Data Collection Network Modernisation

What You Need to Know

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Abstract:

Many industries and organisations are crying out for improved critical weather intelligence so they can make more accurate, timely, cost effective and safe decisions in relation to their weather impacted operations. At a higher level there is a continuing global objective to reduce and manage risk to life, the environment and infrastructure. To achieve these objectives requires more accurate, more frequent, more timely, and targeted weather forecasting and data products. The three pillars of weather forecasting are observations, modelling and forecasters, so "high quality" observations are a fundamental requirement towards producing high value critical weather intelligence at local, country, regional and global scales. Therefore operating a "high quality" automated network is one of the important objectives for any organisation providing critical weather forecasts and data products.

If your organisation is considering converting a network of manual observations to an automated network, or considering significant technology upgrades to an existing automated network, the management processes are for the most part the same. The main differences are that for automating a network of manual observations there will be additional steps associated with provision of infrastructure (equipment siting, power and communications), and redeployment and retraining of observing staff.

This paper will present the management considerations and processes needed to perform a successful transition to, or upgrade of, an automated data collection network. Topics covered will include: high level management requirements and responsibilities; pre-project scoping requirements and involvement of stake holders; identifying and documenting new system technical, infrastructure, and financial requirements; system transition planning; staff re-deployment and re-training; project management and network roll out; identifying and implementing new system operating and support requirements; disposal of old equipment; real time performance monitoring; optimised fault response and repair by alerting and using prioritisation; and system longer term performance monitoring.

System specification, tendering and purchasing will not be covered as these topics are dealt with elsewhere.

Abbreviations

AWS	Automatic Weather Station
CIMO	Commission for Instruments and Methods of Observation
DRR	Disaster Risk Reduction
ECV	Essential Climate Variables
IoT	Internet of Things
IPET	Inter-Programme Expert Team
MHEWS	Multi-Hazard Early Warning Systems
NMHS	National Meteorological Hydrological Service
TAHMO	Trans-African Hydro-Meteorological Observatory
ToR	Terms of Reference
WIGOS	WMO Integrated Global Observing System
WMO	World Meteorological Organisation

Introduction

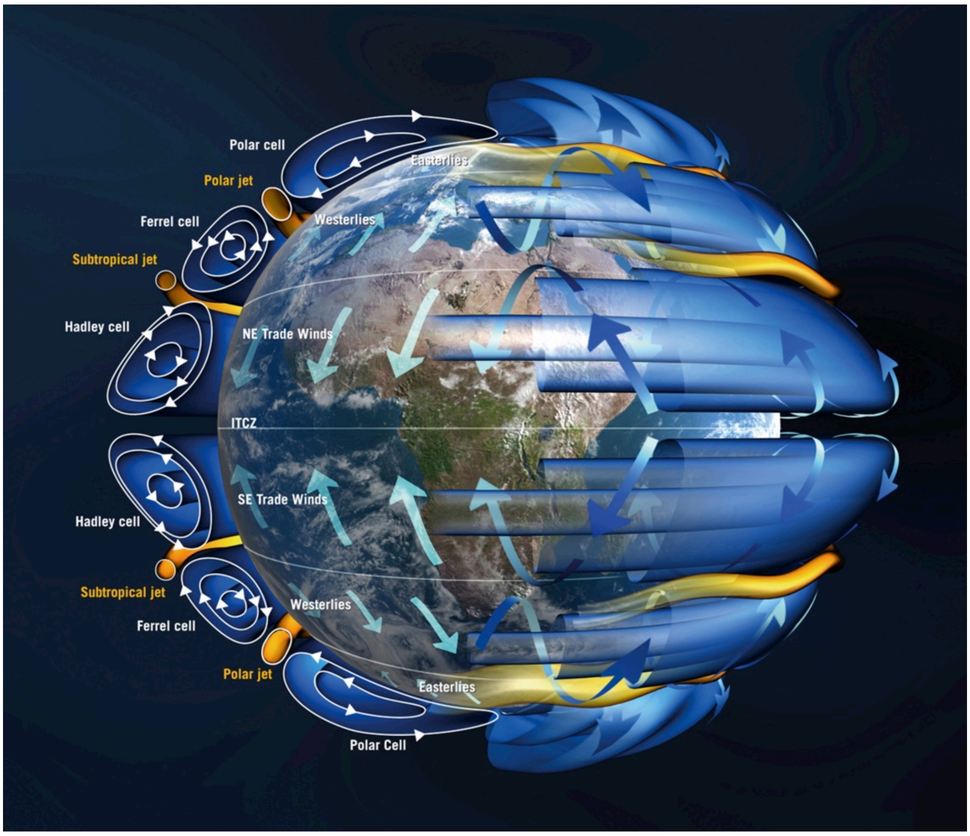
My interest in writing this paper has been stirred by my awareness of many very recent related topics and activities in CIMO and at associated conferences where two continual recurring themes stand out: 1) the planned upgrade of manual or automated networks to modern systems; and 2) members of the community sharing their experiences of recent upgrade programmes. In particular the following conference had over 40 papers on these and other closely related topics. [ref: ICAWS-2017]

I also note that there are some 16 papers on specific user plans or experiences with network modernisation that are being presented at this TECO.

At a political level it is well recognised that additional guidance material is required and seen as having high value if it can assist NMHS and others to successfully and cost effectively transition to more modern networks, so that high value information can be achieved for the good of communities from a local to a global scale. So significant is this topic that the establishment of a WMO IPET on the "migration from Manual to Automatic Observations taking into account the whole involvement of the whole data chain from observations, data processing, data management to the information systems operated by the users of weather services" is under consideration [ref: CIMO/MG-15/Doc. 2.2(6), 28.03.18]. It is recognised that the subject of the IPET is a complimentary to the process of upgrading an existing automated network and that some of the management processes are common to both, therefore this paper goes beyond the IPET and will outline the management processes for modernisation of both manual and automated networks.

