements. Management should ensure that customer requirements are determined, for example, via face-to-face engagement user forums or surveys, with the aim of enhancing customer satisfaction. Feedback mechanisms such as surveys and consultation should be put in place to monitor user satisfaction and to improve the products and services provided (WMO, 2018).

NMHSs are encouraged to provide the following list of recommended national climate monitoring products (WMO, 2014*a*):

1. Monthly area-average mean temperature time series;
2. Monthly area-average of total precipitation anomalies expressed as percentages;
3. Monthly area-average of standardized precipitation indices calculated for each weather station;
4. Monthly area-averaged percentage of days that the daily maximum temperature exceeds the ninetieth percentile;
5. Monthly area-averaged percentage of days that the daily minimum temperature is less than the tenth percentile;
6. Significant climate and weather events relevant to the area or region.

NMHSs should identify and calculate performance indicators relevant to:

— Timeliness (if the monitoring products are issued in time to be useful)
— Customer satisfaction and relevance (if the monitoring products are delivered to users in a form that can be understood)

4.2 Implement, monitor and improve the process

Implementing and improving the climate monitoring process are similar to those described in the climate data process sections 3.2 and 3.4 above. Performance indicators should be calculated on a regular basis – weekly, monthly and annually – depending on the type of climate monitoring products.

5. QUALITY MANAGEMENT IN CLIMATE PREDICTION

Climate prediction is another important realization process in NMHSs. Best practices for implementing quality management in a climate prediction process are given below, following the step methodology described in Chapter 2. It is advisable that the owner of the process be a person with good experience in climate and particularly climate prediction.

5.1 Plan the process

The activities of the process should be defined and described. In the context of climate services, the processes that make up climate prediction and delivery of a forecast should include the following:

— Prepare input to the climate prediction model(s)
— Run the model(s)
— Post-process the model output(s)
— Interpret and/or tailor the forecast information
— Disseminate the forecast(s)
— Activate user support

NMHSs must assess and analyse each step and substep of the forecast process to determine where problems may exist and how best to correct them, to improve the quality of products and services. The generic flow chart in Figure 6 represents the main activities to be undertaken by NMHSs in implementing the climate prediction process. Each activity should be documented in detail, taking into account NMHS practices and specifications. Some organizations like to number the steps in a process and expand these in a work instruction or standard operating procedure, and may want to number each step of the process.

