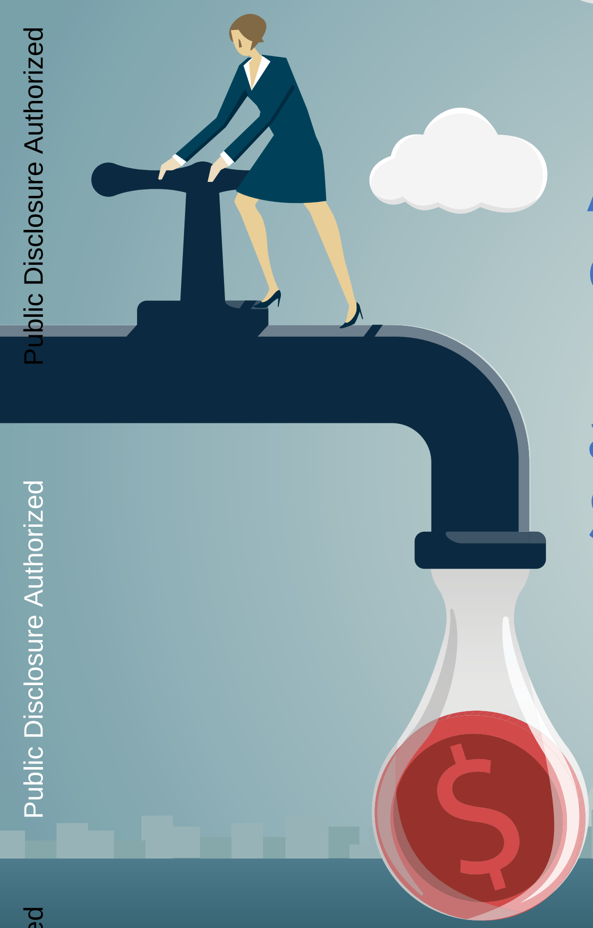

Affordability of National Meteorological and Hydrological Services

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Abstract

When low levels of government investment are combined with outdated management practices, even high levels of effort and investment by development partners will not bring about any significant improvement in the services provided by National Meteorological and Hydrological Services (NMHSs) in low- and middle-income countries (LMICs). The result is often a cycle of a low quality of services that improve slightly following investment in new systems; this is then followed by a steady decline due to lack of maintenance of observational networks and other systems. The upshot is a return to a service with diminished ability to fulfill its public task. This technical note explores management practices and argues that good practice is critical to the success of investments. It considers how advanced NMHSs are managed and how they can create sustainable, high-quality services, as well as their applicability to less-advanced services. Making observational networks affordable is highlighted as a priority in improving the financial stability of NMHSs.

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Introduction

Leaders and managers of National Meteorological and Hydrological Services (NMHSs) comprise the primary target audience for this technical note, although it is also intended to be useful to development partners that are planning and financing projects to improve meteorological and hydrological services in low- and middle-income countries (LMICs).

The sustainability of NMHSs is an ongoing issue in many LMICs. Constraints on public spending exist everywhere, and budget justification for the maintenance or improvement of public services is challenging. This problem is often coupled with inefficient institutional management practices that prevent the optimum use of limited resources.

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International finance in the form of loans and grants is often used to improve infrastructure, including meteorological and hydrological networks and information and communication technology (ICT), and to provide staff training. These investments, however, are not intended to (and generally cannot) support NMHS staff salaries or the operation and maintenance (O&M) of equipment beyond the lifetime of the financed project, which is typically no more than five to six years. Upgrades to infrastructure usually increase the cost of O&M because of the complexity of the equipment, the greater technical skills required to maintain it, and the expense of running it—the required electricity, replacement parts, telecommunications, and so on. In addition, since the acquisition is intended to fill a specific role, any downtime will have social and economic impact if the expected services are unavailable. Institutional budgets need to reflect these additional expenses accurately to ensure that the asset remains affordable throughout its expected lifetime. Government owners of the NMHS are often expected to provide additional resources to absorb the additional financial and human capital expenses. Greater understanding of the total cost of ownership (TCO) at the start of a proposed investment would help provide guidance to the government on the support required to ensure that any acquisition fulfills its long-term objectives. Invariably, the TCO of an acquisition is far higher than its initial capital cost.

Experience suggests that additional financing and staffing are extremely difficult to achieve in practice given the limited flexibility in public sector financing and given the civil service structures in most countries (Rogers et al. 2019). Consequently, there is the apparent paradox of relatively high available capital through borrowing and grants and little or no opportunity to ensure the sustainability of the investments.

There is no obvious panacea. Closer scrutiny of the financial viability of services, however, would help to identify areas where repurposing could increase value and benefit without compromising safety and security. Put simply: the level of services and the associated infrastructure must match the funding available to sustain them. Current economic realities make it imperative that NMHSs focus on least costly solutions to achieve their public tasks, compete effectively within the public sector for government support, and, where possible, provide services in a competitive commercial market to broaden their base income without cross-subsidizing the public sector (Rogers et al. 2021b; Rogers and Tsirkunov 2021). Low-cost solutions and competitiveness reflect both the fiscal reality of public sector services and the role of NMHSs in the wider economy, where the public task focused on safety and security is complemented by the growing importance of weather, climate, and water services to economic development.

A significant impediment to effective financial management is the lack of sufficiently detailed knowledge of the costs of existing NMHS business activities and information on the expenses and technical requirements for the operation of the systems that NMHSs are trying to build. Given the many requests for public sector financing, it is essential that NMHSs properly account for their income and expenditures and make informed decisions on how resources are allocated to achieve their service objectives. Such flexibility is not always possible, in part because of the way NMHSs receive their financial allocations. It is not uncommon, for example, for salaries to be paid separately as part of a civil service–wide administrative system. Revenue, costs, and expenses are not often related to activities and, consequently, it is difficult to justify increasing operating expenses because these cannot be directly related to improved service objectives.

In this note, we examine some basic ways to improve financial and management practices that may help NMHSs justify their budget requests through increased transparency of the link between service objectives, the meteorological and hydrological value chain, and the TCO of any acquisitions and assets. Our first consideration is financial accountability. This is followed by the application of activity-based accounting practices to the NMHS operations, and, finally, some of the analytical tools that are needed to help NMHS management, investors, and government owners make better-informed investment and planning decisions. Two case studies are considered. One focuses on an advanced meteorological service that provides both public and commercial services; the second, in a least developed country, requires considerable external help to build a sustainable service that fulfills its public tasks.

Although the discussion applies to the entire value chain, the observational networks are often the largest operating expense of NMHSs and are where the bulk of technical staff are usually assigned in an LMIC. For this reason, it is essential that efforts to upgrade these systems are mindful of the overall impact proposed changes may have on the utility and viability of the entire service.

Given the many requests for public sector financing, it is essential that NMHSs properly account for their income and expenditures and make informed decisions on how resources are allocated to achieve their service objectives.

Financial accountability

Fundamental to the public sector financing of NMHSs is adequate budgeting. Most governments and other public sector entities, including NMHSs, prepare budgets. An approved budget may be a constitutional requirement that sets taxation levels and is part of the process for obtaining legislative approval for spending. Because of the significance of an approved budget, information that enables government and the public to compare financial results with the budget facilitates an assessment of the degree to which an NMHS has met its financial objectives. This information promotes accountability and informs decision-making in subsequent budgets. It supports assessments of whether the NMHS provides its services in an efficient and effective manner, the adequacy of the resources currently available for future expenditures, any changes in the burden on future-year taxpayers of paying for current services, and whether the ability of the NMHS to provide services has improved or deteriorated compared with the previous year.

The International Federation of Accountants (IFAC)[1] recommends that governments report on accrual rather than cash, which is currently the more common method of accounting.[2] Accrual reporting is essential to recording the substance of transactions when they occur rather than when cash settlement occurs. This is fundamental to good decision-making, transparency, and accountability and is essential to gain a complete picture of the financial health of an entity. The International Public Sector Accounting Standards Board (IPSASB) develops accounting standards,[3] with the aim of achieving consistent and comparable financial information across jurisdictions. The adoption of International Public Sector Accounting Standards™ (IPSAS™)[4] by governments is expected to improve both the quality and comparability of financial information reported by public sector entities around the world. The resulting greater financial transparency would be particularly beneficial to donors and multilateral development banks' efforts to assist governments cope with weather, climate, and hydrological hazards by improving the performance of their NMHSs (Rogers et al. 2019) and all services in a country that form the elements of a wider national weather enterprise.[5]

Incomplete financial data impair the ability of governments, development partners, donors, and lenders to adequately assess the ability of NMHSs to absorb and sustain new capabilities and to scale investments appropriately (Box 1).

The primary objective of the NMHS is to provide needed services to the public rather than to make a profit and generate a return on equity to investors. Consequently, the performance of the NMHS will not be fully or adequately reflected in any measure of financial results alone.

Box 1 **Resource provider requirements**

Government, donors, lenders, and customers require information on whether the NMHS

- Is achieving its objectives as justification for the resources currently allocated or paid for a service objective,
- Can finance current operations from funds raised from all sources, and
- Is likely to need additional (or fewer) resources in the future, along with the likely sources of those resources.

Information is also required about the consequences of decisions made, and activities undertaken, by the NMHS, as well as about the resources available to support the provision of services in the future, the NMHS's anticipated future service delivery activities and objectives, and the amounts and resources necessary to support those activities (Box 2).

Information about the financial position of the NMHS enables assessments of the extent to which its management has discharged its responsibilities for safekeeping and managing resources, the extent to which resources are available to support future service delivery activities, and changes in the amount and composition of those resources as well as claims to those resources.

The primary objective of the NMHS is to provide needed services to the public rather than to make a profit and generate a return on equity to investors. Consequently, the performance of the NMHS will not be fully or adequately reflected in any measure of financial results alone. Therefore, their financial results need to be assessed in the context of service delivery objectives measured through key performance indicators.

Quantitative measures of the outputs and outcomes of the NMHS's service delivery activities provide relevant information about the service delivery objectives—for example,

Box 2 Necessary financial information

Financial information is needed in the following areas:

- The performance of the NMHS.
- The ability of the NMHS to meet its current obligations (its liquidity) and its ability to meet its obligations over the long term, including maintenance and operation of equipment and its commitments to its public task (its solvency).
- The sustainability of the NMHS's service delivery and operations over the long term, and changes therein because of activities including:
  - The capacity to continue to fund its current activities and to meet operational objectives in the future (its financial capacity), and
  - The physical and other resources currently available to support the provision of services in the future (its operational capacity).
- The capacity to adapt to changing circumstances.
- Whether the NMHS is using resources economically, efficiently, effectively, and as intended.
- Whether the range, volume, and cost of services provided are appropriate, and the amounts and sources of resources are sufficient to maintain the volume and quality of services currently provided.

the timeliness and utility of weather and flood impact warnings, the availability of meteorological and hydrological observations, and the relationship of the services provided to the resource base of the NMHS.

Reporting nonfinancial as well as financial information about service delivery activities, achievements, and outcomes provides input to assessments of the economy, efficiency, and effectiveness of the NMHS's operations. Reporting such information is necessary for NMHS management to discharge their obligation to be accountable—that is, to account for, and justify the use of, the resources raised from or on behalf of their constituents. Decisions that donors and other development partners make about the allocation of resources to a particular NMHS and related entities are also made, at least in part, in response to information about service delivery achievements and future service delivery objectives.

Costing service objectives

Migrating to full accrual accounting may be a long-term goal. However, mapping finances to an activity-based system that tracks how resources are used to create services is much less onerous. In addition, introducing concepts such as TCO and life-cycle costing (LCC) as one part of asset management would enable the NMHS to estimate the costs of its service objectives and their affordability and to set priorities and better direct development partners' investments to those activities with the largest input for their services.

