Draft guidance on technical specifications of WIS2

World Meteorological Organization

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Standing Committee on Information Management and Technology (SC-IMT)[1]

Commission for Observation, Infrastructure and Information Systems (INFCOM)[2]

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Chapter 1. PART I

[1] https://community.wmo.int/governance/commission-membership/commission-observation-infrastructures-and-information-systems-infcom/commission-infrastructure-officers/infcom-management-group/standing-committee-information-management-and-technology-sc-imt

[2] https://community.wmo.int/governance/commission-membership/infcom

Chapter 2. Introduction of WIS2

Since the Global Telecommunication System (GTS) entered operational life in 1971, it has been a reliable real-time exchange mechanism of essential data for WMO members.

In 2007, the WMO Information System (WIS) entered into operations to complement the GTS, providing a searchable catalogue and a global cache to enable additional discovery, access and retrieval. The success of WIS was limited as the system only partially met the requirement of providing simple access to WMO data. Today's technology developed for the Internet of Things (IoT) opens the possibility of creating a WIS 2.0 able to stand to its expectations of delivering an increasing number and volume of real-time data to WMO Centres in a reliable and cost effective way.

WIS 2.0 has been designed to meet the shortfalls of the current WIS and GTS, support the WMO's Unified Data Policy and the Global Basic Observing Network (GBON), and meet the demand for high data volume, variety, velocity and veracity.

WIS 2.0 technical framework is based around three foundational pillars: leveraging open standards, simpler data exchange and cloud-ready solutions.

2.1. Leveraging open standards

WIS 2.0 leverages open standards to take advantage of the ecosystem of technologies available on the market and avoid building bespoke solutions that can force NMHSs to procure costly systems and equipment. In today's standards development ecosystem, standards bodies work closely together to minimise overlap and build on one another's areas of expertise. For example, the World Wide Web Consortium provides the framework of Web standards, which the Open Geospatial Consortium and other standards bodies leverage. WIS 2.0 leverages open standards with industry adoption and wider, stable, and robust implementations, thus extending the reach of WMO data sharing and lowering the barrier to access by Members.

2.2. Simpler data exchange

WIS 2.0 prioritises public telecommunication networks, unlike private networks for GTS links. As a result, using the Internet will enable the best choice for a local connection, using commonly available and well-understood technology.

WIS 2.0 aims to improve the discovery, access and utilisation of weather, climate and water data by adopting Web technologies proven to provide a truly collaborative platform for a more participatory approach. Data exchange using the Web also facilitates easy access mechanisms. Browsers and search engines allow Web users to discover data without specialised software. The Web also enables additional data access platforms, e.g. desktop GIS, mobile applications, forecaster workstations, etc. The Web provides access control and security mechanisms that can be utilised to freely share the core data per the WMO Unified Data Policy and protect the data with more restrictive licensing constraints. Web technologies also allow for authentication and authorisation for the provider to retain control of who can access published resources and to request users to accept a license specifying the terms and conditions for using the data as a condition for providing

access to them.

WIS 2.0 uses a "publish-subscribe" pattern where users subscribe to a topic to receive new data in real time. The mechanism is similar to WhatsApp and other messaging applications. It is a reliable and straightforward way to allow the user to choose her data of interest and to receive them reliably.

2.3. Cloud-ready solutions

The cloud provides reliable platforms for data sharing and processing. It reduces the need for expensive local IT infrastructure, which constitutes a barrier to developing effective and reliable data processing workflows for some WMO Members. WIS 2.0 encourages WMO centres to adopt cloud technologies where appropriate to meet their users' needs. Whilst WMO technical regulations will not mandate cloud services, WIS 2.0 will promote a gradual adoption of cloud technologies that provide the most effective solution.

The cloud-based infrastructure allows easy portability of technical solutions, ensuring that a system implemented by a specific country can be packaged and deployed easily in other countries with similar needs. In addition, using cloud technologies allows WIS 2.0 to deploy infrastructure and systems efficiently with minimum effort for the NMHSs by shipping ready-made services and implementing consistent data processing and exchange techniques.

It should be clear that hosting data and services on the cloud does not affect data ownership. Even in a cloud environment, organisations retain ownership of their data, software, configuration, and change management as if they were hosting their infrastructure. As a result, data authority and provenance stay with the organisation, and the cloud is simply a technical means to publish the data.