But let us first remind ourselves (and perhaps others) **why measurements are so important.**

1. Surface measurements are one significant part of the data set that describes the state of the Earth's complex and dynamic atmosphere at any particular moment. Measurement networks at the surface (AWS, LiDAR, SODAR, profilers, towers), through the atmosphere (Radar, Upper air sounding, AMDAR etc.) and down looking (satellite) are complementary and reliant on each other to collaborate to "fill in the gaps" that each system can not see, and for cross confirmation or calibration particularly where system boundaries overlap.



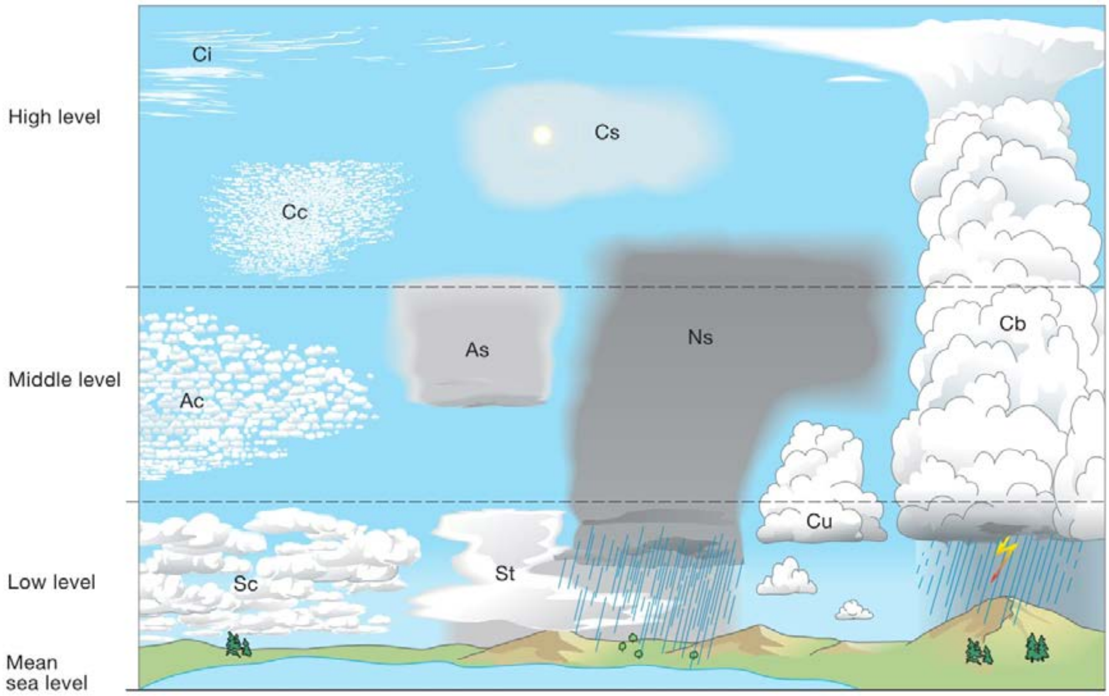
Picture: ESA

This picture shows the complexity of the atmospheric processes taking place, but is not to scale and for interest I like to remind myself how thin the Earth's atmosphere is.

	Altitude in km	Scaled to 1m
Earth mean radius	6,371	1.0 m
Geostationary satellite	36,000	5.7 m
Polar orbiting satellite	850	13 cm
350g weather balloon bursts	30	4.7 mm
Tropopause (9 to 17 km)* **Tops of thunderstorms*** **Commercial airliner (36,000 ft)**	**11**	**1.7 mm**
Mount Everest	8.848	1.4 mm

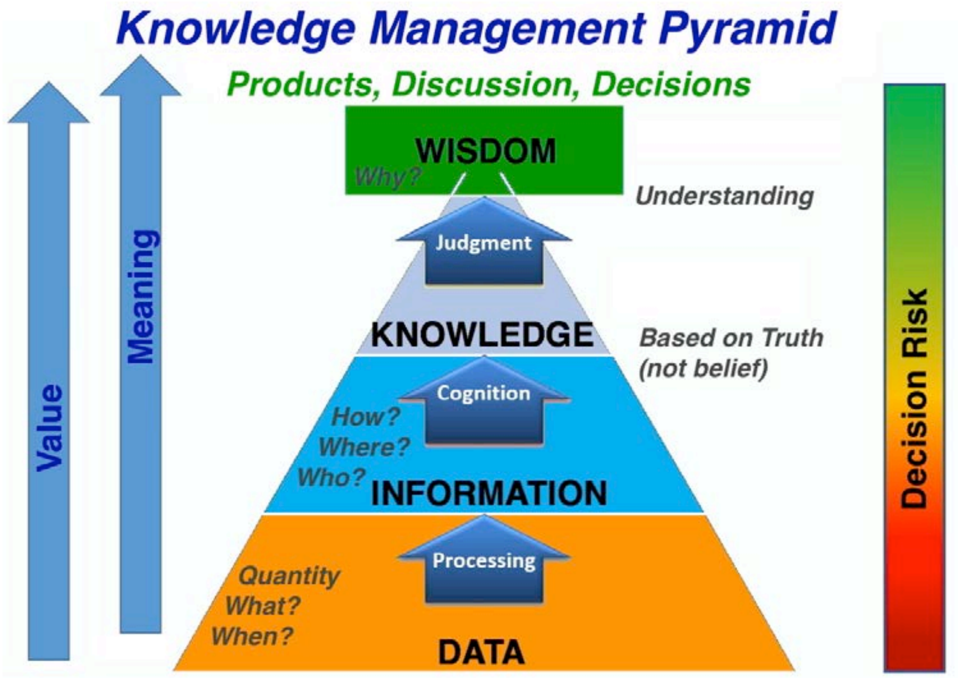
* The Tropopause and thunderstorm tops vary by several km with latitude and season.