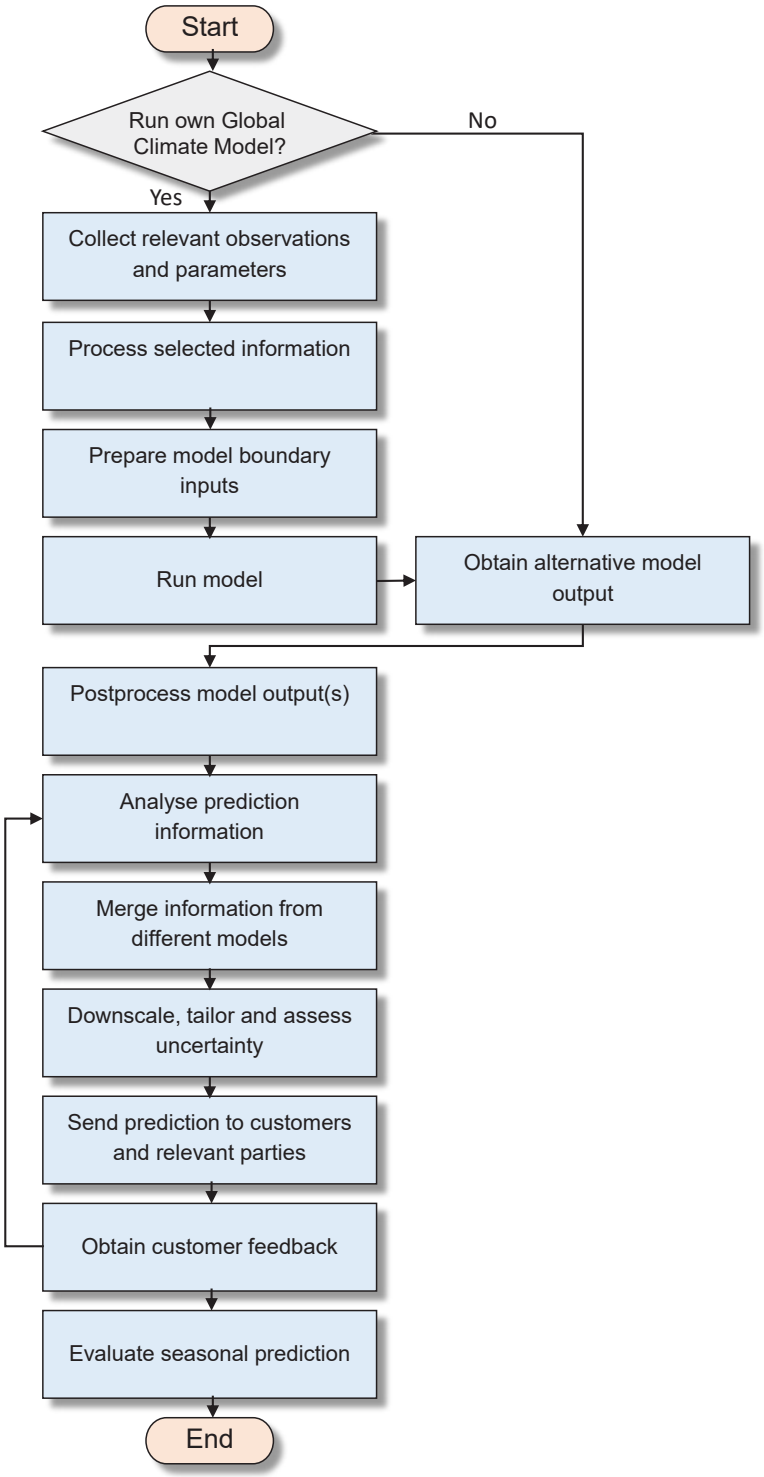


Figure 6. Main activities in the climate prediction process

5.1.1 *Verify process inputs*

The input products, observations and climate model outputs must be verified, along with their uncertainty. NMHSs should use the most-relevant information about the forecast, in particular: current climate states, large-scale phenomena states such as El Niño and sea surface temperature anomalies, climate model outputs and so forth.

Most NMHSs obtain the required inputs for this process from GPCs for Long-range Forecasts or RCCs, which WMO has developed to assist its Members to cope effectively with their climate information needs. The *Manual on the Global Data-processing and Forecasting System* (WMO, 2010*c*) contains definitions and mandatory functions of GPCs and RCCs, which are part of the WMO Technical Regulations.

In addition, WMO has established a Lead Centre for Long-Range Forecast Multi-Model Ensemble and a Lead Centre for the Standard Verification System for Long-Range Forecasts, which provide added value to the operational services of GPCs. There is also the WMO *El Niño/La Niña Update*, which is a consensus product based on inputs from a worldwide network of forecasting centres, and which provides an indication of the phase and strength of the El Niño Southern Oscillation.

Few countries run a climate prediction model; therefore, it is important to document how inputs from other sources are accommodated in NMHS processes. Instructions on how these data are used within the organization are essential. NMHSs should also include the origin of their input data in product descriptions so that customers are aware of this.

Note: It is not a mandatory requirement for suppliers of climate prediction information to maintain a QMS. However, this does not prevent NMHSs from being specific about the quality of what suppliers are providing, and from monitoring and providing feedback to suppliers on quality-related issues.

5.1.2 *Improve personnel competency and develop capacity*

Staff training and competency were mentioned in the climate data process section above (section 3.1.8). The level of competency required for the climate prediction process is high. NMHSs should ensure refresher training on an ongoing basis. This is particularly important due to the continuous progress made at the international level in the area of climate prediction. Staff should also be involved and participate in national and international meetings and workshops dealing with this subject.

5.1.3 *Identify customer requirements*

Standard ISO 9001:2015 (ISO, 2015*b*) does not include any product requirements, as stated previously. Customers, WMO standards and NMHSs specify these requirements. NMHSs should identify their potential users and understand their needs, as well as understand the role of weather-, climate- and water-related information in the different sectors.