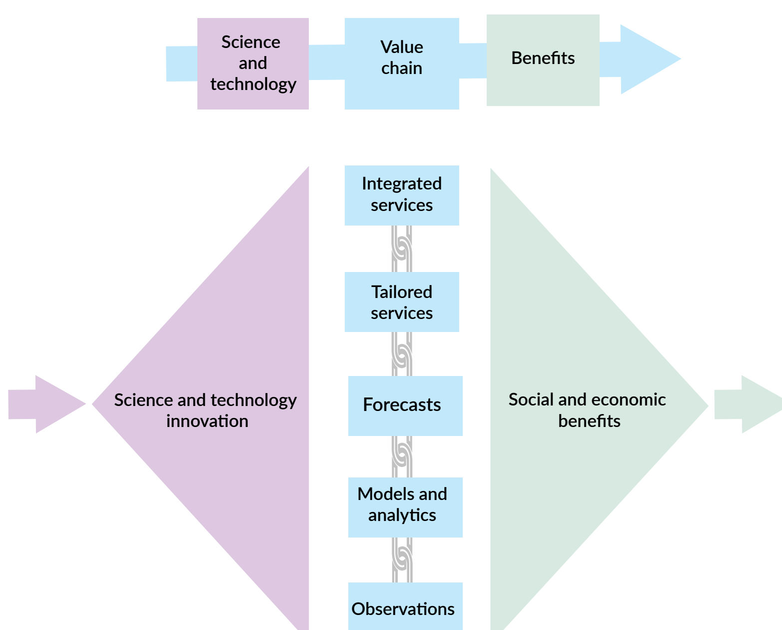
The value chain

The term "value chain" is used frequently in meteorology to describe the general relationship between different activities. It conveys an important construct—the production of value—and it is a useful way of exploring the organization and performance of an NMHS.

The assessments described in the previous section require the NMHS management to relate the cost of production of each of their services to the expenses associated with each element of the value chain that contributes to those service objectives. The term "value chain" is used frequently in meteorology to describe the general relationship between different activities. It conveys an important construct—the production of value—and it is a useful way of exploring the organization and performance of an NMHS. Figure 1, adopted from Thorpe and Rogers (2021), provides one interpretation of the meteorological value chain. It has five links: *observations*, *models and analytics*, *forecasts*, *tailored services*, and *integrated services*. Each link is the product of science and technology infusion, and each provides social and economic benefit. *Observations* are a foundational element of the value chain. Meteorological observations created as part of an NMHS public task are recognized as high value data sets;[6] in many countries, they are provided as open data for anyone to use and reuse (Rogers and Tsirkunov 2021; Rogers et al. 2021b). Within the NMHS, these data are integral to the production of higher-value products and services. *Models and analytics* includes numerical weather prediction, whether produced locally or accessed through global and regional production centers. *Forecasts* includes the production of basic meteorological forecasts and warnings. *Tailored services* are nominally made for a single beneficiary or sector—aeronautical meteorological services, for example. *Integrated services* shift the responsibility for the service to the beneficiary. These are often co-produced by different entities. Meteorology is one component, often among many. In the case of an integrated marine service, this might include logistical data, navigation data, vessel performance data, port information, sea conditions, and so on. Together, these data create a decision support system that optimizes performance. Similarly, *integrated services* include impact forecasts and warnings created collectively by disaster management agencies and meteorological and hydrological services working together. These services are likely to become an increasingly important aspect of services in the fu-

Figure 1

The meteorological value chain.



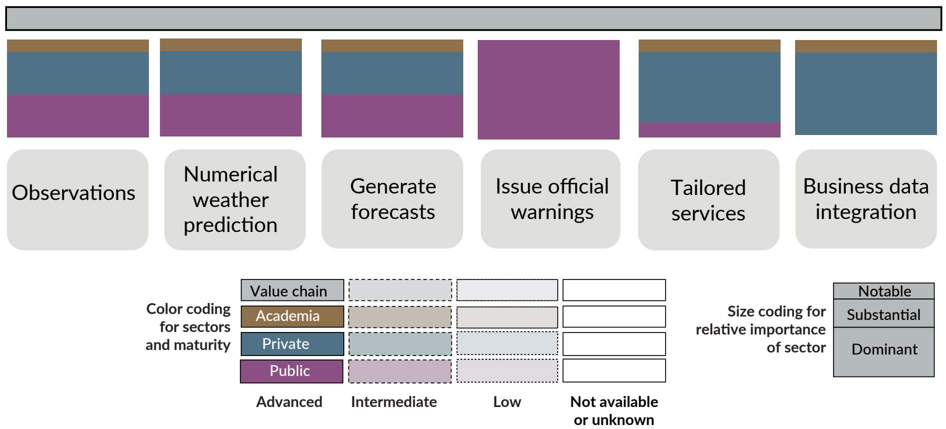
Source: Thorpe and Rogers 2021.
Note: The meteorological value chain, shown in blue, utilizes new knowledge, shown in lilac, to create the social and economic benefits shown in green.

ture, as artificial intelligence and machine learning techniques can combine information from an array of sources to create integrated services.

There are many other interpretations of the meteorological value chain, and each provides insight. The *Power of Partnership* report (World Bank 2019) introduced two important elements to the meteorological value chain: sector balance between public, private, and academic actors, and the maturity level of each link (Figure 2).

Figure 2

Sector balance and maturity diagram based on the hydromet value chain.

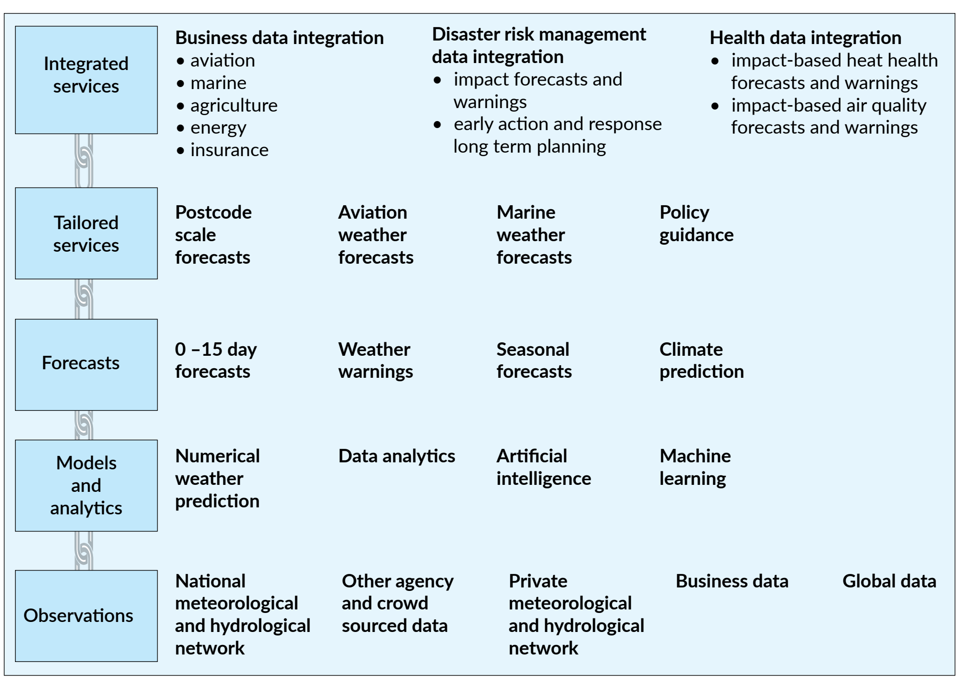


Source: World Bank 2019.
Note: The maturity of the value chain shown here is advanced.

The elements in the *Power of Partnership* value chain differ from those described by Thorpe and Rogers (2021) primarily in name rather than substance, except that the *Power of Partnership* explicitly includes *issue official warnings* as a separate element. Examples of the activities that contribute to each link in the value chain are shown in Figure 3.

Figure 3

Examples of the activities that contribute to each link in the value chain.



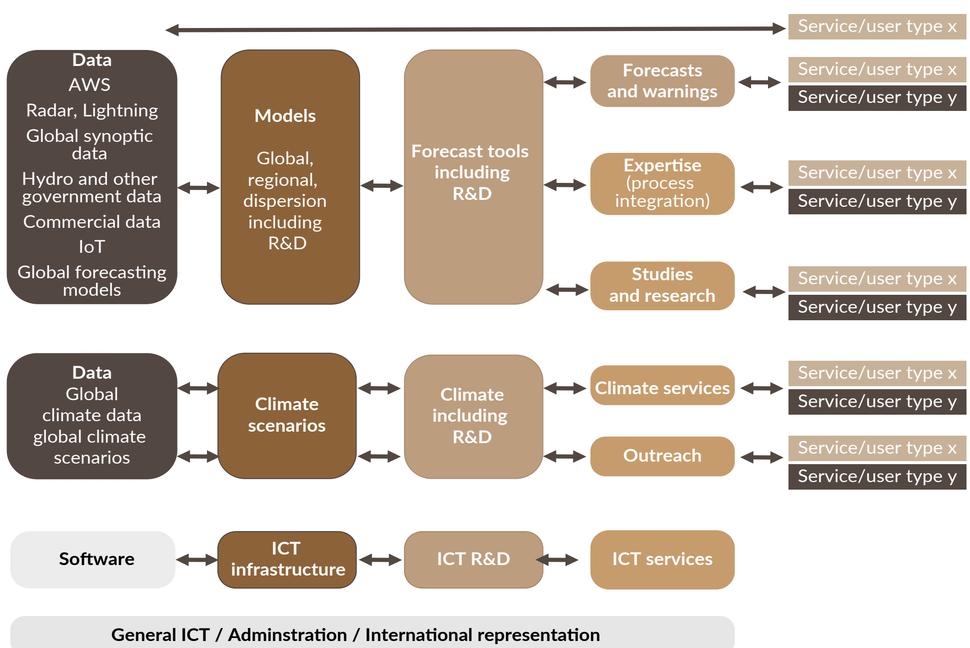
Source: Thorpe and Rogers 2021.

A hydrological service that features assessments in addition to forecasts may define the *forecasts* link as *forecasts and assessments* to capture the broader interpretation of the hydrological value chain. In practice, the hydrological and meteorological value chains are a composite set of individual value chains created for each individual service. *Integrated services*, for example, do not necessarily depend on *tailored services*. Health data integration may depend on meteorological observations only or on a combination of observations and model-derived forecasts. In contrast, business data integration for aviation services might include aviation weather forecasts that are provided as part of *tailored services*.

The notion of "maturity," defined in *The Power of Partnership* (World Bank 2019), is a useful proxy for value. By highlighting the level of maturity of each element in the value chain, it is possible to understand where interventions are likely to be needed and would have a positive impact on the organization and its services. Many NMHS financial reports are limited to a few large categories: salaries, O&M, utilities, computing resources, works, and sometimes simply "other." Clearly the absence of detail makes it almost impossible to assess the financial and operational performance of the NMHS. It is, therefore, necessary to migrate to an activity-based accounting system whereby the costs and expenses associated with the production of a service objective can be better quantified. The basic structure is summarized in Figure 4.

Figure 4

Schematic of the cost of production of services mapped to the allocation of expenses by activities in each of the value chain elements.



Note: Available to most NMHSs improvements to global models, including resolution and assimilation, is a significant reduction of the value of limited area models, especially if those models do not include data assimilation (as is typical for most NMHSs in developing countries). The additional expense of local models is not offset by improvements in services provided. The percentages are nominal budget allocations to the value chain. The scenario in Panel B can provide a higher level of services beneficiaries. ICT = information and communication technology; NWP = numerical weather prediction.

By following the connections between links in the value chain, it is possible to construct a more detailed picture of the expenses associated with the production of any service objective. Consider, for example, the service objectives related to climate. The climate service consists of long-term climate data as well as seasonal and longer-term predictions. The production of climate services depends on climate research and development; ICT research and development to optimize calculations for computing resource-intensive regional and global climate scenario calculations; and global, regional, and national climate data. ICT research and development and regional climate scenarios also depend on ICT infrastructure. Activities that cannot be assigned fall into a general category, normally associated with overhead, and are shared among all the activities. By analyzing the human resources, operating costs, maintenance, and so forth used within each link in the value chain, a more complete picture of the total cost of each service objective is obtained. The analysis also helps to understand potential bottlenecks in production—from understaffing key activities or technical issues or both— that contribute to difficulties in meeting the performance goals of a particular service objective. It is also possible to identify services that have very high costs but that may not be regarded as having sufficiently high value to justify continuing the activity in a resource-constrained operating environment.