Or if you like, the Earth's atmosphere up to the Tropopause, the place where I live and play, is the same relative thickness as the skin on a large apple!



Picture: WMO-ICA

2. All observations are a foundation and fundamental part of the process towards making informed and high value/low risk decisions.



The DIKW pyramid hierarchy in a measurement context:

- **Data** - Discrete elements (words). Raw unprocessed elements like numbers, text, images, and sounds, before correction and transformation i.e. without meaning, obtained with the intent of eventually making decisions.

  e.g. Sensor samples, IoT data, web camera image, upper air sounding data points.

- **Information** - Linked elements (sentences & paragraphs). Definitive information that are facts collected about the measurement process (algorithms, calibration, technical performance) in support of data to create knowledge.

  e.g. Technical metadata, equations, field tests, maintenance regime, [ref: Siting classification scheme], [ref: Measurement Quality Classification scheme].

- **Knowledge** - Organised information (chapters). Principles gained through experience or study, based on truth and not belief (science and rigorous verifiable practice) to create an understanding of the system that was being measured to transform data and information into knowledge (facts and truths).

  e.g. Quality control, Calibration information, performance history, time processing, analytics.

- **Wisdom** - Applied knowledge (books). Using knowledge gained through time (experience) and therefore understanding the system it is then possible to: infer other states of the system, study and understand the systems history; and then extrapolate with high value and confidence.

  e.g. forecasts (mesoscale, synoptic, ECV), warnings, commercial products.

In summary, high quality measurements (data with information about that data) are the foundation for creating high value intelligence (knowledge and wisdom) about the weather. The intelligence then being used to make confident decisions applicable to real world situations right now that will minimise risk and protect public and property (safety, DRR, health), enhance life (commercial and economic systems, quality of life), and be used for future planning (medium term forecasts to long term climatology, improve natural resource resilience, target vulnerable areas).

The **purpose** of a modernised network is to quantify in terms of measurand and quality, everything about the Data and Information layers in the pyramid. This means creating information on the state of the atmosphere, as it is happening now (typically 1 minute to 1 hour temporal resolution and latency of seconds to a minute or two), with a known representativeness and quantified accuracy.

The technical **benefits** of the transition to a modernised network will include things like improved data accuracy and timeliness, increased data frequency, higher spatial density, more reliable data availability, lower system costs, easier to use.

Very early on in the process you must identify what the **objectives** of your modernisation project will be. Noting that the objectives will be driven at the most fundamental level most likely entirely by the **stakeholder ToR** (high level **outcomes**, **budgets** and **time-line)**. To identify a solution to fit your objectives may mean compromises in design, operation or performance - measuring and achieving this fit is not an exact science and may include subjective rationalisations. This concept is succinctly captured by the proposed new CIMO vision “Members achieve fit-for-purpose environmental measurements through appropriate standards and technologies”.

The approach to network modernisation must initially be broad and consider the complete information chain from the measurements (Data) through to the end "Users" (Products, Discussion, Decisions) i.e. through the Knowledge Management Pyramid.

The objective of this paper is to go beyond specific user plans and experiences, which are by themselves enlightening and very valuable in identifying successful methods and for identifying challenges and pitfalls to avoid, to a wider management view on when to start, who to consult, what to consider, and how to proceed.

This paper will focus on surface observations for the examples and the references, but the processes identified will be extensible to other measurement systems e.g. upper air sounding, weather radar, profilers etc.

This paper also assumes that the organisation performing the modernisation process will be purchasing the equipment and supporting the network themselves through capital investment. There are new options emerging where commercial organisations will provide a contracted service as an operating cost over some period, where the network setup and operation is performed solely by the supplier with data provided from a cloud server Application Program Interface (API). The organisation may even include modelling and production services as part of a package. This type of modernisation has a different set of deliverables that are all managed through contractual arrangements.

The path to Data Collection Network Modernisation - paper contents

- When to start
- Background reading
- Project management (oversight)
- The need to consult (objectives and deliverables)
  - stakeholders, equipment operators and information users
- Rationale (technical design and a implementation plan)
- Transition planning - Identify associated impacts
- Collaboration with others
- System has supportable business processes
- Equipment design and construction is sustainable
- Equipment design and construction is sustainable
- Data management and quality control
- Network Design
  - Current network performance
  - Network technical requirements
  - Network Topology
  - IoT
  - IP network based solution
  - AWS hierarchy
  - Information Security
- Station Design
  - Technical design
  - Whether to retain technical control
- Costs and budget review
- Specification
- Final steps

When to start

The need to modernise a network will be triggered by some internal or external force that will likely become one of the major drivers on how the project proceeds. A need can be identified within an organisation by one or more of the following:

- Stakeholders (prompted by "Users") expressing new needs based based on real or perceived requirements (political pressures, international obligations, DRR, statutory, legal, commercial, an incident);
- Budgets being reduced or even expanded;
- Human resources limited or reduced or even expanded;
- Existing systems becoming unsupportable (spares or support unobtainable or too expensive, unsafe (minimata); and
- Opportunities to be more efficient, reduce operating costs and therefore expand.

Background reading

A thorough understanding on the management and operation of measurements systems is necessary to enable those responsible for the project to understand and effectively communicate with all parties involved. It is also helpful if a measurement systems technical knowledge is held.