NMHSs are encouraged to attend and participate actively in Regional Climate Outlook Forums, which:

— Bring together national, regional and international climate experts, in the context of climate prediction, on an operational basis to produce regional climate outlooks. These are the best state-of-art climate prediction products, based on input from NMHSs, regional institutions, RCCs and GPCs.
— Facilitate enhanced feedback from users to climate scientists, and catalyse development of user-specific products. They also review impediments to the use of climate information, share successful lessons regarding applications of past products and enhance sector-specific applications.
— Offer very good opportunities for training on seasonal climate prediction to strengthen the capacity of NMHS staff involved in this process.

NMHSs are encouraged to provide probabilistic forecasts (which are more robust), rather than categorical forecasts. The methods and procedures for doing this should be clearly documented and in as much detail as staff need to perform such tasks. Consideration should be given as to how feedback from customers might improve the products in terms of content, frequency of release and relevance. An NMHS may allocate significant resources and effort in providing a probabilistic forecast, but if the customer does not understand it or cannot use it, then a review of the product should be undertaken to find ways to tailor it to meet customer needs and requirements. Another approach could be to run training events for customers, so they are better equipped to use forecast products and services.

5.1.4 *Ensure traceability of products*

See section 3.1.7 in the climate data process above.

5.1.5 *Define monitoring and measurement requirements*

NMHSs should identify and calculate performance indicators relevant to:

— Timeliness (if the forecasts are issued in time to be useful)
— Customer satisfaction and relevance (if the forecasts are delivered to the users in a form that can be understand and used)
— Quality of climate forecasts (skill scores)

5.2 Implement, monitor and improve the process

Climate forecast products can be provided directly to users, but NMHSs should provide assistance, as required, to interpret the meaning of forecasts to users. Users also need to be made aware of the meaning and usefulness of climate prediction products, which should always include their uncertainties.

Climate forecasts should be accompanied with information about their quality, computed in hind-cast mode over many years, due to the limitation of climate models. One way of doing this is by using and assessing skill scores. Verification scores such as the root mean square skill score and relative operating characteristics should be used (refer to the standardized verification system for long-range forecasts (WMO, 2010*c*) and *Guidance on Verification of Operational Seasonal Climate Forecasts* (WMO, 2016*a*)). The hind-cast verification statistics should be updated once a year based on accumulated forecasts.

Standard ISO 9001:2015 (ISO, 2015*b*), clause 8.5.1(f), refers to processes for which the output cannot be effectively verified nor will it become apparent until after the product or service is delivered to the customer. The climate forecast process is a key activity. The accuracy of seasonal forecasts cannot be verified at the time of issuing the forecast, which is when it is delivered to the customer. NMHSs must validate the production and service provision processes for such climate predictions once the period for the prediction has passed, to fulfil the requirement of the clause above. The validation must demonstrate the ability of the processes to achieve the planned results.

NMHSs should undertake regular evaluation and verification of the quality of the climate forecast products over the target areas against the operationally desirable accuracy. This could be done after the end of each target season and over a period of 1 year or more. The climate forecasts must be verified with respect to the observations. The observed climate anomalies may be posted alongside the forecasts. Statistical scores can be used over a period of time to evaluate the accuracy of the climate forecasts to validate the process.

Verification is only one aspect of the quality of a forecast. Verification is usually understood to mean evaluation of the quality of the forecast, by objectively measuring how well the forecast corresponds with the actual weather, as revealed by observations. Another important aspect

of a forecast is its "goodness", that is, its consistency, quality and value.[1] Value is defined as the increase or decrease in economic or other benefits to the user, resulting from using the forecast. It is thus important that the methods of verification of the forecast are clearly documented and communicated to staff involved in the process.

The performance indicators used for monitoring and analysis should be calculated on a regular basis: monthly or seasonally and annually.

Monitor customer satisfaction

There are various tools that can be used to assess customer satisfaction, including:

— Customer satisfaction surveys (from which annual comparability should be ensured to enable trend analysis)
— Focus groups
— Feedback received during meetings

NMHSs should perform regular internal audits for this process, at least twice a year. Verification skill scores should be used to identify the improvement possibilities and take decisions about the forecast or system being verified. Scientific verification of climate forecasts will help identify the strengths and weaknesses of a forecast so that decisions can be made about how to improve the product.

6. QUALITY MANAGEMENT IN SERVICE DELIVERY

Climate services disseminate climate information to the public or specific users. Service delivery is a continuous, cyclic process for developing and delivering user-focused services, which are defined as products or activities that meet the needs of users or which can be applied by users. It can also include the provision of climate information for the enhancement of a customer's existing or new product, who then passes this onto a user, for example a farmer advisory bulletin. Service delivery involves user engagement, design, development, delivery, evaluation and improvement. Effective service delivery is about providing products and services that are useful to users and customers (WMO, 2014*d*).