2.3.1. Why are datasets so important?

WMO enables the international exchange of observations and model data for all Earth-system disciplines.

The WMO Unified Data Policy, Resolution 1 (Cg-Ext(2021)) [3], describes the Earth system data that are necessary for efforts to monitor, understand and predict the weather and climate - including the hydrological cycle, the atmospheric environment and space weather.

WIS is the mechanism by which this Earth system data is exchanged.

Common practice when working with data is to group them into "Datasets". All the data in a Dataset share some common characteristics. The Data Catalog Vocabulary (DCAT) defines a Dataset as a "collection of data, published or curated by a single agent, and available for access of download in one or more representations" [4].

Why is this important? The "single agent" (i.e., a single organisation) responsible for managing the collection ensures consistency among the data. For example, in a Dataset:

- All the data should be of the same type (e.g., observations from weather stations).
- All the data should be have the same license and/or usage conditions.

- All the data should be subject to the same quality management regime - which may mean that all the data is collected or created using the same processes.
- All the data should be encoded in the same way (i.e., using the same data formats and vocabularies).
- All the data should be accessible using the same protocols - ideally from a single location.

This consistency means that one can predict what data is in a Dataset, at least as far as the common characteristics, making it easier to write applications to process the data.

A Dataset might be published as an immutable resource (e.g., data collected from a research programme), or it might be routinely updated (e.g., every minute as new observations are collected from weather stations).

A Dataset may be represented as a single, structured file or object (e.g., a CSV file where each row represents a data record) or as thousands of consistent files (e.g., output from a reanalysis model encoded as many thousands of GRIB files). Determining the best way to represent a Dataset is beyond the scope of this guide - there are many factors to consider! The key point here is that we consider the Dataset to be a single, identifiable resource irrespective of how it's represented.

Because we group data into a single, conceptual resource (i.e., the Dataset) we can:

- Give this resource an identifier, and use this identifier to unambiguously refer to collections of data.
- Make statements about the Dataset (i.e., metadata), and infer that these statements apply to the entire collection.

All this means that the Dataset concept is central WIS:

- We publish discovery metadata about Datasets, as specified in the WMO Core Metadata Profile [5].
- We can search for Datasets that contain relevant data using the Global Discovery Catalogue.
- We can subscribe to notifications about updates about a Dataset via a Global Broker.
- We can access the data that comprises a Dataset from a single location using a well described mechanism.

It is up to the Data Publisher to decide how their data is grouped into Datasets - effectively, to decide what Datasets they publish to WIS. That said, we recommend that, subject to the consistency rules above, Data Publishers should organise their data into as few Datasets as possible.

For a Data Publisher, this means fewer discover metadata records to maintain. For a Data Consumer this means fewer topics to subscribe to and fewer places to access the data.

There are some things that are fixed requirements for Datasets:

1. All data in the Dataset must be accessible from a single location.
2. All data in the Dataset must be subject to the same license or usage conditions.

Here are some examples of Datasets:

- The most recent 5-days of synoptic observations for an entire country or territory. Why 5-days in this example? Because only 5-days of observations is retained in the system used to publish the data.
- Long-term record of observed water quality for a managed set of hydrological stations.
- Output from the most recent 24-hours of operational numerical weather prediction model runs.
- Output from 6-months of experimental model runs. It's important to note that output from the operational and experimental should not be merged into the same dataset because they use different algorithms - it's very useful to be able to distinguish the provenance (or lineage) of data.
- A multi-petabyte global reanalysis spanning 1950 to present day.
- [more examples from other Earth system domains?]

In summary, Datasets are important because they're how data is managed in WIS.

2.4. Data consumer

As a Data Consumer wanting to use data published via WIS2 you should read the guidance presented here. In addition, a list of references to useful sections in this guidance document is provided where Data Consumers can gain a better understanding of how WIS2 works.

2.4.1. How to search the Global Discovery Catalogue to find Datasets

A Data Consumer may browse discovery metadata provided by the Global Discovery Catalogue to locate a Dataset of interest. Discovery metadata follows a standard scheme (see PART V Discovery Metadata). A Data Consumer may discover a Dataset using keywords, topics, geographic area of interest, or date(s) associated with the Dataset. Matching search results from the Global Discovery Catalogue provide high-level information (title, description, keywords, spatiotemporal extents, data policy, licensing), from which a Data Consumer can assess and evaluate their interest in accessing/downloading the Dataset's data.