It is recommended to start with the following sections in the WMO Guide to Meteorological Instruments and Methods of Observation [ref: CIMO Guide]:

- As a general topic start with "Part I. Measurement of Meteorological Variables"...

  Chapter 1. General

- and more specifically for the modernisation of AWS the following chapters in "Part II. Observing Systems" are a must read...

  Chapter 1. Measurements at Automatic Weather Stations

  Chapter 2. Measurements and Observations at Aeronautical Meteorological Stations

Also recommended are the very current and relevant ICAWS-2017conference papers [ref: ICAWS-2017] and the 16 relevant papers also being present at this conference.

Though somewhat dated (from 1997) and having very specific with examples, the general concepts presented on the guidance material for AWS specifications, implementation and training are worth a read [Ref: wmo-td_862 Guidance on AWS].

Project management (oversight)

It is important that the function of high level project management is recognised as a function in its own right. If practicable the Project Manager should not be involved in technical design or implementation matters as this will create conflicts in work flow and priorities. i.e. the project manager has an objective role independent of all "User" groups and implementation and operational staff.

The project management function will look after at least the following:

- Co-ordinate and consolidate technical design and budget forecasts
- Project approvals and financial requirements
- Maintain clear responsibilities and demarcations between organisational groups
- Monitor work flow against objectives and planned time-lines
- Monitoring of financials (purchases and labour) against budgets
- Project level record keeping
- Regular meetings with implementation teams
- Regular update meetings with "User" groups
- Co-ordinate and documentatuion of all project variations

The need to consult (objectives and deliverables)

Note that in this paper I have taken a "User" driven point of view on how a modernisation project will be driven - as compared to an alternative atmospheric system and "what do I need to measure?" point of view. Several of the stakeholders are national and global organisations and it is through these stakeholders that the best practice atmospheric system view point is still being captured.

Why do we need to consult all those involved with the current system and the likely modernised system even before a project starts?

Thorough research into the "User" requirements creates a greater chance of defining and implementing a system that meets as many user requirements as possible, has less chance of missing important requirements, and avoids ending up with a closed design that will not meet future foreseeable (and perhaps crystal ball) requirements. Those involved with the current system will have valuable experience and insights i.e. lessons learned into what works well and does not work well in your operational environment. This initial contact will also enable operators and users to be informed about potential changes to data, derived products and delivery mechanisms so they can be prepared for, and assist with analysis and changes during, implementation.

The outputs of the consultation process will be the project **objectives** and **deliverables** and these should consider and implement as many of the user requirements as practicable while still remaining within the stakeholders ToR. The clearly identified set of objectives and deliverables are imperative before a project starts as this will allow initial project scoping to be performed, progress to be measured, and adjustments to be made if required (defined, justified, approved and documented).

The "Users" that are likely to be involved and usefully consulted can be categorised into the three following groups: **stakeholders**, **equipment operators** and **information users,** and consulting these groups early in the process will allow the high level and then detailed objectives and deliverables to be identified.

Stakeholders - These people or groups will define and control the high level terms of reference (outcomes, budget, time-line), and they will not be concerned about the technicalities of the solution.

The complete stakeholder group may include the likes of...

- Company executives (and hired consultants)
- Local and Central government
- Donors providing funding
- International (global or regional) organisations e.g. WMO
- Industry leaders
- Partner organisations or countries
- Other network operators (with potential for information sharing)

The WMO has no financial function, but through its member countries provides the technical regulations and manuals that are the high level internationally agreed WMO ToR [Ref: Manual on WIGOS]. In particular under chapter 2. COMMON ATTRIBUTES OF WIGOS COMPONENT SYSTEMS the following topics are covered: Requirements; Design, planning and evolution; Instrumentation and methods of observation; Operations; Observational metadata; Quality management; and Capacity development.

Equipment operators - These are the people or groups that, on a day-to-day basis, will interact with the system and i.e. install, configure, operate, repair, calibrate, test and otherwise use it. They will care deeply about the technical capabilities of the system, the quality of the data deliverables, and how any changes may disrupt the system or affect them personally. This group will include those that interact directly with the system...

- Stores and purchasing
- Calibration facility
- Systems level processes
- Field operations staff
- Manual observers whos work programme may be affected

And will include other organisations that provide infrastructure and services...

- Land owner(s)
- Power and Telecommunications providers
- Cloud processing and storage

- Corporate data ingest and storage
- Corporate networking, system architecture, server throughput and information storage

Some services may reside in either of the above categories depending on how you organisation prefers to perform the following either internally of by using contractors...

- Site Maintenance (first line or in depth)
- Security

Information users - These are the groups that, on a day-to-day basis, use the information from the system. They will care deeply about the quality of deliverables and their timely availability, and how changes that will impact on their existing systems . This group includes the likes of...

- Agrometeorologists, Hydrologists
- Client data services (customers)
- Climatologists
- Communications and media
- Direct delivery data users i.e. direct on-site e.g. aviation, port, meteorological office
- Emergency services
- Forecast operations (public, aviation, marine, urban, commercial, warnings)
- Foriensic services
- Military
- Modelling
- Research
- WMO (also a stakeholder)

Rationale (technical design and a implementation plan)

At this point it is assumed that the "User" **project objectives** and **deliverables** have been defined and now the technical design and a implementation plan, with budgets, will be started. The design and plan should consider and implement as many of the "User" requirements as practicable while still remaining within the stakeholders ToR.

The specific technical aspects of how automated unattended equipment operate are already well documented elsewhere and are somewhat a rapidly developing field, and so will not be covered here. What will be discussed are the design and decision making methodologies that will assist the reader in making their own technical design and implementation plan.