The concepts and best practices of service delivery are applied to all WMO activities and accepted by the entire WMO community. Enhancing the capabilities of NMHSs to deliver climate services to users with the best available technology is one of the WMO goals. WMO has developed a strategy to assist NMHSs in the provision of weather-, climate- and water-related services to the public and decision-makers (WMO, 2014*d*). It also provides guidance for service delivery, which serves as high-level guidance for developing detailed methods and tools for better integrating users into the service delivery process. Service delivery is adaptable to the unique capabilities of providers in developed and developing countries, regardless of who the users are and whether providers deliver public or commercial products and services. This strategy can thus be used by NMHSs when focusing their QMS on service delivery activities.

The pillars of service delivery in ISO 9001:2015 (ISO, 2015*b*) are defined by:

— User engagement (clauses 5.1.2, 8.2.1 and 9.1.2)
— Service design and development (clause 8.3)
— Delivery (clause 8.5)
— Evaluation and improvement (clauses 9 and 10)

The methodology is ultimately linked to the QMS by:

— Encouraging and supporting continual improvement of product and service quality

[1] See https://www.nssl.noaa.gov/users/brooks/public_html/feda/note/topic4.html.

— Focusing on quality control, quality assurance and quality improvement

The users of climate services are many and varied, ranging from schoolchildren to global policymakers. However, the three fundamental principles for providing climate services to these varied customers are the same:

— Know the user and understand what is needed. This includes the climatic elements that are relevant to the user, how the user wishes to receive information, how the user is likely to interpret the information, for what purpose the information will be used, the decision process of the user and how the information might improve the decision-making processes. This is important in light of ISO 9001:2015, clause 8.2.3.1, which focuses on the ability of an organization to meet the requirements for products and services offered to customers. It is also important to know that even if requirements for a product or service are not stated by the customer but are necessary for the specific or intended use of the product or service then these should be made known.
— Make the information user relevant, accessible and timely. Provide products that can be understood and readily applied by the user, along with easy access to follow-up professional advice.
— Ensure quality. Provide products that have been developed with an understanding of possible applications and analysis techniques, complete with appropriate documentation and backed up by thorough knowledge of up-to-date data availability and characteristics.

The service delivery process is a key process in any NMHS. Best practices for implementing quality management in the service delivery process are given below, following the step methodology described in Chapter 2. It is advisable that the owner of the process be a member of the management team. It is also recommended to designate a cross-functional team with members from the realization processes to work with the process manager to oversee the process on an ongoing basis. It would also be beneficial to include a person who is customer focused in terms of the work they do for the NMHS, because they have knowledge when it comes to working with customers. They are also able, in most cases, to obtain the necessary customer feedback, which is vital in improving service delivery. If the data or product provided are an input to another organization's product or service, a member of that organization may be considered to form part of the process team.

6.1 Plan the process

NMHSs should ensure that user requirements feed into the development and operation of climate services to make them appropriate and demand driven, and to define and describe the activities of this process. The service delivery process should follow the procedures for the control of documents of the QMS. NMHSs should ensure that the procedures, manuals, work instructions and external documents related to this process are legible, and are quickly and easily retrievable, for all climate service staff.

It is advisable to keep contact details of all stakeholders involved in service delivery so that they can be informed about any changes that may affect a process. Requirements for design and development of products are well defined in ISO 9001. The procedure for design, development and implementation in ISO 9001:2015 (ISO, 2015*b*) is as follows:

— Design and development planning (clause 8.3.2)
— Design and development inputs (clause 8.3.3)
— Design and development controls (clause 8.3.4)
— Design and development outputs (clause 8.3.5)
— Design and development changes (clause 8.3.6)

The main activities or subprocesses in service delivery are:

— Evaluate user needs and decisions: meet users and define their requirements
— Negotiate a service delivery contract, when appropriate
— Develop climate products: link service development and delivery to user needs

— Implement products and services production and, where possible, automate this part of the process
— Evaluate and monitor service performance and outcomes
— Sustain improved service delivery with due consideration to what happens in the case of service delivery failure
— Develop the skills needed to sustain service delivery

The product or service production should be documented, including aspects such as inputs, personnel and their competencies, product specifications, schedule, dissemination means and users. Figure 7 provides an example of a process that makes up service delivery.