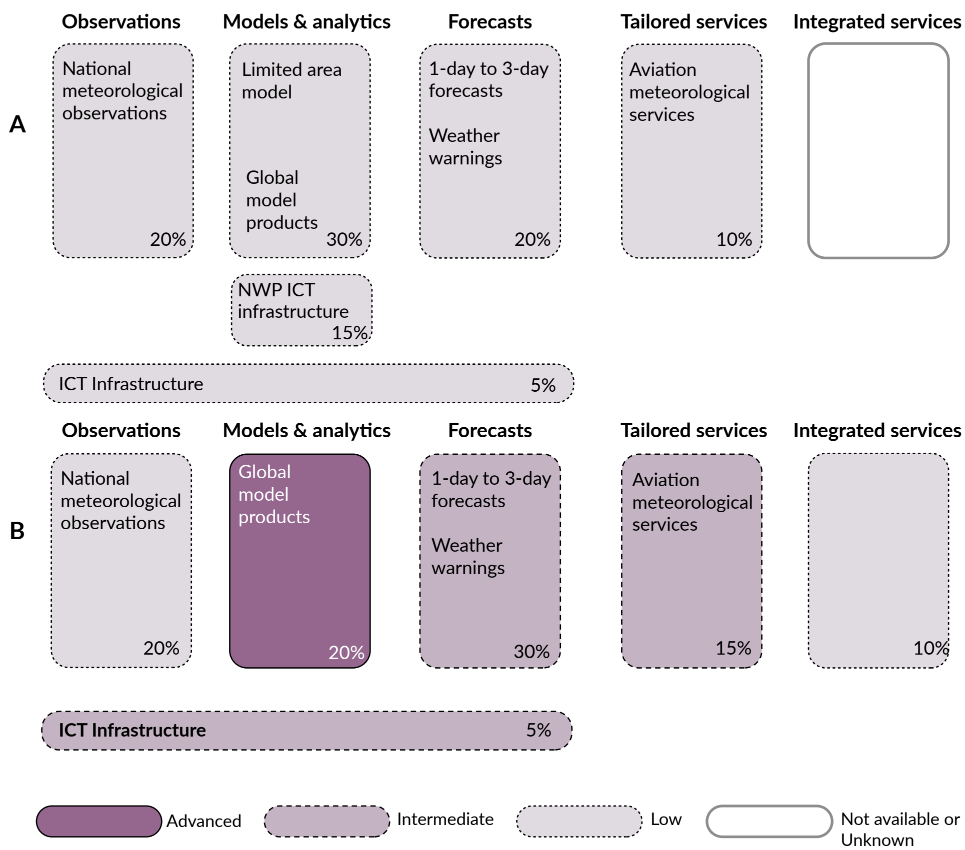


Figure 5

Schematic value chains of 1- to 3-day forecasting and warning service.

A: With limited area modeling.
B: Without limited area modeling.

Note: This structure is based on the operational structure of the Austrian Weather Service Zentralanstalt für Meteorologie und Geodynamik (ZAMG). AWS = automated weather stations; ICT = information and communication technology; IoT = Internet of Things; R&D = research and development.

Some regional and local weather prediction activities may become obsolete because of advances in numerical weather prediction (NWP) in global centers, for example. The resources applied to operating high-performance computing for a national model that provides little or no additional value to the products from a global center could be redirected toward other activities that may be under-resourced. The more detailed the assignment of expenses to activities, the more accurate and transparent the finances and operations of the NMHS, and the easier it is to understand the individual cost of each service objective. This in turn informs future strategic and operational decisions. Even a rather simple estimation of person years and their costs along with estimates of investments and depreciations for different activities can give a robust idea of the real costs of different activities and provide a basis for monitoring and evaluation with key performance indicators.

This point is illustrated in Figure 5 with two hypothetical operations designed to provide weather forecasts and warnings up to three days ahead (1- to 3-day forecasts and warnings) as well as aviation meteorological services. Both operations have the same budget allocation, but management decisions result in different levels of maturity. Scenario A is a national meteorological service with a relatively low level of maturity (palest purple) in all aspects of the value chain. The national network provides a limited amount of data sufficient to support daily forecasts with measurements at, say, its international airport.

Despite its low level of maturity, the NMHS shown in the Panel A scenario of Figure 5 ("scenario A") elects to run a local NWP model on its own computers. Boundary conditions to run this model are supplied by a global modeling center, and no local data assimilation is performed. Is the expense of this activity justified? Typically, the resolution of the locally run model is coarser than the global model, and without data assimilation it is unlikely to provide a quantitative improvement in the weather forecast. The limited staff may be expected to focus on the output of the local model at the expense of fully exploiting the global model products. The computing resources, while relatively expensive, are also often only marginally adequate to the task. The presence of local numerical modeling capabilities does not contribute positively to the maturity of the service if it adds little or no value.

The maturity level is higher in the scenario in Panel B ("scenario B") because the NMHS has focused its efforts on accessing and using digital products from a global center. Most of the post-processing can be done remotely, and only the relevant products are retrieved locally. National observations, albeit limited, can help bias correct the global center's predictions. The lighter solid shading in Panel A corresponds to intermediate level for forecasts and warnings and for aviation meteorological services. The model and analytics link are rated "advanced" because the service can take full advantage of all the products provided by the global prediction center. ICT infrastructure maturity is rated "intermediate" based on the need to provide broadband internet access and data management.

The presumption that scenario B is superior to A is based on the authors' experience and knowledge of the high value of global predictions, particularly ensemble prediction systems (Palmer 2019). The capital and operating expense of running a local model is quite significant. Given that both scenarios start with the same budget allocation, scenario A has allocated more resources to local modeling at the expense of other aspects of the value chain. In the authors' opinion, this would result in a lower quality of service for beneficiaries in scenario A than in scenario B.

This type of exercise, properly conducted with reasonable financial and technical assumptions, would allow NMHS management to assess the feasibility and affordability of any proposed changes in the operations and the potential implications of one change on another. Both scenarios avoided enhancing the national observational network to avoid increasing operational costs. Scenario B would require staff to have the skills required to interpret the global model products—these may be the same staff dedicated to running the local model in scenario A. It is assumed that all other staffing remains the same, so there is no opportunity to save expenses through staff changes. However, the infrastructure capital and operating expense associated with local high-performance computing could be redirected toward enhancing internet access and data management and providing additional capital investment and operational support for an expanded observational network. Justification for this investment would depend on the ability to use these data to calibrate the global models for the local environment and to demonstrate service objective improvements.

NMHSs' operations are constrained by service objectives that are largely determined by their stakeholders and users and the availability of financial and human resources.

NMHSs' operations are constrained by service objectives that are largely determined by their stakeholders and users and the availability of financial and human resources. Obviously, not all desired outcomes can be met if the resources are not available. Consequently, choices must be made to prioritize the development of realistic and achievable performance goals. Transparency in the process is an important element in convincing both service recipients and resource providers of the level of services that can be achieved.

The concept of operations

An important tool in assessing feasibility and affordability of any new system is the concept of operations (CONOPS). This is the first step in a system life-cycle process (Figure 6) that includes requirements, design, and implementation as part of a project definition, followed by integration and testing, system verification, and O&M as a part of project testing. Assessment starts the process cycle again with the CONOPS.

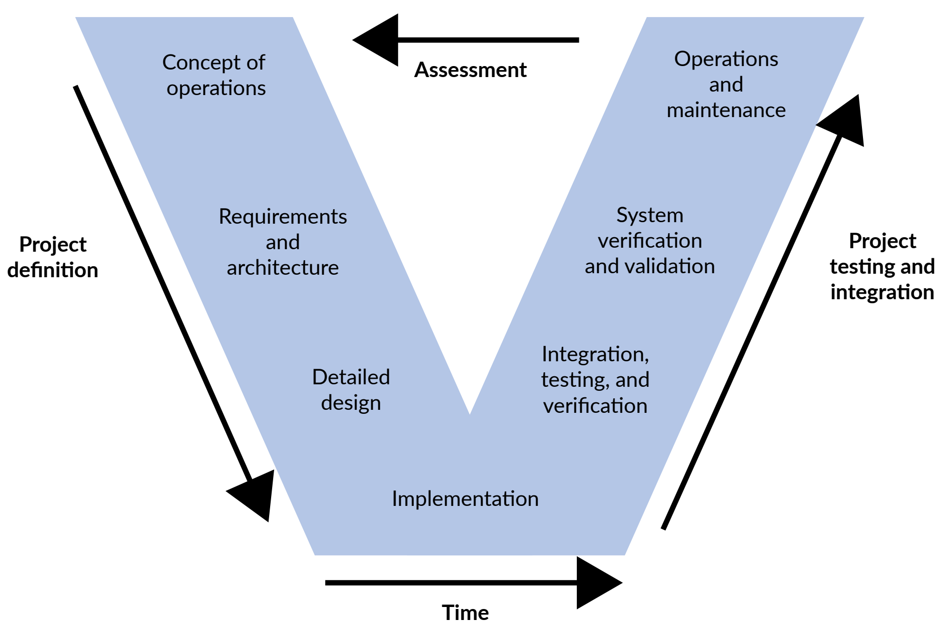


Figure 6

System life-cycle process.

The CONOPS has been discussed in detail in Rogers et al. (2019), and it has been used extensively in the design of NMHS modernization projects ranging from the acquisition of single systems to the overhaul of the entire organization. Here the main points relevant to observational network development are summarized. The purpose of the CONOPS is to ensure that: (1) there is a consensus among all stakeholders so that every partner understands the proposed operational observational network; (2) risks are reduced by ensuring that every aspect of the observing system is determined before it is procured or implemented, and (3) quality improvement is built in by taking every opportunity to leverage existing and new observational infrastructure to increase overall NMHS system performance. Creating consensus around observational networks is difficult because the observations are foundational to the production process and cannot be readily assessed without understanding the entire process. Consequently, the main stakeholders are internal to the NMHS as well as to those involved in the production of services within a commercial weather service provider or within other government agencies, such as water resources, agriculture, or energy. Properly engaging all relevant stakeholders as decision-makers in this process is non-trivial and hence is the focus of the CONOPS. The greater the number of stakeholders involved, the greater the likelihood of coproduction and sharing in the expense of operating the national networks—an important component in minimizing the operating expenses of any single entity contributing to the network.

As described by Rogers et al. (2019), the CONOPS is a document that describes the scope and characteristics of the proposed system and the way the observing system (or the overall NMHS system of systems) will be used. The CONOPS must consider all stakeholders, ensuring that it is readable and relevant to high-level decision-makers and system operators (UCAR 2010). It should build on strategic planning, business modeling, and stakeholder requirements. The CONOPS can be used to identify the status of any NMHS and to visualize investments, component by component, in the observing system and any of the other components in the value chain. All associated equipment, facilities, material, software, hardware, policy and technical documents, services, training, and personnel required for operations and support of the NMHS are included.

The CONOPS should evolve with the system. It is a vehicle for communicating high-level quantitative and qualitative characteristics of the system to the user, developer, operator, and other stakeholders. The CONOPS addresses the challenges involved in ensuring each system of the NMHS is fit for purpose (Box 3).

Analysis of the current system is a critical element. Based on the status, alternatives and tradeoffs should be considered in developing any future observational network. This could include: (1) maintaining the current business model, (2) privatizing some functions (purchasing data as a service, for example), (3) establishing partnerships with other government departments and private entities, (4) outsourcing some functions, and (5) taking advantage of commercial opportunities. The future proposed system should also consider the activities of development partners, which may be actively investing in observational networks. They can have a significant impact if those efforts encompass key components of the system or require business and financial models to be sustainable.