Focus should be on the "Measurand" (which includes metadata) required to meet the "User" group requirements and not on buying technology or instruments. Once these measurand are fully defined they can be used to define the required data parameters and installation specifications. The network and station topologies may still not yet be decided at this point, but likely options will be becoming clear.

Transition planning - Identify associated impacts

When designing a modernised system and creating the plan to implement it, the complete information chain (measurement to product) needs to be consider so that the impacts of all proposed changes to the information flow can be assessed and any required upgrade work included in the modernisation project. The information chain typically has elements from the following:

- Measurands from all observation sources (sensors, sensor exposure)
- Site data processing and storage if implemented
- Local data communication
- Local data presentation systems
- Wide area/global network data communication
- Direct-to-customer (wide area/global) data reception
- Centralised data reception

- Centralised data processing and storage
- Data management
- Data production systems
- Product delivery systems
- Systems maintenance and support - remote monitoring, updates, configuration and diagnostics

During all of the above elements the following ideas need to be considered and where appropriate steps taken to ensure existing information flows are not disrupted or are upgraded as required: data elements, metadata, algorithms, security, quality control, quality monitoring and status reporting.

Collaboration with others

In the current age of reducing financial resources, increasingly higher performance expectations, and the recognition that many organisations are doing similar things in the environmental (and other) measurement spaces, there is an increasing expectation that organisations, public and private, will collaborate to increase cost efficiencies and enhance data sets (spatial, temporal, local-to-global). Therefore it is important to know and communicate with other organisations within your country and at it's borders so that you can effectively contribute to wider initiatives - e.g. the network of United Nations agencies involved in early warnings of natural hazards. One of the four Checklist Elements is: Detection, Monitoring, Analysis & Forecasting of Hazards and Possible Consequences [Ref: MHEWS]

Collaboration may be simply the sharing of infrastructure like physical sites, power and telecommunications, but also includes considering broadening of data sets e.g. NMHS measuring beyond only Meteorological data. After all we all live on one planet and often networks must operate beyond borders. Thankfully the advent of ubiquitous IP communication networks are making the telecommunications part of collaboration easier. Areas where collaboration are possible and that should be perused include:

- Sharing infrastructure (physical space, towers, buildings, cables).
- Sharing power.
- Shaing network communications (though security when connecting networks is often a challenge).
- Sharing information (data and metadata).
    - WIGOS framework.
    - Organisational information exchange .
- Making measurements for others by operating your own sensor when it was not required, or hosting the sensors of others.
- Providing aide to others (supplying technical expertise and equipment at cost or for free).

An example of a successful collaboration on an international scale is the joint not-for-profit foundation initiative to create a specific purpose low cost AWS to meet an identified need [ref: TAHMO Update].

System has supportable business processes

The modernised system must be supportable within the business processes in your organisation. The following system operating criteria need to be considered and documented as part of the supplier contractual requirements:

- The supplier and manufacturer are technically capable and their companies are financially sound.
- The system is able to be implemented and supported by your staff (with appropriate training).
- Required spares holding is technically acceptable and spares must be included with the project deliverables.
- Required maintenance schedules required to maintain operation within specification are acceptable.
- Support staff skill level requirements are acceptable and training is included in the project deliverables.
- System guaranteed up-times and data availability meet the project objectives.
- Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR) are technically acceptable.
- Expected Lifetime and lifetime cost meets the project objectives.

Equipment design and construction is sustainable

The second sustainability consideration is that, as far as practicable, all supplied equipment must be environmentally friendly:

- All manufacturing, installation and operating processes use sustainable materials.
- As far as practicable all components and modules use non-hazardous substances and where this is not possible appropriate labelling, documentation, handling and disposal processes are provided.
- As far as practicable all materials are recyclable or bio-degradeable, and where this is not possible they are safely disposable.

Data management and quality control

The quality of the knowledge and wisdom created from data and metadata is only as strong only as the weakest link in the information chain. It is important that the information chain identified during the Transition planning is reviewed from a quality management perspective and when data is moved or processing takes place quality control processes with monitoring and alerting must be in place.

Data processing quality (tests, corrections, filters, alerts) should include at least the following:

- Checks on metadata validity including its age.
- Record all access and changes made to metadata (access should be secure and logins and changes recorded).
- Correct technical perfomance of sensors and support systems (converter calibrations, references, power supply levels) at the measurement point.
- Data adjustment for calibration, exposure and other corrections.
- Turn off data during maintenance or other known outside corrupting influence.
- During all communications (local or wide area) confirm timeliness of data arrival, check for corruption and completeness of data records.
- During all of the above - Correct and filter, or flag suspect data for remedial action, and record all adjustments made to data and metadata (which creates even more metadata).

New data using complex analytics: New non-traditional data sources are emerging where complex analytics are used to extract data from seemingly unrelated information streams, for example precipitation type and intensity from camera imagery, and visibility from camera imagery. Due to the ubiquitous nature of alternative data sources this method is seen as a way to extract additional high value from existing infrastructure using mainly software. Traceability and quality control of these methods are currently in their infancy so no solid methods have yet been designed.

Database homogenisation: When modernising a network there will be an existing database of data and metadata. The new systems may have different data storage requirements so a review of database requirements for both systems should be made and then adjustments, either to the existing data set or the new data set implemented if required. All proposed adjustments must be rigorously checked before being implemented to ensure data quality and integrity will be preserved, and all adjustment processed must be recorded. This is particularly significant to the climatological community where data homogeneity is imperative, particularly for the ECV.