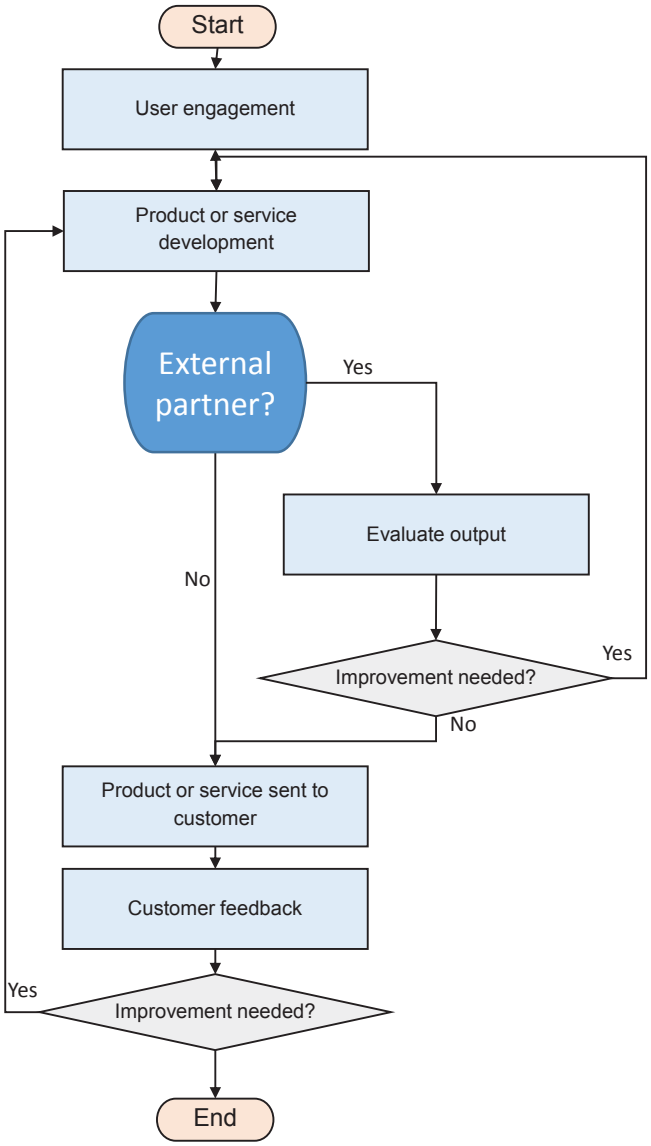


Figure 7. Main activities in the service delivery process

If the service delivery is for data or a product on an ongoing basis, the process may also include a step that considers setting up a service level agreement (SLA). There will also be a need to monitor the delivery to make sure the products are provided on time and in the correct format, and that the user is satisfied with the service. This is especially important if the delivery is automated in some way. Thus, the inputs and outputs of the process should be carefully monitored. Consideration should also be given to what happens when the data or products are not available as per the SLA for whatever reason.

6.1.1 *Improve personnel competency and develop capacity*

Climate service staff should be prepared to respond to requests for data and products with additional information about sites, elements, instrumentation, mathematical definitions of various parameters, the many aspects of how observations are performed, and the methods and software used to derive the products, as well as the science of meteorology and climatology in particular. Climate service personnel should cultivate a broad range of skills and expertise or have access to people with the necessary expertise.

NMHSs should ensure that expertise in the communication and interpretation of climate information is available so that user requests and needs can be responded to efficiently.

While technical knowledge and capabilities are necessary to develop products and services, other skills such as communication, presentation, consultation with users and analysis of their needs will also be required. These may not be the traditional areas of expertise for staff of NMHSs. A gap analysis of existing competencies should be used to identify areas requiring training, which could lead to the development of standard training modules for in-house training or identification of outsourced courses, to ensure that all staff members have the opportunity to learn and develop these skills.

6.1.2 *Identify customers and their requirements*

The customers of NMHSs are varied and include the media and public information sector, agriculture, defence forces, government departments, business and industry, water and energy sectors, the public, tourists, legal professionals, health officials, and humanitarian and relief organizations. Their needs for climate services may be a simple interest in the weather and climate or a more detailed request such as for the design of a building, agricultural operations, water management, operating a large dam, planning of energy production and distribution, or the preparation for and response to food or water shortages. Service delivery for all these users should follow the same process to ensure a high quality of service provision.