A key component of Dataset records in the Global Discovery Catalogue is that of "actionable" links. A Dataset record provides one to many links that clearly identify the nature of the link (informational, direct download, API or Web service) so that the Data Consumer can interact with the data accordingly. For example, a Dataset record may include a link to subscribe to notifications (see 2.2.2 how to subscribe to notification about availability of new data) about the data, or a API or Web service, or an offline archive retrieval service.

TODO: To be completed

2.4.2. How to subscribe to notifications about availability of new data

A Data Consumer may browse the topics provided by a Global Broker to locate a Dataset of interest to them. Topic structures follow a standard scheme (see WIS2 messages Standard topic hierarchy). A Data Consumer may discover more about the Dataset associated with a particular topic by using the topic-name as a key to search the Global Discovery Catalogue.

Data Consumers should subscribe to receive "data availability" messages from Global Brokers.

Exceptionally, a Data Consumer may choose to subscribe directly to the local message broker at the originating NC/DCPC – but note that the NC/DCPC may not provide public access to its local message broker. Data Consumers should not subscribe to the local message broker at Global Cache instances.

Real-time and near real-time data designated as "Core" in the WMO Unified Data Policy (Resolution 1) will be available from the Global Cache. As per clause 3.2.13 from the Manual on WIS, Vol II. Data Consumers should access data from the Global Cache.

When a Dataset is available from the Global Cache, its discovery metadata will include a link to subscribe to "data availability" messages from the Global Cache instances. Data Consumers will subscribe to these "Global Cache" topics and not to the topic that contains messages from the originating NC/DCPC.

TODO: To be completed

2.4.3. How to use a notification message to decide whether to download data

Each Global Cache will publish a "data availability" message as the associated data object becomes available from that Global Cache instance. Each "data availability" message will refer to the same logical data object but hosted at a different location within WIS. Data Consumers need to consider their strategy for managing these duplicate messages. From a data perspective, it does not matter which Global Cache instance is used – they will all provide an identical copy of the data object published by the originating NC/DCPC. The simplest strategy is to accept the first "data availability" message and download from the Global Cache instance that the message refers to (i.e., using a URL for the data object at that Global Cache instance). Alternatively, a Data Consumer may have a preferred Global Cache instance, for example, that is located in the Region. Whichever Global Cache instance is chosen, Data Consumers will need to implement logic to discard duplicate "data availability" messages.

TODO: To be completed

2.4.4. How to download data from the Global Cache and WIS nodes

Dataset links are made available through Dataset discovery metadata (via the Global Discovery Catalogue) as well as data notification messages (via Global Brokers). Links can be used to download the data (according to the network protocol and content description provided in the link) using a mechanism appropriate to the workflow of the Data Consumer. This could include web and/or desktop applications, custom tooling, or other approaches.

TODO: To be completed

2.4.5. Additional sections of interest to a Data Consumer (TODO: fix crossref)

- 1.2 What is WIS2?
- 1.3 Why are Datasets so important?

2.5. Data publisher

As a Data Publisher planning to operate a WIS node, you should read the following sections: TODO: fix crossrefs * 1.2: What is WIS2? * 1.3 Why are Datasets so important? * PART III Data Metadata flows * PART X Information Management

2.5.1. How to publish Dataset discovery metadata to the Global Discovery Catalogue

A Data Producer publishes discovery metadata to the Global Discovery Catalogue by generating a discovery metadata record (see PART V Discovery Metadata) and publishing it via a WIS Node broker in accordance to the standard topic hierarchy. Global Services subscribed to WIS Nodes then validate, ingest and publish the Dataset discovery metadata record to the Global Discovery Catalogue.

2.5.2. How to publish data notifications

A Data Producer publishes data notifications by generating a notification message (see 7.2.2 Notification_messages) via a WIS2 Node broker in accordance with the standard topic hierarchy. Global Brokers subscribe to WIS2Nodes and then re-publish the data notification. If applicable, Global Cache ingests the associated file or data for re-publication to the Global Broker.