Measurement homogenisation: Existing measurement systems will have sensors that are exposed in a particular way, are calibrated and adjusted in a particular way, and the data is captured and processed at the source in a particular way. Modernising a station will change all of these processes and therefore create a potential for differences (whether the new system be more correct or less correct may not be known) in performance and the resulting measurands. This is particularly significant to the climatological community where data homogeneity is imperative, particularly for the ECV, and therefore it is generally a requirement that for stations providing ECV that measurement systems are operated for an overlap required period, typically one or two years and either at all stations or some representative ones depending on the measurands and the data use cases. The details of the station overlap will need to be discussed with the User groups and a consensus for implementation arrived at.

Once the data is quality controlled and homogenised it will be stored to the central **database**. The database must be extensible so that as new user requirements are identified and new measurements and metadata items (from new technology, instruments and standards) are implemented these can be added to the database easily without the need for re-construction.

Data ownership will need to be identified (in the metadata) and preserved as information is processed and communicated thereby ensuring intellectual property can be identified, ownership recognised (branding) and costs charged as appropriate the income distributed to the appropriate parties. Ownership metadata can also be used to signal data privacy so that only those that are authorised may use the data or products derived from the data.

Network Design

Current network performance: By embarking on network modernisation the upgrade objective will likely include the realisation of potential benefits in network operation in the areas of temporal coverage, data quality, increased geographical representativeness. As a minimum it would be expected that at least the current network consistency of observation method and performance would be retained. To enable this to be measured the current design and performance of your measurement network should be documented so that there is a baseline from which to make comparisons, and during network commissioning and testing these metrics may be useful to confirm whether the new network is performing adequately. Time should be provided in the project to review network performance as a result of changes and then, if required either changes made to the equipment to bring it back to within network performance bounds or to review the overall network design.

Modernising a network provides the opportunity to review the overall network design and how this fits into modern organisational requirements. Design methodologies to be considered may include:

- How this will the new network fit with and compliment other sources (satellite, upper, AMDAR etc.)?
- Are there any existing systematic faults that can be remedied?
- Is a unified solution being implemented i.e. replacing all old systems with one new network, Or replacing all old systems with multiple new systems (heirachial AWS and/or diverse telecommunications), Or ading one or multiple new systems while retaing some or all of an existing network?

Network technical requirements: When deciding if a unified solution will meet your requirements the **Network Topology,** and the broader network technical requirements at stations must be considered. This will require documenting the cross network technical features that are available at all stations and then deciding whether to:

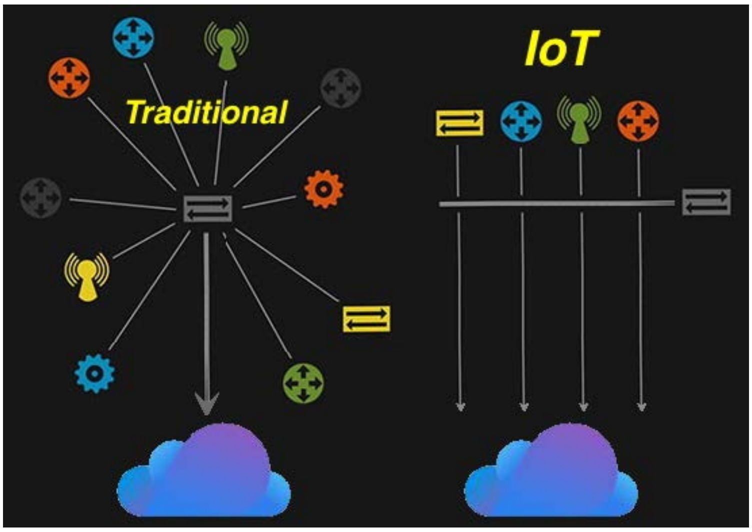
- Have a single unified AWS solution and adjust the nework design to fit this .
- Have multiple AWS solutions (**AWS heriachy**) e.g. retaining cost effective older systems and replacing/expanding the neteork with one or several AWS models.

Both AWS solutions above may still have module options e.g. mains, solar, fuel cell, wind, or third party power supply). Documenting the network technical features will also form the basis for the **Station design** and the technical **Specification** that will be required later. The technical network features to be reviewed should include:

1. Physical site longevity (owned, leased or third party shared).
2. Power supply type (commercial, self contained or third party shared).
3. Off site telecommunications (commercial or third party shared).
4. Local telecommunications (if required, connection to customer systems).
5. Representativeness of measurements.
6. Physical safety (of operating and mantenance staff, and others outside your organisation).
7. Equipment physical security (environmental conditions, transient protection, theft, vandalism, interference).
8. Information security (data theft, data vandalism, communications interference, interface tampering).
9. Operating and support requirements
    - Infrastructure and utility costs (rentals, communications, power, site maintenance, security)
    - Maintenance (mechanical wear, corrosion, paint, bearings, theft, vandalism)
    - Spares requirements (hot standby or cold standby, numbers, store management)
    - Training (installation, operation, maintenance, calibration, fault interpretation and diagnosis)
    - Fault alerting, monitoring and prioritisation
10. Systems architecture (telecommunications and central databases).
11. Metadata requirements.
12. Performance monitoring - real time for station faults - network wide and longer term for systematic faults.
13. Methods of data management and quality control.

Network Topology

The future where an AWS is a station in the traditional sense (a logger or processor with many sensors connected and local data processing and message coding) is changing. Already new IoT network topologies are in existence where measurements are “data points” and each data point exists in the central database (wherever that may be) as its own entity with full metadata e.g. location (point or geo-area), technical specifications, quality, exposure, ownership, security, control/admin, and “alias" metadata.



Data points can be any type of data e.g. surface based in-situ sensor, upper air flight, camera image, satellite image, forecast model, manual observation, crowd sourced.

For an AWS (anybody's AWS) measurements are parsed at ingest to create data points for storage into the central database - An accompanying metadata item would identify the collective data source. More metadata "aliases" will flag grouping of data points into station-like output products like METAR and SYNOP etc.