Many customers with a need to use climate information have little understanding of meteorological science and related concepts. Thus, they may not know what information they really need or how best to use the information. If possible, it is very important to meet with customers, to help them define their requirements and recommend the products that are most appropriate for them. The requirements usually dictate the level of service and nature of products that need to be developed. Nevertheless, NMHSs should consider the following general considerations for developing climate products and services:

— Provide the best services at the lowest cost
— Utilize climate product generation software, tools and automation routines
— Deliver products timely
— Enhance user awareness of the available climate products and services
— Encourage user feedback and utilize the feedback to improve products
— Comply with quality management principles
— Provide information security
— Provide relevant documentation especially concerning product creation (for example, categorical long-range forecasts[2])
— Ensure transparency regarding the reliability and uncertainty associated with the products
— Comply with WMO Resolutions 40 and 60 relating to the exchange of data and products
— Comply with other local, national and international laws and treaties

Evaluation of user needs is not a one-time requirement but a continuous and collaborative part of the service delivery process. NMHSs should pay much attention to the means of products delivery. Data and products can be delivered via several methods, ranging from telephone and mail to Internet file transfer protocol, email, apps and website access. It is recommended to have a main delivery method and a fallback procedure in case the main one is not operational.

[2] Description of forecasted weather parameters from 30 days up to 2 years (WMO, 2012*a*).

Quality consistency should be looked at, so that customers get the same quality of product no matter the means of delivery. The information or service provided should be consistent across all delivery platforms. It is important that a procedure is established for what happens if the service provider is unable to deliver the information according to the service contract, due to data problems or other issues.

It may sometimes be necessary for NMHSs to explicitly outline user requirements and proposed climate products and services agreed on with the user in an SLA or a service delivery contract. These agreements should be prepared in such a way as to reflect the current scientific uncertainties associated with the proposed products such as forecasting weather, climate and hydrological events. Appendix 3 gives a template for an SLA document.

NMHSs are encouraged to participate in customer events. It is important and very beneficial to be involved in user activities such as seminars, conferences, workshops or meetings. They are an opportunity to listen to and learn about user issues and decision-making processes, which will lead to better products and services. NMHSs can then be in a better position to anticipate, investigate and understand the requirements of government decision-makers, industrial and commercial interests, and the general public.

How well a user interprets climatological information depends on how the information is presented. It is important that NMHSs focus on presentation of the products. Graphical products are usually the best way for presenting climate information instead of simple text. Climate information can be presented in many ways, such as data files, time series, tables, diagrams, statements or maps, and it is up to NMHSs, in consultation with end users, to select the most suitable format that meets customer needs.

6.1.3 *Define monitoring and measurement requirements*

NMHSs should define performance indicators reflecting the following aspects:

— Timeliness (if the products are reliable and delivered on time to users)
— Customer satisfaction (if the products are clear, useful, credible, responsive and flexible)
— Quality (if the products are well documented and meet user requirements)

6.2 Implement, monitor and improve the process

The following should be implemented to maintain control of the service delivery process (with reference to ISO 9001:2015 (ISO, 2015*b*), clause 8.5.1):

— Availability of documented information that defines the characteristics of the product to be produced, the service to be provided or the activities to be performed, as well as the results to be achieved
— Availability and use of suitable monitoring and measuring resources
— Monitoring and measurement activities at appropriate stages to verify that criteria for control of processes or outputs, and acceptable criteria for products and services, have been met
— Use of suitable infrastructure and environment for the operation of processes
— Appointment of competent qualified persons
— Validation, and periodic revalidation, of the ability to achieve planned results of the processes for production and service provision, where the resulting output cannot be verified by subsequent monitoring or measurement
— Actions to prevent human error or delivery failure
— Release, delivery and post-delivery activities

NMHSs should ensure that:

— Products have a statement concerning the confidence that can be placed in the product, where appropriate, and guidance concerning limitations of the information; this is so that

all users, especially those who are less accustomed to climatological products, can assess the appropriateness of a certain product to their needs and incorporate the associated uncertainty into their own decision-making process
— Frequent monitoring of the production and delivery of products is undertaken, when multiple products are being provided or when products are being provided on a regular basis
— Customers are advised that they must ensure they are accessing current product pages, and not cached product pages that may be out of date, where products are provided via the Internet

If there is a need for provision of real-time delivery of data or information to a user, this can leave little or no time for quality control of data other than that done automatically. At the very least, some basic checks should be made as the data are received. In this case, users must be alerted to possible problems concerning the data, and this should be included in the service contract. A disclaimer could also be considered and should form part of a service contact.