Box 3 A sample CONOPS

The CONOPS may include the following:

- Why the system is needed and an overview of the system itself—for example, a meteorological observation network
- The full system life cycle from deployment to decommissioning
- Different aspects of the system-operations, maintenance, support and decommissioning
- The different groups of users—for example, service recipients, forecasters, technicians, and their different skills and limitations.
- The physical environment and locations in which the system is used and supported
- The relationship between the system and other systems
- When the system will be used, and under what circumstances
- How and how well the needed capacity is currently being met
- How the system will be used, including operations, maintenance and support
- Scenarios illustrating specific operational activities involving the use of the system

The CONOPS should answer the following questions:

- Who are the stakeholders involved with the system?
- When will the activities be performed?
- Where are the geographical and physical locations of the system?
- Why does the NMHS requires this system?
- What are the know elements and the high-level capabilities of the system?
- How will the system be resourced, designed, built, and maintained?

It is recommended that the CONOPS address the following issues:

1. SCOPE
   a. Vision for the system
   b. Outline of the contents of the document
   c. Purpose of implementing the system
   d. Intended audience/beneficiaries
   e. Limitations of content covered

2. KNOWLEDGE REFERENCES
   a. Discussions with stakeholders and experts
   b. Studies of systems from other countries
   c. Analysis of mission requirements and operational needs
   d. Recommendations offered by vendors and product manuals

3. OPERATIONAL DESCRIPTION
   a. Summary of each user's role and activities
   b. Clarification of the order of user operations
   c. Summary of the operational process procedures
   d. Description and flow diagrams associated with organizational decision-making and management structures

4. SYSTEM OVERVIEW
   a. Specific goals and objectives that are measurable and time bound
   b. Interdependencies between subsystems
   c. Confirmation that the system's capabilities will satisfy the mission

5. OPERATIONAL AND SUPPORT ENVIRONMENTS
   a. Facilities
   b. Equipment
   c. Hardware
   d. Software
   e. Personnel
   f. Operational procedures
   g. Maintenance, training and support requirements

6. OPERATIONAL SCENARIOS
   a. A range of stakeholders' perspectives
   b. A range of stress/failure scenarios (both typical and extreme circumstances)

Source: Based on Rogers et al. 2019 and the approach taken by the COMET program of the University Corporation for Atmospheric Research (UCAR 2010).

Increasing the volume of real-time observations adds little to the capabilities of the NMHS unless it can use the additional data in nowcasting, in very short range forecasting systems, to downscale global models, as input to global models or as a service to clients, such as agriculture or transport.

As noted by Rogers et al. (2019), very often the proposed investment is made because the NMHS's processes rely on outmoded systems. A strong motivation includes the acquisition of new observational capabilities. NMHSs tend to pay more attention to modernizing monitoring networks and instruments, which is usually the most expensive part of an investment and the largest operating expense.

With the development of the WMO Global Basic Observing Network (GBON) Program,[7] a clear definition will emerge describing the necessary minimal requirements for station density per area, observation methods, data quality control, and data dissemination to regional and international data hubs of WMO.

While the discussion here is primarily focused on observations, this investment cannot be made without a consideration of other components of the value chain. Increasing the volume of real-time observations adds little to the capabilities of the NMHS unless it can use the additional data in nowcasting, in very short range forecasting systems, to downscale global models, as input to global models or as a service to clients, such as agriculture or transport. Above all, the observing system goal must focus on affordability and ease of maintenance.

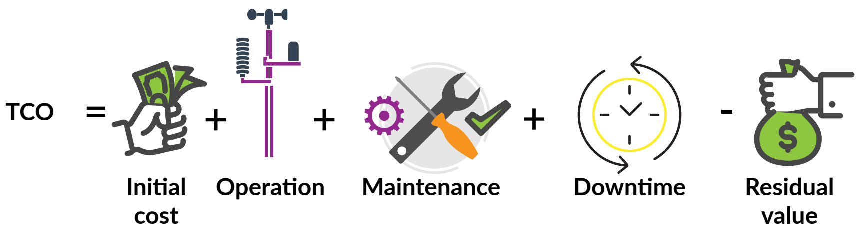
A primary objective of modernization programs for NMHSs is to provide services that meet the needs of their service recipients—needs that are often growing in response to the growing sensitivity of society to weather, climate, and hydrological impacts—and that stimulate the healthy growth of the entire hydrometeorological (hydromet) ecosystem. User requirements almost universally focus on timeliness, accuracy, and usefulness of forecasts and warnings. More frequent, high-quality meteorological data would improve short-range forecasts and improve services for specific users. However, the level of financial resources available is the deciding factor in tradeoffs in the quality of services and the prioritization of some services over others. Generally, it is not possible to meet all user requirements, so it is important that the analysis helps prioritize services based on their value to service recipients, statutory requirements, and economic characteristics, and that it takes full account of the expense of providing those services and engages key service recipients in the definition of the system.

Asset management

The infrastructure of an NMHS consists of a diverse set of assets ranging from observation stations to ICT systems and buildings. Performance indicators used to evaluate the individual systems are often subjective. Decision-makers must optimize their investments based on uncertain criteria. A starting point is to understand the inventory of the assets of the NMHS and how they are managed. This includes tracking and recording all hardware and software within the organization; analyzing the performance of each asset; determining licensing, security, staffing, and maintenance requirements; determining value and depreciation; and verifying status with respect to obsolescence and replacement. These data enable prioritization about the management of the asset life cycle. Different single criterion techniques can be used, based on considerations such as age, condition, initial cost, risk, and life-cycle cost. More complex multiple criteria approaches are also possible (Vanier et al. 2006). Here, the focus is on life-cycle costing (LCC) as the most appropriate for observational networks.

Total cost of ownership and life-cycle costing

The CONOPS refers to the full system life cycle from deployment to decommissioning. This is often referred to as the “total cost of ownership” (TCO), which is determined through LCC. The TCO is the sum of all costs incurred during the lifetime of owning or using an asset. LCC is a technique used to establish the TCO. This is primarily used to analyze potential purchases from a broad perspective that, in addition to the initial purchase price and cost of acquisition, includes the expenses associated with operating and maintaining the acquisition, the loss of opportunity that would occur due to downtime, less any residual value of the asset (Figure 7).



Note: TCO = total cost of ownership.

Figure 7

Schematic of the total cost of ownership comprising five key components.

How is this useful? By analyzing what are often called the “hidden costs,” the organization has a more complete understanding of the expenses associated with acquiring and utilizing a particular asset. If the expected lifetime of the asset is more than a few years, the TCO will be substantially larger than the acquisition costs. Figure 8 presents some of the components that contribute to the TCO. Accurate estimates of these expenses are often difficult to obtain; however, a well-crafted request for information or request for proposal, or both, in a procurement process should answer most of the questions related to the O&M of the equipment, including electricity consumption, planned maintenance and part replacement schedules, license fees, and consumables. Other expenses will be known to the organizations; these include staff costs, building maintenance, and any penalties associated with the failure of the equipment to perform as expected. A best guess will be better than assuming no expense. By building a TCO model in this way, the organization can make more informed, albeit not perfect, decisions about the acquisition of assets and their ability to operate and maintain them through their projected lifetimes. Unfortunately, there are many examples where the capital costs are uncoupled from the operating expenses and the organization is unable to maintain the acquired equipment satisfactorily.

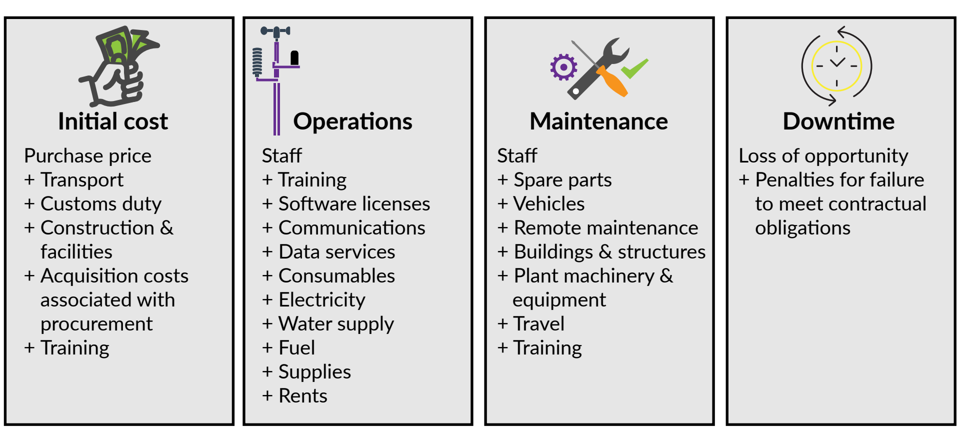


Figure 8

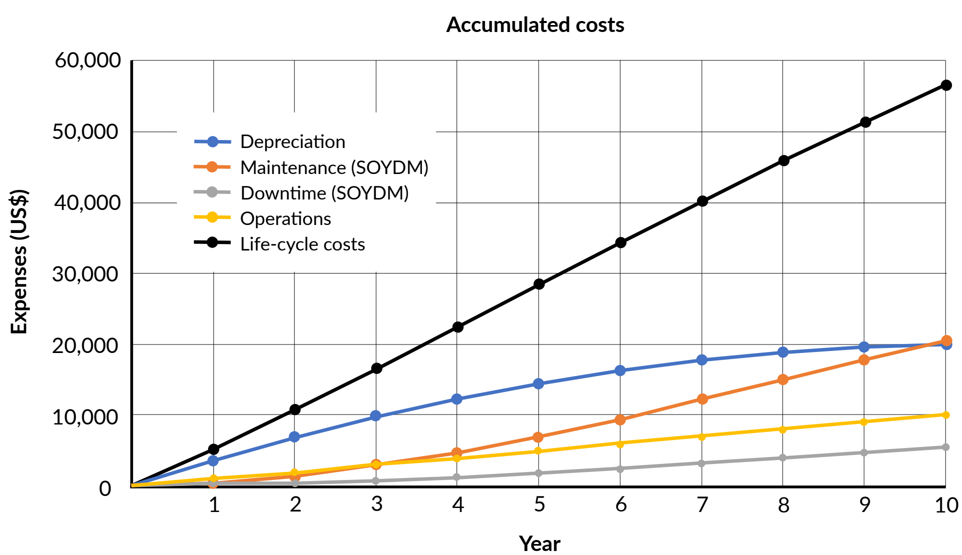
Costs and expenses associated with owning a meteorological asset.

Besides understanding the total cost over the expected lifetime of an asset, the LCC methodology is also useful for informing management, owners, and development partners of the current state, trends, and drivers of any component of the meteorological or hydrological value chain and for making informed decisions about its sustainability and suitability for the evolving services it supports. It is very helpful for informing about different approaches to the observational network design, selecting in-house or cloud computing resources, and monitoring the financial and operational status of the value chain and replacement of assets. As discussed earlier, this is a means to assess the economy, efficiency, and effectiveness of the NMHS's operations. By accumulating the life-cycle costs year on year, it is possible to determine the actual TCO over the asset's operational life as well as to make decisions about accelerating or deferring maintenance or replacing worn components on or ahead of a planned maintenance schedule, which may reduce subsequent maintenance and downtime expenses.

There are many ways to allocate the costs of operation, maintenance, and downtime. One method assumes that each is a percentage of the initial cost. Although this probably underestimates the cost associated with the asset being out of service, it enables comparison across different assets and potential acquisitions. Another approach uses accumulated depreciation, which is a component of LCC. Depending on the depreciation method used, this will be either a straight line or a curve that more closely reflects the aging of the asset if other common accounting methods—such as declining balance or sum-of-years' digits—are applied. At the end of the expected life of the asset, the accumulated depreciation will be equal to or close to the initial purchase costs. Figure 9 shows the accumulated costs associated with the acquisition of an asset for an initial capital expenditure of US$20,000. The TCO is US$56,600, or 2.83 times the cost of the original purchase, which would be typical for meteorological equipment such as automated weather stations that have an operational life of about 10 years.

Figure 9

Example of the life-cycle costing of an asset with an initial capital expenditure of US$20,000.