If you are pursuing an IoT topology then the biggest challenge will be to create the database to manage all the above. This task will need to be included in the modernisation project.

However technology is not yet at a point where IoT can completely replace traditional AWS (multiple sensors with a logger or data concentrator that pre-process data into efficient messages with wider temporal values e.g. METAR, SYNOP). Particularly because NMHS do not yet have IoT back-end data support systems or technical support systems in place, and IoT networks require low cost and low power telecommunications networks which are not yet available at very remote locations.

With the IoT model the Traditional AWS method can still be implemented if desired to support the likes of back logging of data during network outages, local data presentation, and local production and delivery of derived data products. An example of the value for this would be to support mission critical applications where direct connectivity, independent of wider networks, is required between the sensors and the client systems e.g. Air Traffic Control displays, ATIS, Port shipping control. In this case the AWS is just another client to the IoT connected sensors and operates independently of the information flow from the sensors to other clients.

IoT

“An IoT is a network that connects uniquely identifiable "Things” to the Internet. The “Things” have sensing/actuation and potential programmability capabilities. Through the exploitation of unique identification and sensing, information about the “Thing” can be collected and the state of the ‘Thing’ can be changed from anywhere, anytime, by anything.“ [ref: Towards IoT].

True IoT is raw data sent from "data points" to central (cloud) servers in a less controlled way. It is independent of the communications method, is IP based, is planet wide, and is one data parameter (a sensor or actuator with as little processing as possible), from the source to a data server to a client or clients.

The first implementers of IoT for data collection were all about VOLUME (Big Data) which, unless you have good analytics, does not create Big Value. Therefore smart central analytics must be used to ensure data is evaluated and presented in an appropriate way, without this there is little value in the data.

IP network based solution

Most new traditional AWS networks are becoming IP based (the end point connection is Ethernet) at least to the AWS as this allows ubiquitous IP based telecommunications networks (DSL, cellular, radio, LAN, WAN, satellite broadband) to be used with little or no changes when implementing the AWS on any network (most required changes are networking configurations which are soft based).

At some time in the future all sensors on a network will be able to communicate using IP networking bi-directionally with head office, to local or distant (planet wide) display/other customer systems, and/or to a local data processor. This will happen under the Traditional AWS model (IP communications through the AWS) and the IoT model (IP communications fro each sensor directly to the cloud).

There are some current limitations to IP communications...

- The power required to operate IP (Ethernet) ports is relatively high.
- IP communications normally requires a processor to control the communications (also requires more power).
- Information security while transversing global and physicall public networks.
- Teaching engineers how networking works.

Solutions to these limitations are being worked on in the industry e.g. specific data communications protocols have been developed that are capable of handling sensor data traffic under low bandwidth (MQTT), low power versions of Ethernet are being developed.

AWS hierarchy

In the past it was common to operate an entire AWS network to one performance specification, the highest common specification that would meet the requirements of all "Users" (normally as recommended and defined by the WMO in the CIMO Guide). However this is now often not the case as different "User" information (data parameter, quality, cost) requirements mean it is more cost effective to operate a hierarchy of AWS systems. The different types of AWS being characterised by their different: measurement accuracy and temporal measurement reporting characteristics, exposure methods, communications diversity and resiliency, power supply characteristics, reliability, service requirements, and cost.

Up until now organisations have developed their own hierarchy of AWS based on their "Users" (particularly customers) specific requirements and this has produced data sets that are not easily exchanged outside the operator - "User" relationship i.e. there have been no recognised international standards. WMO has started the process to create repositories and standards that will allow data to be exchanged with knowledge of the data meaning and quality through the OSCAR database [ref: OSCAR], and the classification schemes for siting [ref: Siting classification scheme] and measurement quality [ref: Measurement Quality Classification scheme].

For information the CIMO proposed measurement quality classes that quantify the measurement uncertainty, and ongoing maintenance and calibration requirements are as follows:

- **Class A**: Measurement meets the WMO required measurement uncertainty and stated achievable measurement uncertainty, that is Annex 1.A e.g. **reference climatological or research stations**.
- **Class B**: Measurement has a wider uncertainty than class A e.g. **synoptic or aeronautical stations.**
- **Class C**: Specifications more relaxed than class B. e.g. **well-maintained public weather stations**.
- **Class D**: Wider than class C or no information is available e.g. **crowdsourced weather stations**

Information Security

With the widespread implementation of IP communications information security has become a significant because the information communication and systems control is being performed over electrically shared cable in the communications networks. The time where you would have your own cable that was physically separate (and generally physically secure) from others are disappearing, mainly as a result of it being far more efficient to share unused bandwidth, therefore being more cost effective. It would also be physically impossible in most cases to run a cable for every customer that needed a point-to-point connection.

Therefore as the IP networks are shared the communications users must employ security systems to protect information and to protect access to systems. The techniques that need to be considered are:

- Virtual Private Networks (VPN) where information is encrypted during communication.
- Logins (appropriate usernames and passwords that are secure).
- Firewalls or network rules (at BOTH ends of all IP communication cable).
- Usage policies (known access groups, software installation lists, rules for web browsing and email etc.)
- Virus protection software on computers that are not fixed in configuration.
- Physical access to computers is restricted.
-

The connection between networks of two operators can be very problematic because even if all the techniques above are employed there is still a risk that someone on one network can maliciously attack systems on the other network. If the connection between the networks is local (within 100s of meters) and the information be transferred between the networks is simple in nature e.g. an ASCII formatted text message like a METAR, then using a simple serial connection (RS232, RS485 etc.) can mean that none of the security measures above are required i.e. keep it simple.