2.5.3. How to publish data to the Global Broker

Data publishing is realized as a function of publishing data notifications (see 2.1.2 How to publish data notifications).

TODO: To be completed

[3] WMO Unified Data Policy, Resolution 1 (Cg-Ext(2021))

[4] Data Catalog Vocabulary (DCAT) - Version 2, W3C Recommendation 04 February 2020 https://www.w3.org/TR/vocab-dcat-2/#Class:Dataset

[5] WMO Core Metadata Profile version 2

Chapter 3. PART II

3.1. WIS2 Architecture

3.2. Implementation and operation of WIS2 Node

3.2.1. Practices and procedures

3.2.1.1. Registration and decommissioning of a WIS node

This section describes the process used to register or remove a WIS node within WIS2. During the initial part of the WIS2 pilot phase, a Member simply needs to notify the WMO Secretariat and primary GISC of the intent to register a new WIS node. The Secretariat and GISC will then assist in the registration. More formal procedures will be developed as the number of WIS nodes increases.

TODO: To be completed

3.2.1.2. Registration and removal of a Dataset

This section describes the process used to register a Dataset so that it may be discovered and shared within WIS2. In cases where a WIS Centre no longer wishes to share a Dataset via WIS, it must be removed as per the procedure described here.

TODO: to be completed

3.2.1.3. Connecting with Global Services

This section describes the process by which a WIS node is registered with one or more Global Broker and Global Cache components.

TODO: to be completed

3.2.2. Publishing data, discovery metadata, and notification messages

3.2.2.1. Discovery metadata

Discovery metadata shall be encoded according to the WMO Core Metadata Profile version 2 (WCMP2). See WCMP2

Discovery metadata may be published one of two ways. The simplest method is to encode the discovery metadata record as a file and publish it to an HTTP server. The URL of this file is included in the notification message advertising the availability of new metadata. Alternatively, a Data Publisher may choose to host a local catalogue themselves, enabling them to share discovery metadata records through an API (e.g., OGC API Records). In this case, the URL used in the notification message will refer to the API endpoint identifying the specific discovery metadata record (e.g., an item as part of their discovery metadata catalogue/collection).

These discovery metadata records are then propagated through the Global Service components into

to the Global Discovery Catalogue where Data Consumers can search and browse.

Discovery metadata must be published before data sharing through WIS begins.

TODO: to be completed

3.2.2.2. Notification messages

There is no requirement for an NC/DCPC to publish "data availability" notification messages relating to infrequently changing Datasets, such as a data archive, especially where the user community have no requirement to be instantly updated about changes to a Dataset (e.g., the addition of new records into a climate observation archive). Data Publishers should note that without providing notification messages their data will not be copied into the Global Cache. However, since the Global Cache only holds real-time (or near real-time) Datasets, this is not a concern for Data Publishers with infrequently changing Datasets.

TODO: to be completed

3.2.2.3. Data

WIS2 provides the "plumbing" for data sharing within the WMO community, but it defines neither which data to share, nor how that data should be encoded. WIS Centres need to evaluate WMO Programme requirements and the WMO Unified Data Policy to determine which Datasets should be made available through WIS.

WMO Technical Regulations may require that data is encoded in particular formats. For example: synoptic observations should be encoded in BUFR. The Manual on Codes (WMO No. 306) provides details of data formats formally approved for use in WMO.

However, Technical Regulations don’t cover all data sharing requirements. In such cases, Data Publishers should select data formats that are widely adopted and understood in their target user community.

WIS2 does not require the use of specific file-naming conventions. Where communities commonly use file-naming conventions (e.g., with embedded metadata), Data Publishers should ensure that adequate documentation is provided to users. Data Publishers cannot assume that users will understand (or respect) their file-naming rules – many Data Consumers will simply treat the filename as an opaque string.

Data publishers also have choices about how they publish data.

As a minimum, Data Publishers may publish data objects (e.g., the atomic bits of data that comprise a Dataset) as files using a Web server (HTTP protocol) or FTP server (FTP protocol), using secure communications (e.g., HTTPS/SFTP). As each data object is published, a notification message should also be published to a topic in a message broker (see 4.3 Notification message format and structure, and WIS2 messages 4.4 Standard topic hierarchy).