Note: Depreciation is calculated using the sum-of-years' digits accounting method. In turn, this is used to estimate maintenance and downtime expenses. Operating expenses are assumed to be constant. The sum of these expenses adds up to accumulated life-cycle costs, which at the end of the 10th year is the TCO. In this example, the TCO is US$56,600, or more than 2.8 times the original capital expense. SoYDM = sum of years depreciation method; TCO = total cost of ownership.

If we assume that the figure represents the ideal situation projected over 10 years, we can compare actual performance against this ideal. If the asset is properly maintained and not exposed to adverse environmental conditions, we can expect it to remain close to the ideal. However, environmental conditions or poor maintenance could be expected to accelerate asset depreciation at a faster rate than the ideal; monitoring this helps understand changes in the life-cycle costs that may differ from the expected behavior over the anticipated lifetime of the asset. In this model, accelerated depreciation would also increase maintenance and downtime expenses. Alternatively, we could introduce a one-time charge that would increase the life cycle cost without affecting accumulated depreciation based on the assumption that this expense is used to restore the asset to near ideal conditions.

Early in the life cycle, unexpected downtime expenses might indicate a problem with maintenance or a poor choice of instrumentation for the operating environment. The objective of the approach is to minimize the TCO while ensuring that the asset operates within its expected parameters and to inform optimal renewal decision-making.

Case studies

The following sections highlight two extremes in the provision of meteorological services. The case of Austria highlights the importance of a well-structured and managed service that provides both public task and commercial services; the case of Sierra Leone highlights the difficulties of providing minimum basic services where the available public sector budget support is severely limited.

Providing meteorological services in a high-income country: The case of Austria

Besides the statutorily required public services, the Austrian Meteorological Service ZAMG had, through a law governing the organization of scientific research in Austria for meteorology and geology enacted in 1990, the opportunity to provide commercial services as part of its portfolio. Commercial services now cover a significant part of ZAMG's overall costs, and the organization is challenged to provide services in a very stimulating and competitive environment. This has enabled ZAMG to contribute to a rapidly evolving field of technical and scientific possibilities.

The legal background for this construction states that cross-subsidies are prohibited, liabilities from commercial activities must be carried by the commercial part of ZAMG, and separate cost allocations must be made for both the public and the commercial part of ZAMG. Activities undertaken in the public domain cannot be hindered by commercial activities of ZAMG. Yearly audits are performed to evaluate the situation considering performance indicators for all types of services, the overall financial performance, and the separation of the cost allocations.

After more than 25 years of commercial activities by ZAMG, several experiences and conclusions can be drawn from this type of setup (Box 4).

Box 4 Principles and preconditions for sustainable meteorological services

In order to run sustainable services of this kind, the following principles and preconditions have proven to be imperative:

- A competitive mindset in the public sector is not the standard setup, but it can enhance the performance quality of public services considerably.
- Commercial activities can contribute significantly to encourage this mindset.
- Feedback—in the form of market acceptance of a service or via a customer satisfaction index for public services—is essential for understanding the behavior of users.
- A clear definition of the public tasks and a readiness to change over time with increasing technical and scientific possibilities are a subject of dialogue with many different types of stakeholders.
- Autonomous management with clearly defined deliverables and a background both in meteorology and market mechanisms are a necessary precondition.
- Accrual accounting and cost allocation through the value chain for each service is the basis for understanding the financial viability of all services.
- Audits both for quality assessment and for key financial indicators provide the responsible authorities with sufficient confidence about the accomplishment of the tasks dictated by law.

Other government agencies often have an initial reluctance to share data across sectors, as data ownership and data usage can provide an advantage in competition for public funding.

Activities

The public tasks performed by ZAMG are centered around the precautionary principle and the safety not only of people in Austria, but also Austrians active abroad; such as providing weather forecasts for expeditions in the Himalayas. Warnings for extreme weather events are one of its main activities, but ZAMG also provides climate services for a wide range of users in land planning and agriculture as well as for regional and local authorities. The environment sector is taken care of by its emergency planning tools to use in the event of contamination by natural and anthropogenic sources, like volcanic eruptions or incidents in chemical plants as well as environmental impact assessments.

Typically, ZAMG's user-oriented approach was modified to provide delivery of impact-oriented and impact-based warnings for extreme weather events. Meteorological warnings that are focused on meteorological phenomena only are easy to produce and can, in some cases, be products taken directly from numerical weather models. The input of experienced forecasters can improve the quality of the forecasts via knowledge of local climatic and other conditions, but this input does not have to be limited to meteorology alone. Impact-based forecasts see the forecast problem from the point of view of different users and describe the probable effects of a given weather situation. This approach requires additional information about other parameters such as local conditions of previous inundations, soil moisture, and so forth in the case of flooding or landslides.

In all cases, impact-based forecasts require cooperation and data exchange with a wider field of data producers and/or data gatherers. Other government agencies often have an initial reluctance to share data across sectors, as data ownership and data usage can provide an advantage in competition for public funding. To overcome problems of this kind, through the United Nations Office for Disaster Risk Reduction (UNDRR), ZAMG organized a National UNDRR Platform for natural and manmade hazards following the Sendai Framework.[8] This platform comprises members of most ministries, emergency responders, regional authorities, the insurance sector, and other stakeholders, including some from the private sector.

This circle of actors allows an exchange of ideas, concepts, and user requirements across sectors, building trust and mutual support when it comes to the use of public funds. Another effect of this cooperation is a significant increase in the user orientation of all participants toward each other and toward the users of public activities. Impact-based warnings were one of the first requirements of emergency responders, who, on their side, contribute to the warnings and situation assessments by providing crucial online field information to the forecasters in the form of images via a ZAMG-designed application.

The separation between public and commercial activities can be a delicate process for a weather service as users tend to require as many products and services as possible to be public and free of charge.

In terms of climate services, ZAMG provides downscaled climate scenarios for a variety of purposes, such as land and city planning, agriculture, tourism, insurance, and energy, and all activities connected with the changing water resources of the future. Here again close interaction and data exchange with other government agencies and institutions is important to cross barriers between silos of different thinking and concepts. Impact concepts and user orientation in these fields mean following the value chain to the very end and understanding, for example, the cost implications of a certain measure in a city planning process to prioritize research activities.

The commercial activities of ZAMG are based not only on classical business integration of the services mentioned above but also on other elements of the internal value chain of ZAMG services. Having research and development funded by national and international (mostly European Union, or EU) sources comes with a framework of conditions of cooperation with other institutions in consortia, common intellectual property rights (IPR), and business cases for the final products. This allows ZAMG to share scarce resources with other partners, share the income from common products, and gain experience and expertise in fields where the capacity and the resources of a midsized weather service alone would not be sufficient.

Cooperation on production development is also undertaken with partners from the private sector without external research funding when the knowledge elements are complementary, and where a common goal and business case can be defined and followed through. The future local-scale radar system in Austria is one example of this outsourcing in cooperation: it is undertaken with a private company setting up the stations and developing radar data interpretation together with ZAMG. Dissemination of the data and products and the division of incomes are undertaken together in a public-private enterprise-type cooperation.

The separation between public and commercial activities can be a delicate process for a weather service as users tend to require as many products and services as possible to be public and free of charge. The legal basis for the public service elements defined by law is often only cursory and quickly outdated. In Europe, the 2019 Public Sector Information Directive defined “High Value Data Sets,”[9] which have to be further detailed in national law from 2021 onward. The free supply of data both to private sector companies and the commercial arm of ZAMG defines and levels the playing field for the provision of meteorological services on a zero-cost basis. At least as important as the actual producer-user relationship of a particular meteorological service is the readiness to pay for services. This reflects directly how much the service contributes to the value chain of the user and how satisfying the service is in the long run.

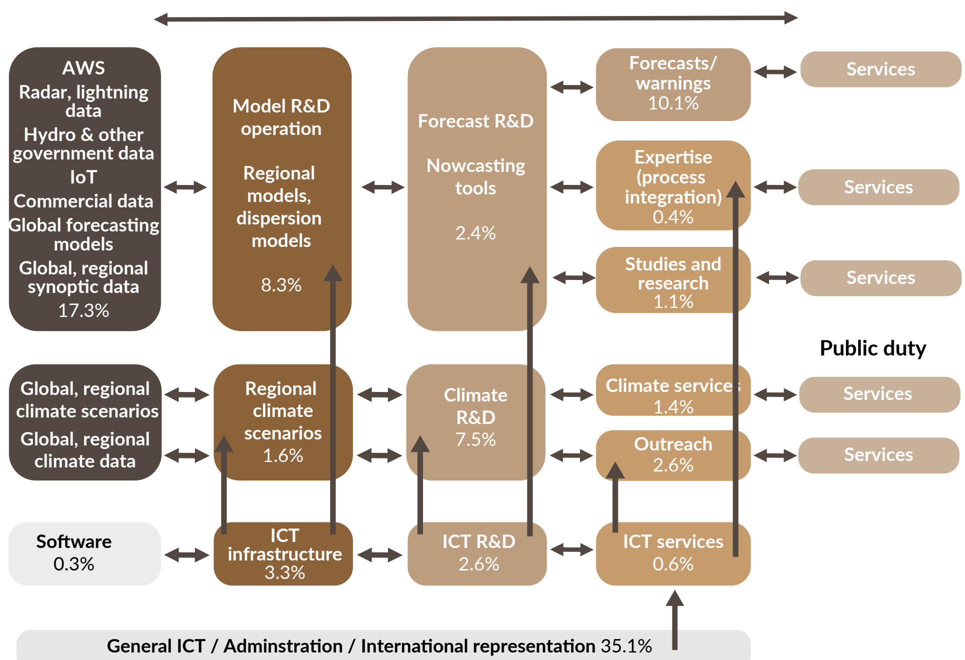
A yearly detailed customer satisfaction index evaluation is therefore undertaken at ZAMG to give each department direct feedback about the efficiency and effectivity of its contribution to the value chain, along with indications or direct advice for possible improvements. This "management-by-objectives" approach is in many cases a change of paradigm for public services, but it helps to quantify performance in a very straightforward way.

Costing service objectives at ZAMG

Financial controlling at ZAMG is done via accrual accounting and cost allocation for each element of the value chain as described in Figure 10 and Figure 11 for the public and commercial arms of ZAMG. Budgets are on the order of €21 million for the public component and €12 million for the commercial one.

Figure 10

Value chain and costs attribution to the main elements of the public sector component of ZAMG.



Note: AWS = automated weather stations; ICT = information and communication technology; IoT = Internet of Things; R&D = research and development.

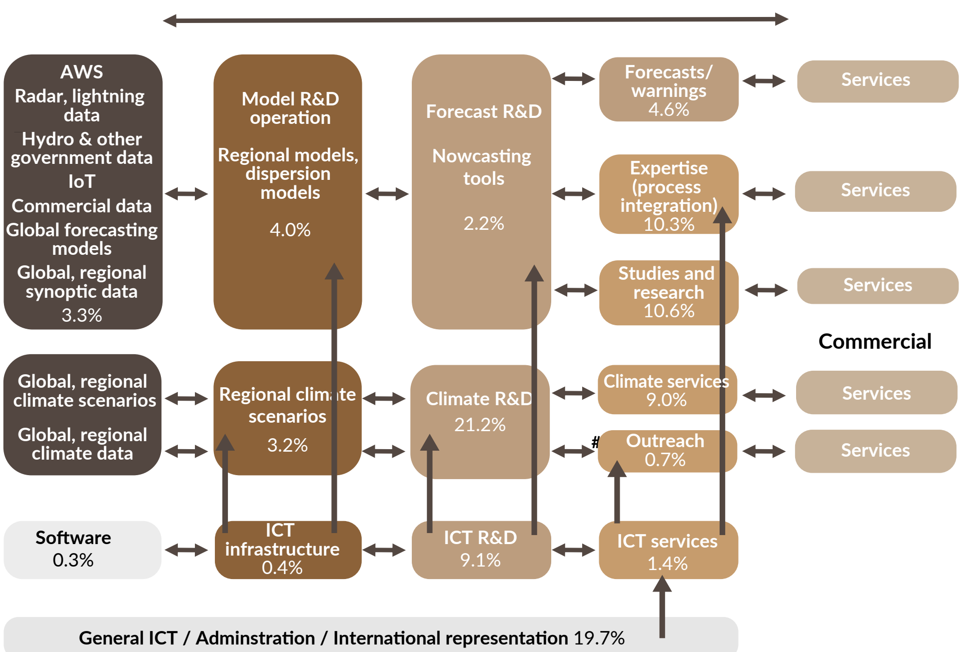
The main purpose and principle of accrual accounting and cost attribution are to allocate costs of service types to all elements of the value chain with as much direct attribution as possible, with unattributable general costs designated as "overhead." The *General ICT / Administration / Infrastructure /* and *International representation* category contains contributions to international institutions, so this component is probably larger for Austria than it is for other midsized meteorological services outside Europe. It includes, for example, Austria's contribution to the European Centre for Medium-Range Weather Forecasts (ECMWF), which co-funds all the Center's activities and free service provisions outside Europe as well. If ZAMG were to buy only ECMWF products without membership, costs would be reduced to a tenth of its present contribution. Membership in ECMWF allows it to participate in the development of models with the associated exchange of knowhow and reflects the obligation of high-income countries to contribute to development cooperation, as ECMWF products are available to developing countries in most circumstances for free and provide one of the most cost-efficient forms of support for these countries.