Station Design

Technical design

Using all of the information collected during the processes above you should now be able to create the technical design for the system e.g. AWS that is required for the modernisation of existing, or the installation of new, stations. The following is a list of technical features that should be covered in the design and then later expanded in the specification:

- Equipment Configuration - See Network Topology.
- Power supply methods required e.g. mains, solar, wind, fuel cell, battery backup.
- Telecommunications methods that are required e.g. cellular, DSL, radio link, cable (serial), satellite
- Environmental operating conditions of the target installations (with details of extremes to be experienced) e.g. tropics, desert, temperate, alpine, marine, polar/fridgid, winds, hail, volcanic, chemical, dust, sand, insects, radio frequency noise, transients (lightning, static electricity), vibration. [ref: Whatever the Weather]
- Equiment housing preferred construction (materials, layout format) and configurations.
- Measurands that are required and their uncertainty budget (end-to-end)
- Indicate how much modularity and interoperability is needed (connection, installation mounting, calibration, maintenance).
- Algorithms for quaity control.
- Algorithms for derived data parameters.
- Message codes and message transfer protocols, including error handling and backlogging.
- Off site communications methods e.g. IP based using TCP, UDP, Email, FTP.
- On site communications methods e.g. IP, serial, radio, WiFi, Bluetooth, LoRaWan, SigFox etc.
- Enclosure layout and relevance to the data user applications e.g. ECV, aviation, road transport, Synoptic.
- Equipment Physical Security:
  - Threats - theft, vandalism, tampering with sensors to create false information, curiosity.
  - Mitigation - Signage, education of system value to communities , camera (motion detection), fence, alarms.
- Health and safety of workers and the public e.g. electrical, fatigue, lifts, bumps, cuts, trips, laser eye safety.
- EMI/RFI susceptability and protection methods.
- Transient protection scheme.
- System software preferred hardware and software platforms e.g. Industrial computer, Windows10, Linux etc.
- System software configurability and control method e.g. Single web server interface using platform independent web browser allowing access, processing, archiving and quality control of data received
- Built in test systems.

- Maintenance regime and techniques for sensors and AWS processor (calibrations of sensor and interfaces, hardware inspections,
- Equipment lifetimes e.g. batteries, solar panels, plastics in the sun, metals in corrosive environments etc.

Whether to retain technical control

Traditionally a NHMS would purchase systems for their network, purchase adequate spares and have their staff fully trained to install, configure, operate and modify/upgrade the equipment. In recent time the number of suppliers has increased that can offer different levels of support from the technique described above - to installing and operating stations that provide data to NMHS central servers for a lease fee - to providing an entire network with data servers in the cloud and an API, and any combination of options in-between.

The foremost option enables the system operator to retain control of some levels of equipment choice and quality (sensor and module choice, algorithms, message codes, message protocols, communications network methods, calibration), and to retain flexibility which may provide better competitiveness in a commercial data market. If these features are not required then a closed system where the supplier can only make design changes may be acceptable and be therefore be available at lower cost.

Costs and budget review

Once the technical design is complete is should be possible to refine the system budgetary costs and thereby enable a review of the project against the stakeholder ToR, in particular to identify if budgets are adequate. If not then either additional budgets will need to be approved or the "Users" consulted to see if the design can be made more cost effective (perhaps by reducing the performance requirements). The costs will need to be reviewed for at least the following:

- Capital expenditure - funds and labour (installation, spares, calibration systems, support tools)
- Operating and maintainance - funds and labour (storage, calibration, site up-keep)
- Utilities (telecommunications, power)
- Training (installers, operators, maintenance, systems management, data receivers and users)
- Dis-establishment at end of life - removal and site clearance.

Specification

Whether purchasing outside your organisation (with tendering) or designing and building in house the Specification is a necessary step to ensure all the deliverables, budgets, resources, and timelines are documented before purchasing and implementation commences.

The specification process is where the Network Design and Station Design are translated into detailed specific deliverable requirements that will become contractually binding between the purchaser and supplier. The Specification will be accompanied by other documents that will cover other topics like:

- Contract members and their obligations.
- Payment terms and conditions, and time line.
- Delivery terms and conditions, and time line.
- Warranties.
- Support arrangemments.

This paper will not go into any more detail on the contents of the above documents as this is well covered else where. The WMO also has available tender guidance material that is the outcome of a collaboration between CIMO and the Hydro-Meteorological Equipment Industry (HMEI) [ref: WMO-AWS Tender Specification].

Final steps

The implementation of the modernised system that has been specified, and project and ongoing reviews are performed next. These topics are beyond the scope of this paper, however as guidance the following should be performed:

- Equipment Choice, further contract negotiation (if required) and Purchasing.
- Roll-out (training, delivery and installation).

- Dis-establishment of existing equipment (removal labour and other costs, site restoral, packaging and transport, storage or disposal or sale costs, special requirememnts for hazardous goods). Dis-establishment may be a separate project performed one to two years later if station overlap was required.
- Dis-establishing a manual observation program (Dis-establishment may be a separate project performed one to two years later if station overlap was required.):
  - Preferred staff re-deployment and re-training.
  - If contracted - Terms for existing contract termination need to be followed.
  - If employed - Terms of redundancy need to be followed. Staff wellbeing and assistance with transitioning must be provided. Re-training and redeployment may be an option.
- A project review should be held at the initial completion of the system roll-out and commissioning. This will enable confirmation of deliverables made against the original project deliverables, and allow management "lessons to be learned" to be captured for future reference and perhaps for the guidance of others .
- Ongoing network performance reviews should be performed by the network operator and the "Users" to assess if the network operating characteristics and the data AND metadata are fit for their designed purpose.

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