Users should be brought in at various stages of the design and development process to evaluate and test products and services, to ensure they meet requirements and allow for optimal decision-making.

Service delivery does not stop once the product or service has been delivered. User outreach and engagement must continue to ensure that services are received and utilized appropriately.

NMHSs should have a core set of metrics to measure the end-to-end service delivery process and its outputs. Each metric should measure a specific aspect of the process, but, collectively, the metrics should enable an organization to demonstrate its strengths and identify areas for improvement in terms of effectiveness, efficiency, impact, satisfaction and value. Metrics should have the following attributes:

— Specific (for example, a good metric for customer satisfaction would be direct feedback from customers on how they utilized a specific product)
— Measurable (ability to collect data that are accurate and complete)
— Actionable (easy to understand, interpret and act upon)
— Relevant (measure only those things that are important and relevant to an organization's goals and objectives)
— Timely (data can be collected when needed)
— Owned (ideally, owners should be individuals with the ability to take action to ensure targets are met)
— Consistent (any two given metrics should not promote conflicting behaviours)

These metrics could be used to measure, for example, forecast accuracy, customer satisfaction, compliance and timeliness.

7. IMPLEMENTING AND PREPARING FOR CERTIFICATION OF A QUALITY MANAGEMENT SYSTEM

Table 3 outlines the recommended steps for ensuring implementation of a QMS based on ISO 9001:2015 (ISO, 2015*b*) and preparing for certification. Further details are given in the *Guide to the Implementation of Quality Management Systems for National Meteorological and Hydrological Services and Other Relevant Service Providers* (WMO, 2017).

Table 3. Steps for implementing and developing a QMS

Step	*Action*
1	Obtain formal endorsement of top management
2	Select the quality manager or coordinator for the NMHS to oversee the development of the QMS; the quality manager may also engage a climate services focal point to provide subject matter expertise
3	Enlist the assistance of an experienced organization or individual to facilitate implementation of the QMS
4	Provide training and awareness programmes; staff should have training on standard ISO 9001
5	Conduct a gap analysis to identify which clauses of ISO 9001 are currently not being fully applied
6	Define and maintain the following documented information: scope of the quality system, quality policy and quality objectives
7	Identify, define and implement processes and develop procedures
8	Plan and implement actions to address risk and opportunities
9	Establish appropriate measures and tools to acquire information on customer satisfaction
10	Identify and train appropriate staff to undertake the role of internal auditor
11	Conduct internal audits (including all the processes)
12	Conduct quality management review meetings; management need to review specified data from the activities of the QMS, including the performance of processes, to ensure there are adequate resources to be effective and improved
13	Select a third-party organization to perform ISO 9001 certification of compliance
14	Prepare and conduct an external audit

APPENDIX 1. MANDATORY DOCUMENTS AND RECORDS

Mandatory documents required by ISO 9001:2015 (ISO, 2015*b*) include:

— Scope of the QMS (clause 4.3)
— Quality policy (clause 5.2)
— Quality objectives (clause 6.2)
— Criteria for evaluation and selection of suppliers (clause 8.4.1)

Mandatory records required by ISO 9001:2015 include:

— Monitoring and measuring equipment calibration (clause 7.1.5.1)
— Training, skills, experience and qualifications (clause 7.2)
— Product/service requirements review (clause 8.2.3.2)
— Design and development output review (clause 8.3.2)
— Design and development inputs (clause 8.3.3)
— Design and development controls (clause 8.3.4)
— Design and development outputs (clause 8.3.5)
— Design and development changes (clause 8.3.6)
— Characteristics of product to be produced and service to be provided (clause 8.5.1)
— Customer property (clause 8.5.3)
— Production/service provision change control (clause 8.5.6)
— Conformity of product/service with acceptance criteria (clause 8.6)
— Non-conforming outputs (clause 8.7.2)
— Monitoring and measurement results (clause 9.1.1)
— Internal audit programme (clause 9.2)
— Results of internal audits (clause 9.2)
— Results of management review (clause 9.3)
— Results of corrective actions (clause 10.1)

APPENDIX 2. PROCESS DESCRIPTION TEMPLATE

The template below is an outline of a generic process description document used by the National Meteorological Office of Morocco, which could be used by any NMHS to document and describe climate services processes.