The cost distributions between the public and commercial arms differ quite significantly in some elements for various reasons: 17.3 percent of the public budget is intended for data acquisition, quality control, and related activities. The commercial arm pays the public arm for data at the same price other commercial companies pay for these data, which is 3.3 percent of the total commercial costs.

Climate research and development costs are higher in ZAMG's commercial arm than in its public arm, as serious investments have been undertaken here. It is very important to know and calculate internal ICT services in detail as they are a significant cost driver. Here a cost allocation is also an important decision-making element for possible outsourcing options.

Figure 11

Value chain and costs attribution to the main elements of the commercial sector component of ZAMG.



Note: AWS = automated weather stations; ICT = information and communication technology; IoT = Internet of Things; R&D = research and development.

In summary, the combination of public and commercial activities in one service requires a transparent overview of costs in both components with audit mechanisms that reveal both the efficiency and effectiveness of the public means provided and entire avoidance of possible cross-subsidies. A competitive mindset introduced through competitive commercial activities and management techniques have proven to be one of the most achievements for the public component.

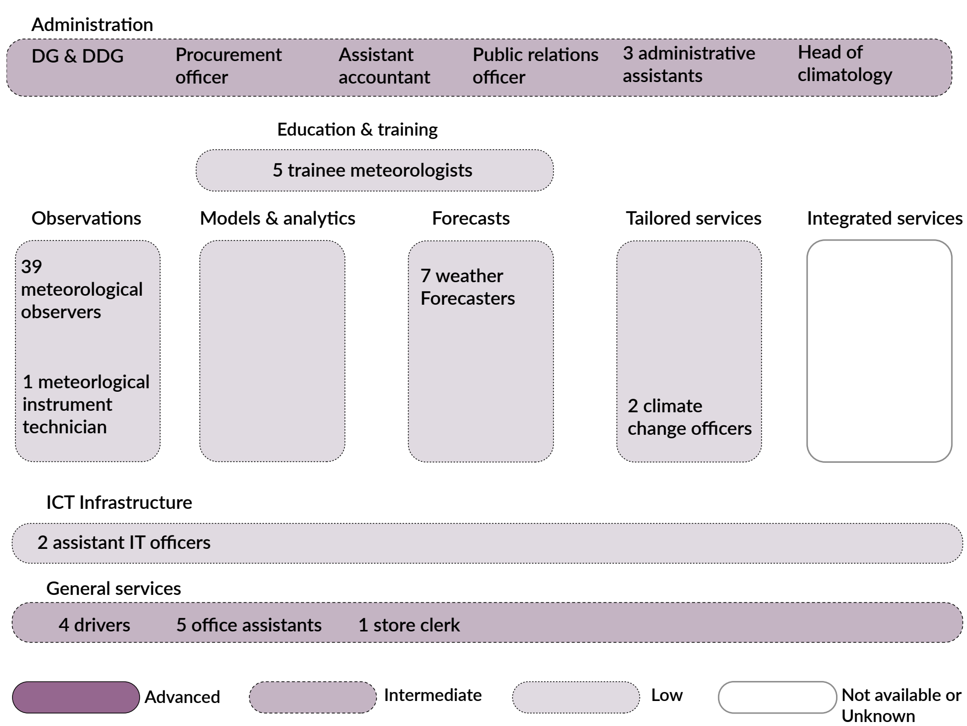
Providing meteorological services in a least developed country: The case of Sierra Leone

The Sierra Leone Meteorological Service, SLMet, is a small agency mandated to provide weather and climate services as the country's national service provider. Its mission is to provide timely, accurate, and reliable weather and climate observations, data, forecasts, and early warnings to protect life and property and to enhance the resilience of citizens, institutions, and the economy to severe weather and climate extremes. It has 75 employees (47 existing staff plus 28 new staff recruited in recent years) located in its headquarters, the national airport, and eight subnational offices. Its annual budget allocation is approximately US$576,000, of which US$418,000 is for staff salaries that are paid directly by the Ministry of Finance. The remaining allocation covers operating costs, but in practice SLMet receives only half its funding allocation.

A recent survey by the authors of this technical note assessed the maturity level of the observing network. The results showed a relatively satisfactory total number of stations; however, the actual number of functioning stations is far lower than the total because of faulty or missing sensors. The functioning sensors record basic parameters such as air temperature, wind speed and direction, relative humidity, rainfall, solar radiation (plus a few other parameters for the agrometeorological and marine observing stations). All stations are operated manually. The observing staff totals 39 plus 1 meteorological instrument technician stationed at eight subnational offices in addition to the headquarters and the international airport, where general forecasters and aviation forecasters are situated. Other technical staff include 7 forecasters (only 2 of whom are trained meteorologists).

Figure 12

Schematic of maturity level of the SLMet value chain including allocation of staff to different links in the value chain.



Note: DG = Director-General; DDG = Deputy Director-General; IT = information technology.

In theory, SLMet occupies four links in the value chain: *observations*, *models and analytics*, *forecasts*, and *tailored services*. The *models and analytics* link is included because SLMet has access to outputs from the UK Met Office's tropical convection and unified models—with the former running at a resolution of about 4 kilometers. This tool has the potential to provide high-quality guidance. However, it is under-utilized (Figure 12) primarily because of the limited training of the forecasters, The tailored services include their support to aviation, marine, and some climate services. Since activity-based accounting is not practiced by SLMet at present, it is not possible to assign expenses to each of the services produced directly. However, the following assumptions can be made:

- All available observations are used in the production of all services.
- Fifty percent of forecasters' time is spent on general weather forecasts and warnings.
- Thirty-five percent of forecasters' time is spent on aviation services.
- Fifteen percent of forecasters' time is spent on marine services.
- Two staff are dedicated full time to the provision of climate services,
- ICT supports all services.
- Administration and general services are overhead costs applied to all services.
- Trainee meteorological staff are distributed across all services.

Current expenditures in the various value chain links and supporting activities and staff assignments as percentages of the budget and total staffing of the organization are shown in Table 1. The budget is a combination of the government allocation, receipts from tailored services, and donor support—particularly for training and equipment.

Table 1

Schematic of the total cost of ownership comprising five key components.

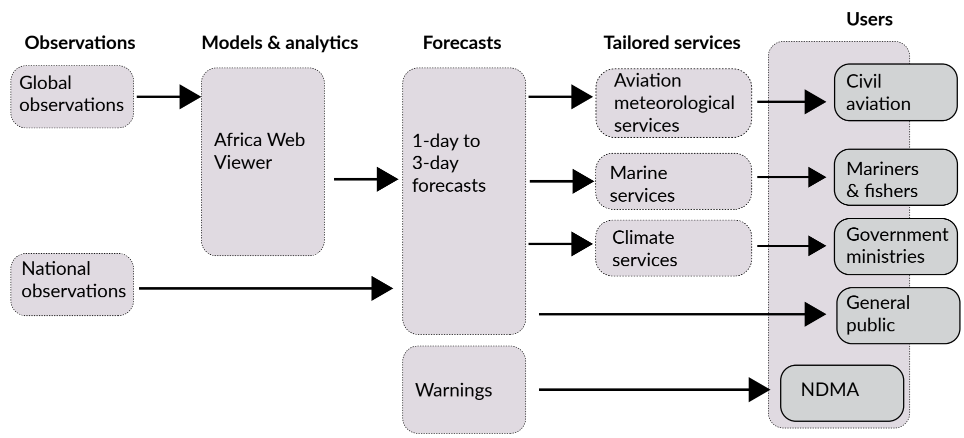
Link or supporting activity	Percentage of expenditure (including salaries)
Observations	42.3
Models and analytics	0
Forecasts	6.5
Tailored services	2.2
ICT infrastructure	5.2
Administrative and general services	26.4
Capacity building and training	11.9
Equipment	5.5

Source: Data from SLMet.

Based on these assumptions, SLMet expenditures, and staffing levels, it is estimated that approximately 42.3 percent of SLMet resources support observations. The largest category of expenses is associated with indirect or overhead costs, including administrative and general services, ICT infrastructure, capacity building and training, and equipment. Forecasts and tailored services include general forecasts and warnings, aviation meteorological services, marine forecasting services, and support for climate services. These services can be shown along the value chain along with the main users of these services (Figure 13).

Figure 13

Summary of services provided by SLMet following the value chain.



Note: Warning information is made available to all sectors through the National Disaster Management Agency (NDMA). Non-warning-related information flows are indicated by the gray boxes.

The *tailored services* link in the value chain is used to include any service to which value has been added beyond the *forecasts* link. This does not imply that those services are compensated directly. Warnings apply to all users and are delivered either directly to users or through the National Disaster Management Agency (NDMA) or both. The *Africa Web Viewer*, which incorporates global observations and numerical products, is the only analytical tool currently available to SLMet, and it is assumed that this is used directly by forecasters. National observations are assumed to contribute to the forecasts and are therefore incorporated into all the services provided by SLMet. These are observations taken by staff rather than through any automated process. This summary of services does not take into consideration the quality of each service separately but assumes a low level of maturity for all services based on the assessment summarized in Figure 12.

The applicability of the ZAMG model to SLMet

What insights can be deduced from a comparison of the distribution of the operational expenses of ZAMG and SLMet and can this understanding be more generalized to other meteorological services? Albeit subjective, it is apparent that SLMet spends much less of its budget on the actual provision of services than ZAMG does. Staffing is heavily skewed toward the observational network, which is a typical difference between high-, middle-, and low-income country meteorological services. More skills and, of necessity, more staff are clearly needed in the provision of services in SLMet. Could the level of services be expanded while at the same time improving the quality of service? In SLMet, there is a large staff commitment to observations. Is there an opportunity to enhance the observational network by improving field observers' skills? Nowcasting and very short range forecasting are obvious needs given the frequency of potentially life-threatening, short-lived, intense convection-driven rainfall events.

European and tropical weather differ considerably. Where model guidance can be used with limited intervention from forecasters in Europe, the skill of models in tropical Africa, where convection is dominant, remains limited and the role of the forecaster is critical. As already mentioned, tools such as the UK Met Office's tropical convection-permitting model are available operationally; however, these are not well calibrated for Sierra Leone using local observations. Consequently, the guidance from this model is underutilized. It is noted that ZAMG makes full use of model products, including its own regional model. While the latter is not recommended for Sierra Leone, given the high resolution of the products available from global centers, some staff need to focus specifically on numerical prediction to maximize the utility of model products (Rogers et al. 2020). This work includes bias correction and calibration of existing model products, especially convection-permitting models, and eventually, with more investment and training, downscaling and point forecasting using artificial intelligence techniques.

As developing economies become increasingly sensitive to weather-related information, it is important that national meteorological services look beyond their traditional remit of safety and security to consider how they contribute to the wider economy.

From a budget perspective, apportioning more of the expenses currently allocated to indirect costs would help quantify the full cost associated with each service and the overall affordability of SLMet. As developing economies become increasingly sensitive to weather-related information, it is important that national meteorological services look beyond their traditional remit of safety and security to consider how they contribute to the wider economy. ZAMG achieves this through the provision of commercial services. In the circumstances of SLMet, such economic opportunity may not currently exist and may be a distant goal. However, SLMet could be prepared to develop such opportunity, potentially in collaboration with the private sector. The commercial operating model of ZAMG adheres to the concept of a level playing field; that is, it competes fairly with the private sector. This would be an appropriate model to adopt in developing commercial services in Sierra Leone. Commercial services are discussed in more details in a later section "Potential pathways to affordability."

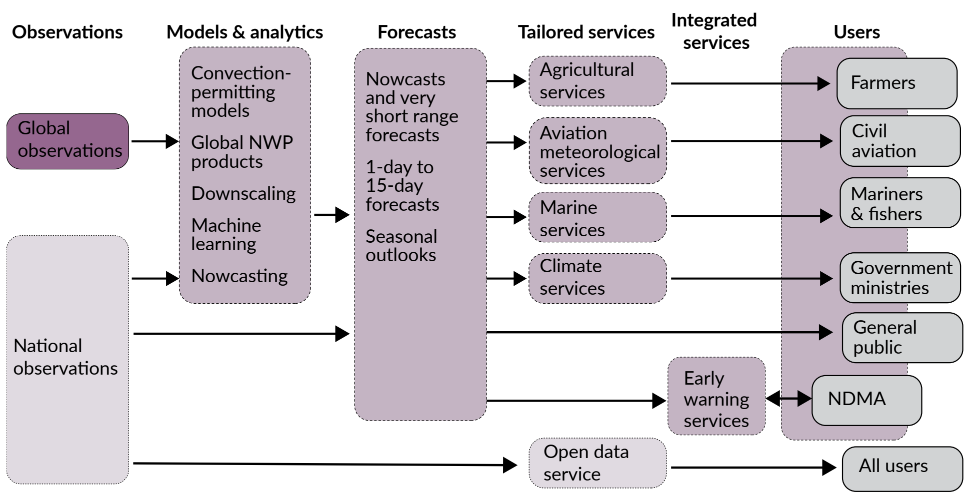
Is this discussion relevant to other meteorological services? The comparison of ZAMG and SLMet serves to highlight the differences between an organization that focuses on relating its costs to activities and one that does not. These are general principles related to business practices that are universally applicable. Applying basic accounting practices do not of themselves ensure funding, but it certainly contributes to understanding how well any organization is managed and financed.

Jump-start

The authors of this note have been exploring various options to improve the situation in Sierra Leone. A "jump-start" approach, based on *The Power of Partnership* (World Bank 2019) is proposed, that would enable an immediate improvement in the ability to provide more accurate forecasts and warnings than are currently available by engaging an external entity specializing in the provision of operational meteorological services.[10] A team of forecasters with access to their own external forecasting center would operate from SLMet headquarters. This would be an integral part of efforts to build long-term capacity within SLMet with existing staff and new recruits working alongside the firm's staff. The approach would enhance all the services shown in Figure 12, adding the capability to use products from global modeling centers more effectively. The maturity levels of the models and analytics, forecasts, and tailored services links and the quality of services to recipients would increase. Initially, national observations would remain at a low level of maturity (Figure 14), with the intervention used to assess the observational requirements and affordability of network improvements. This approach would enable SLMet to quickly meet some of the critical expectations of its service recipients, while providing an opportunity for a measured approach to improving the links in its value chain. Besides improving services, the jump-start would also enable SLMet to demonstrate to the government the benefits and a realistic assessment of the costs of a higher level of services.

Figure 14

Summary of services provided by SLMet using the jump-start approach to enhance key aspects of the value chain.



Note: Warning information is made available to all sectors through the National Disaster Management Agency (NDMA). Non-warning-related information flows are indicated by the gray boxes. Here early warning services are integrated services, meaning that they are jointly developed and include non-meteorological information such as the vulnerability of people and assets. NWP = numerical weather prediction.

At this stage in the development of SLMet services, enhancement would be mostly the result of access to expertise in *models and analytics*—convection-permitting models, global NWP, downscaling techniques, machine learning, and nowcasting. Given the poor performance of global NWP in the tropics—often no better than climatology—emphasis would be on improving short-range forecasts using convection-permitting models or a combination of these and global NWP models that are already available and could be made available digitally. Accurate measurement of the thermodynamics of the atmosphere is vital, so consequently upper-air observations are needed. At present, the only reliable sources of upper-air data in the region are in Senegal and Côte d'Ivoire. The station closest to Freetown in Sierra Leone is Guinea, but it is not currently operational.[11]

An adverse result of convection is heavy rainfall and flooding. Local estimates of rainfall are needed for nowcasts and very short range forecasts. Rain gauges combined with satellite observations are the most cost-effective measurements. Quantitative precipitation estimates from radar would be helpful, but maintaining radars is expensive and requires technical expertise not currently available. Consequently, this is a lower priority, in the authors' opinion, than investing in twice daily radiosonde launches that could underpin a wider range of services.

Together, these enhancements would contribute to improved warnings services, which are now part of the *integrated services* link incorporating inputs from meteorology, hydrology, and disaster management. Although at a low level of maturity, since observation data have value beyond their use in meteorological applications, an open data service is also recommended. This would be expected to be a public service at no cost to the user. Open data policies are highly desirable and likely to increase economic opportunities if the data are shared, used, and reused without restriction (Rogers and Tsirkunov 2021; Rogers et al. 2021b; Thorpe and Rogers 2021).

Figure 12 and Table 1 makes clear that the observational network is very limited and human capital intensive—staff costs come to 91 percent of the expenditure allocated to observations. Given that the jump-start activities would address other aspects of the value chain but also depend on in-situ data, it follows that targeted investment in the observing system would be a complementary step but also would require an increase in the operational budget to accommodate the increase in maintenance associated with an expansion of the observing network. Refurbishing and upgrading the Freetown airport synoptic station and restoring an upper-air station at the airport or in Conakry, Guinea—given its proximity to Freetown—would contribute to this and consequently underwrite improvements in the quality of aeronautical meteorological services.

Since the cost of operations at the airport can be at least partially offset by aviation charges, the additional investment here may be justified and may not require a significant increase in government appropriation. This would depend on reimbursing SLMet, as the service provider, for improvements in the services provided to aviation. This is not current practice. Data shared through the Global Telecommunication System would be available to the global modeling centers. These data would also be used to calibrate the convection-permitting model products for Sierra Leone. These steps could be undertaken prior to any full-scale modernization program. The rehabilitation and expansion of the rest of the network can be informed by analytical work undertaken within the jump-start.

Potential pathways to affordability

The hydromet value chain suggests various pathways to create more sustainable NMHSs. While debate continues about the efficacy of public institutions providing commercial services, Rogers et al. (2021b) conclude that limited public financing restricts both the level of services that can be performed as public tasks and forces NMHSs to actively pursue commercial opportunities, sometimes even at the expense of their public tasks, to sustain the overall integrity of their operations. In some instances, such as the case in Austria, commercial activities are pursued for the opportunity to bring new skills into the service and improve their quality as well as to generate revenue. As in the case of ZAMG, it is assumed that the public entity operates within a competition framework that ensures a level playing field and a stable market. An important step is to include basic meteorological and hydrological observational data and products as part of an open data policy whereby these data can be used and reused without restriction. This is important to ensure a fair commercial market and has enormous macroeconomic benefits inside a country as well as on an international level both for short-term warnings and long-term planning activities to increase resilience and optimize resource usage. If an open data policy is not established, then commercial activities are likely to be limited, inefficient, and monopolistic with little opportunity for growth. Rogers et al. (2021b) highlight other policy and structural reforms required to improve the weather, climate, and water services market and increase social and economic welfare.

Many NMHSs will have some experience in providing tailored services through their responsibilities as aeronautical meteorological service providers. However, many perform this task poorly and do not provide sufficient transparency in accounting to convince the customer that they are receiving the service for a fair price. There is a tendency to overburden airlines with the costs of services that go well beyond those required by civil aviation. Assuming that these services can be offered at a fair market price—the price that the buyer is willing to pay—this approach may be a suitable business model for other commercial services (Box 5).

Box 5 Requirements for an NMHS

An NMHS needs to:

- Ensure that its financial records are transparent and that it conforms as closely as possible to activity-based accounting.
- Be able to cost each service objective by identifying the expenses associated with each element of the value chain.
- Utilize total cost of ownership and life-cycle costing accounting methods to minimize the cost of services while maximizing value to its beneficiaries.
- Be able to clearly state the public task and performance metrics so that the public understands what they can expect from the service and its limitations.
- Understand the commercial service requirements and minimize development costs of new services by using techniques such as the lean startup (Rogers et al. 2021c).
- Develop a business model and plan for each service objective in the value chain, including knowing when to coproduce services with others (Rogers et al. 2021a).
- Be able to retain revenue from cost recovered and for-profit services.

What are the opportunities for an NMHS? These will vary from country to country and the current level of economic development. They may be a mixture of services to the private sector provided by the NMHS or they may be part of a government investment in a private enterprise (Rogers et al. 2021b), or coproduced services as part of a joint venture between the public and private sectors, or in competition with the private sector. Some potential commercial services are listed in Table 2.

Table 2

Some potential commercial weather activities.

Tailored services (non-public tasks)	Description
Water resources	Provide rainfall forecasts to manage dam operations to avoid overtopping and operator-induced downstream flooding. Experienced forecaster intervention may be of high value.
Insurance	Deliver data service providing *quality assured* gridded digital information suitable to optimally price insurance certificates.
Wind farms	Deliver weather forecast products designed to optimize scheduled maintenance for onshore and offshore infrastructure. Experienced forecaster intervention may be of high value.

Table 2

Some potential commercial weather activities (cont.)

Tailored services (non-public tasks)	Description
Wind energy	Integrate meteorological parameters into software tools used to manage energy generation.
Energy distribution	Provide peak load estimates, optimize and minimize electrical energy production costs, and protect infrastructure.
Licensing of commercial service providers	Establish standards and requirements for the operation of commercial weather services in the country (would require national legislation).
Agricultural business	Integrate weather information in precision agriculture software systems to improve the efficiency of planting, farming inputs, and cropping. Provide enhanced farm/climate extension workers.
Seaport operations	Integrate weather and marine information into port operations software designed to optimize the efficiency of ports. Includes information of high winds, sea state, lightning, and so on. Experienced forecaster intervention may be of high value. Could integrate with shipboard systems operated commercially by shipping companies to optimize port arrivals and along route fuel use.
Airport operations	Provide terminal area forecasts, significant weather, and other information as required by civil aviation. Should have an approved quality management system in place.
Rail transport	High-speed train operations are highly susceptible to winds. Require monitoring and forecasting system along route. Integrate information into scheduling and timetables.
Road transport	Optimize routing and departure times of lorries/trucks and long-range buses/coaches; integrate information into schedules and timetables.
Coastal sea transport	Optimize ferry sailings to maximize passenger comfort; integrate information into schedules and timetables.
Marine operations	Provide marine forecasts for offshore activities (oil and gas).
Retail	Optimize sales of food products and clothing.
Tourism	Optimize tourist experiences with enhanced local weather information at important geographical locations with tourist-specific warnings for extreme events.
Construction	Integrate weather information into construction schedules to minimize costs and delays.
Telecommunications	Detect lightning and rainfall for signal optimization and infrastructure protection.
Media	Provide commercial television and radio weather broadcasts, print media, weather apps, and websites with paid advertising.