NMHS logo	*Process: climate data*	*Identification number (reference) Version: Date:*

SUMMARY

1. Front page

Modifications/revisions:

Version	*Modification date*	*Paragraphs modified*	*Modification reasons*
A			
B			
C			
D			
E			

Communication:

Communication tools	*Targets: internal and external*

Elaboration, review, modification, update and approval:

	Title	*Name*	*Date*	*Approved (signature)*
Elaborated by	Process Manager			
Checked by	Hierarchical			
Validated by	Quality Manager			
Approved by	NMHS Director			

2. Process manager: .....

Process management team:

Internal actors	*Process clients*	*Process suppliers*	*Others*

3. Purpose of the process: .....

4. Process goals: .....

5. Application: .....

6. Inputs, outputs and clients:

Process inputs	*Process outputs*	*Process clients*

7. Resources needed:

7.1 Competency requirements: .....

8. Product requirements:

Client requirements	*Statutory and regulatory requirements*

9. Related processes:

Process callers	*Process called*

10. Description of the process:

10.1 Flow charts: .....

10.2 Process, subprocesses and activities:

Action no.	*Inputs*	*Activity/action*	*Outputs*	*Documents, references and means*	*Staff competency*	*Monitoring and performance*

10.3 Explanatory notes: .....

11. Documented information

(Documentation (manuals, work notices, regulatory documents) and software necessary for the implementation of activities)

Reference/ publication	*Title*	*Version*	*Date of application*	*Origin*	*Rating*	*Manager*
e.g. WMO (2011a)						

Type of documented information	*Reference*	*Label*	*Version*	*Date of application*	*Rating*		*Archival*		*Destruction*	*Retention*	*Manager*
					Where	*Retention*	*Where*	*Retention*			
e.g. Message	FM 71-XII										

12. Identified and potential malfunction (causes and effects, risk analysis): ……
13. Monitoring and improving the process:
13.1 Performance indicators: process and customer satisfaction indicators

Objectives	*Indicator name*	*Calculation method*	*Target value*	*Actual value*	*Comment*
Objective no. 1 Improve data quality					

13.2 Process monitoring: ……

Audits, process review, management review

14. Definitions and abbreviations:

Abbreviations	*Definitions*
e.g. WMO: World Meteorological Organization ……..	e.g. Archival:…..

Note: This process description document should fulfil the requirements of the NMHS documented procedure on control of documents; in particular, it should include:
— Name and logo of the NMHS
— Title, purpose and scope of the document
— Document number, revision status and date of issuance
— Review and approval signatures (authors and approver)
— Responsibility and authority
— History of past amendment

APPENDIX 3. TEMPLATE FOR A SERVICE LEVEL AGREEMENT

Article I. Parties

Describe the parties involved in the SLA

Article II. Scope

Section 2.01 Scope

Describe the purpose and extent of the SLA

Section 2.02 Assumptions

Define any assumptions that underlie the defined scope

Section 2.03 Goals and objectives

Describe what the parties are expecting to accomplish with the SLA

Article III. Roles and responsibilities

For all parties involved in the SLA, describe the role of each party and the responsibilities for supporting the SLA and delivering the products and services defined within

Article IV. Effective date and term

Give the date the agreement is effective and its duration

Article V. Delivery and performance

Describe in detail what each party is responsible for delivering, the delivery method(s) and the key performance indicators to ensure compliance

Article VI. Reporting, reviewing and auditing

Describe oversight and reporting on the agreement, when the agreement should be reviewed and reporting points of contact

Article VII. Cost and payment

Document the costs associated with the SLA, who is responsible for paying, or funding, and when payment should occur; costs may be broken down by specific line items, such as labour, supplies, equipment, travel and training

Article VIII. Changes and modifications

Describe the process by which changes or modifications will be made to the SLA and who is responsible for making changes

Article IX. Termination

Describe the terms for termination of the SLA and the process for termination

Signatures and date

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