Except for aeronautical meteorological services, all of the services in Table 2 are primarily economic activities. They may be offered on a cost-recovery basis or on a for-profit one. A level playing field is a necessary pre-requirement in both cases to avoid market distortions or monopolistic market structures. Arguably, other safety-related services to particular sectors could be supported in a similar way but, unlike international civil aviation, which is governed by convention, these would require national legislation. If any of these tailored services exist, except for aeronautical meteorological services that are authorized and regulated by the government, one or more private providers are likely to be active. Assuming that services are nascent or nonexistent, there is an opportunity on the part of the NMHS to develop and shape the future market.

There are a limited number of financial models to support an NMHS that has a public task and pursues commercial activities. First, it is important for governments to understand that they have an obligation to support the agreed public task of the NMHS. The quality of the services that are part of that public task is limited by the amount of funds that the government is willing to provide. There is, of course, an inherent tension between the requirements of the public as service recipients, the desire of the NMHS staff to satisfy those needs, and the affordability of the service. Public services cannot and should not be subsidized by other potential revenue-generating activities; however, this does not mean that the expense of links in the value chain cannot be shared among different services based on the requirements of each of those services. The judgment of the European Court of Justice in the Case Altmark Trans brought clarity for the financing of public services in EU Member States.[12] The decision distinguishes between state aid and compensation paid for the delivery of services of general economic interest and clarified the circumstances in which the financing of public services would qualify as public service compensation. The decision proposes a framework for the application of EU rules. Public service compensation needs clear criteria to avoid market distortion by public subsidies (Box 6).

Box 6 Financing and service models

Possible financing and service models for NMHS are:

- Public tasks are financed by government (scaled to the available funding) with the statutory tasks matching the available financial and human resources.
- Tailored services (which are not part of the agreed public task) to other government departments (reimbursed by department) may be on a cost-recovery basis (see Rogers et al. 2021c).
- Cost-recovery aeronautical meteorological services model reimburses the service provider.
- Flight information region provides payments for overflights of the country (sometimes reimbursed by a third party).
- Tailored services are provided for various economic sectors.
- Coproduced services (integrated services) are provided with private sector entities.

Each of these financial models can coexist. The time taken to prepare a weather warning is a uniquely public task and the expense associated with that activity should be assigned to the public task. However, providing the underlying observational data used in the forecast that results in the warning may be a shared expense among several services. For example, as mentioned above, upper-air data from a radiosonde is used in the preparation of an aeronautical forecast, in analyzing the potential threat of heavy rain, and in various other forecasting applications. Consequently, the expense can be distributed among different tailored services as well as the government-funded public task.

It may be immediately apparent that defining the public task and its limits is critical, otherwise other government departments may assume that all of products of the NMHS are available without direct cost to them. If, for example, the production of warnings of the impact of hydromet hazards may require inputs from the meteorological agency, the hydrological agency, and disaster management, the roles of each should be defined as part of its public responsibility. It is also assumed that assignment of such task will be supported by relevant public resource allocated and not subsidized by fee-based services.

Developing new services and building a recipient base that trusts, uses, and—in the case of a commercial service—pays is difficult. An NMHS that is poorly financed and poorly staffed to provide its public task is unlikely to be able to develop high-value commercial services without external investment and technical assistance. Hence, NMHSs frequently fall back to restricting access to and selling basic data. This kind of activity neither has high intrinsic value nor does it stimulate the development of a commercial market. A roadmap describing the necessary preconditions before an NHMS is ready to undertake commercial activities needs to consider the speed of institutional/regulatory changes and the mindset change within a public service, which is optimistically on the order of at least three to five years. Expectations that are raised too high and poor management often contribute to service failures and result in loss of credibility. Endurance and close monitoring and coaching for these tasks pay off.

It follows that external investment ostensibly focused on improving the delivery of an NMHS's public task could also create opportunities for tailored commercial services. As discussed earlier, observational networks are foundational to the value chain. Life-cycle costs of most of the components of an observing network are high and the cycle is relatively short (about 10 years), with significant expenses associated with O&M. It is important therefore to be able to distribute the expense of the network among as many service recipients as possible. It was noted that about 42 percent of the expenses of SLMet were associated with their observational network. To offer existing service recipients improved services at nominally current costs, new tailored services would have to be developed to match, at a minimum, the increased expense of the network.

Is this feasible? It would require a relatively long period of external support to maintain the operational network while new services are developed. A lean startup (Rogers et al. 2021c) could yield a new service in about 18 months, but—given the need to build staff skills or contract those skills from the private sector or academia—the process would likely take much longer. Assuming that multiple services would be developed, a business division would be needed to manage these activities. In addition to supporting the observational network, this division would also require external investment. In the private sector, a startup takes up to three years to return a profit, but some take longer. In the case of a public institution entering this market, we can assume a longer process—perhaps five years for a return on capital employed. In a nascent market, it would likely be in the interests of a private company or academic entity or both to develop a joint venture with the NMHS since this should reduce risk to all parties. The coproduction of products and services should therefore be encouraged, perhaps initially with targeted support from the government and development partners. A lot depends on the willingness of government to create a flexible business environment for the NMHS. Some of the changes needed for NMHSs' flexible business environment would require changes across the whole public sector. And this would require higher-level engagement. This may be challenging for traditional departments but less so for agencies with more autonomy (Rogers et al. 2021b).

Summary and conclusions

In this technical note, we have explored some of the critical ingredients required to make NMHSs, the infrastructure they operate, and services they provide affordable. While we have often assumed that governments should fully fund NMHSs and thereby achieve a high level of service objectives within the public task of the agency, in practice, the complexity of modern meteorological and hydrological services makes this increasingly difficult to achieve because governments either under-value the public task or lack the financial means to match the increased costs of these services. Observational networks are particularly vexing—they are vital, but, as technology improves, they become increasingly expensive because they require higher levels of skills to operate and maintain. In addition, they often use increasingly more utilities—electricity and telecommunications—as well as more resources to manage and utilize these data.

Poorly managed NMHSs face the reality of falling further behind the more advanced and better financed agencies without broadening their income base. Priorities must be clearly set, and the management of public tasks must be closely monitored before undertaking commercial tasks, especially in the first phase of a new setup.

Inevitably, there are tensions around support for and access to observations. At the base of the value chain, observations are both the most expensive link and have the lowest intrinsic worth because realizing their value requires additional effort. Value is created through analysis, assimilation into models and tools, interpretation, and combination with other data and information. This transformation leads to useful high-value products and services. Accordingly, the value of the observational system is realized only by generating products and services. Maintaining a stranglehold on observations by restricting access so that the NMHS can sell data is a poor business practice among the many that could be developed by an NMHS and should be avoided (Rogers and Tsirkunov 2021; Rogers et al. 2021b).

The global NWP requirements for sustained surface and upper-air observations offer a new source of support for some agencies in countries where these observations are inadequate—mostly small island developing states (SIDS) and least developed countries (LDCs)—through the Systematic Observations Financing Facility (SOFF),[13] which aims to support GBON.[14] Covering capital investment and contributing to the O&M expenses using a results-based financing scheme, such as SOFF, will help stabilize the basic observational network and improve global NWP performance, and, while not a panacea for the underfunding of the NMHSs' public task, this has the potential to provide a firm foundation for future NMHSs' services, at least for SIDS and LDCs. As noted in the case of Sierra Leone, the tropical atmosphere is not readily predictable with present global NWP systems; enhanced upper-air observations will help but will be more useful in convection-permitting models focused on smaller geographical areas. This needs to be kept in mind as the SOFF develops, since many SIDS and LDCs experience similar meteorological conditions dominated by convection regimes.

Intellectual property rights, competition law, and, increasingly, trade policies become significant issues where public and private sector commercial interests become entangled. Here compliance with competition regulations and national and international data policies is critical, particularly around the re-use of data in commercial applications and the level playing field (Rogers et al. 2021b). Table 3 summarizes some of the key areas that need attention to improve the affordability of NMHSs. Ultimately, these areas point to justification for investment in all aspects of the value chain but are targeted to the development of specific services. With respect to national observations, this should result in a network that provides value to a wide range of individual and separately costed services, each of which contributes to the expense of the network.

Table 3

Summary of areas, actions, and requirements to improve the performance of an NMHS.

Area	Actions	Requirements
Legal status	Ensure that the appropriate policies and regulations are in place to enable the development of the NMHS. This should include specific formulation of NMHS public tasks, open data, and intellectual property rights policies.	Acts, regulations, and policies
Financial accountability	Satisfy any entity putting funds into the NMHS that the organization is operating effectively. The scope of investment should match the test of potential sustainability of investment.	Compliance with international public sector accounting practices
Costing of services	Use activity-based cost and accounting that provides insight into the cost and expense of each service provided by the NMHS. This helps to improve efficiency and possibly eliminate high-expense, low-demand services in favor of higher-demand ones. Management is then in a better position to make tactical and strategic decisions.	Service-oriented, activity-based accounting system; benefit-to-cost analysis
New systems	Introduce new systems in a structured systematic manner that tests alternatives to achieve expected improvements in services at minimal expense.	Concept of operations (CONOPS), asset inventory, total cost of ownership (TCO), and life-cycle costing (LCC)
Tailored services (public)	Ensure that public functions are fulfilled and that a legal framework facilitates private sector development. This could be done exclusively by the NMHS or in a joint venture with the private sector or academia.	Investment
Tailored services (commercial)	Establish a unit to develop commercial services to enhance the market, ensuring a level playing field for competition and partnerships with the private sector.	Investment Implementation of processes such as the lean startup to create new products

For many development partners, making NMHS affordable requires expanding and re-focusing investments in NMHSs to explicitly consider their role in the provision of commercial services within the wider enterprise. Although many NMHSs do not regard themselves as providing commercial services, many restrict and sell data; consequently, in practice they are providing commercial services, albeit based on a highly ineffective and flawed business model. Specific investments would be needed to build business skills and increase or engage sector-specific expertise. Some advanced NMHSs have succeeded in developing commercial expertise; others have focused on fulfilling their public task only. The latter tend to be fully supported by their governments to provide a high level of skill in their public service, while the former are encouraged to increase their skills and improve their efficiency through competition and engagement with the private sector. While both approaches are valid, the problem is that most NMHSs in developing countries are not capable of fully discharging their public obligations or providing viable commercial services. The task of development institutions and the WMO is to facilitate the transition described in this paper.

Notes

1. https://www.ifac.org

2. "Cash basis accounting" recognizes all revenue as it is received and all expenses when the money is spent. "Accrual basis accounting" recognizes when revenue is earned and expenses when they are billed. The cash basis of accounting does not always show an accurate image of the true financial state of an organization since it does not reflect unpaid accounts payable. Accrual accounting tends to provide a more realistic financial view over the long term and is helpful for organizations with large inventories.

3. https://www.ipsasb.org/about-ipsasb

4. https://www.ipsasb.org/publications/2020-handbook-international-public-sector-accounting-pronouncements

5. The Global Weather Enterprise is the value chain of activities of the public, private, and academic sectors providing accurate, reliable, and timely weather- and climate-related information. It contributes to the safety of life and property, poverty reduction, and the promotion of economic development.

6. https://www.europeandataportal.eu/en/highlights/economic-benefits-open-data

7. https://community.wmo.int/gbon

8. https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030

9. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2019.172.01.0056.01.ENG

10. This entity would be a firm that could comprise one or more private companies, advanced NMHSs, or a consortium of both.

11. https://wdqms.wmo.int/nwp/land_upper-air/six_hour/availability/ECMWF/2021-03-25/12

12. https://curia.europa.eu/juris/liste.jsf?language=en&num=C-280/00

13. https://public.wmo.int/en/our-mandate/how-we-do-it/development-partnerships/Innovating-finance

14. https://community.wmo.int/gbon

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The Global Facility for Disaster Reduction and Recovery (GFDRR) is a global partnership that helps developing countries better understand and reduce their vulnerabilities to natural hazards and adapt to climate change. Working with over 400 local, national, regional, and international partners, GFDRR provides grant financing, technical assistance, training and knowledge sharing activities to mainstream disaster and climate risk management in national and regional policies, strategies, and investment plans. Managed by the World Bank, GFDRR is supported and directed by a Consultative Group that has 17 members and 14 observers.

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