A Dataset (for example, a collection of climate model runs) may comprise thousands or more files. A Data Publisher may choose to provide users with a mechanism to browse through the set of files, enabling them to identify those which are relevant to them. Examples of such mechanisms include:

- Web Accessible Folders (WAF) – a Web-based folder structure listing the data object files by name .
- Spatio-Temporal Asset Catalog (STAC) – a common language based on GeoJSON to describe geospatial data files so that it can be easily indexed, discovered, and accessed. Freely available, open-source tools present STAC records (one for each data object file) through a Web-based, browse-able user interface.

WAFs and STAC are provided to illustrate options. There is no requirement for a Data Publisher to provide any such browse-able user interface to their data.

Increasingly, interactive Web APIs are being used to provide access to datasets. Although requiring a little more sophistication to implement, a Web API provides significant advantages:

- Data Consumers can select and download only the parts of a dataset that they need – providing them will a smaller dataset subset to work with and reducing the burden on the Data Publisher's network infrastructure.
- Data Consumers are insulated from the complexities of how a Data Publisher chooses to persist their data. The Web API can provide access to Datasets in a way that is easy for users to understand.
- A Web API may allow Data Consumers to download data in their preferred file format or encoding.

WIS-TECHSPEC-2 states:

```
4.3.3 URLs provided for accessing core data, as defined in WMO Unified Data Policy
(Res. 1), and discovery metadata shall be directly resolvable, i.e., data or discovery
metadata can be downloaded simply by resolving the given URL without further action,
such as populating elements of an API, is required.
```

When using a Web API to publish "core" data, the URL included in the data availability notification message must be directly resolvable, i.e., the Data Consumer must not be required to complete any additional fields in the API request. This can be achieved by identifying the data object in the URL. A Data Consumer or a Global Cache instance can simply resolve the URL to download the data object regardless of the manner in which it is made available.

WIS2 isn't yet mature enough to prescribe the use of particular Web APIs. Instead, WIS2 seeks to leverage the experience of Data Publishers who have been using Web APIs to serve their communities.

First, interactive Web APIs should be self-describing. A Data Consumer should not need to know, a priori, how to make requests from a Web API. They should be able to discover this information from the Web API endpoint itself – even if this is just a link to a documentation page they need to read.

Second, we recommend that Web APIs are compliant with OpenAPI version 3 or later. OpenAPI provides a standardised mechanism to describe the API. Effectively, OpenAPI provides metadata that describes the Web API endpoint. Tooling(free, commercial, etc.) is widely available that can

read this metadata and automatically generate client applications to query the Web API.

Third, the Open Geospatial Consortium (OGC) have developed a suite of APIs (called "OGC APIs") that are designed specifically to provide APIs for geospatial data workflows (discovery, vizualisation, access, processing/exploitation) – all of which build on OpenAPI v3. Among these, OGC API – Environmental Data Retrieval (EDR), OGC API – Features, and OGC API - Coverages are considered particularly useful. Because these are open standards, there is an ever-growing suite of software implementations (both free and commercial) that support them. We recommend that Data Publishers assess these open-standard API specifications to determine their suitability to for publishing their Datasets using APIs.

Finally, we're increasingly concerned with providing access to very large Datasets. The OGC has published a series of informative blogs on the subject of cloud-native geospatial data sharing. These are listed among in section 11.4.2 Informative References.

TODO: to be completed

Publication and topic selection

When publishing a dataset, a data publisher selects a given topic according to the WIS Topic Hierarchy. Given the multidisciplinary nature of some data, a data publisher must select a single topic for publication purposes, and always uses WCMP2 discovery metadata to provide a fulsome description of their dataset and its relevance to additional disciplines.

3.2.3. Performance management

3.2.3.1. Service levels and performance indicators

This section describes the minimum performance criteria for operation of a WIS node.

TODO: to be completed

3.2.3.2. Provision of system performance metrics

This section describes how a WIS node should provide metrics to the Global Monitor service and its primary GISC.

TODO: to be completed

3.2.4. WIS Node reference implementation: wis2box

Members may use whichever software components they consider most appropriate to comply with the WIS2 Technical Regulations.

To assist Members participate in WIS2, a freely available, open-source Reference Implementation has been developed: "WIS2 in a box" (referred to as wis2box). It builds on mature and robust free and open-source software components that are widely adopted for operational use.

wis2box provides functionality required for both Data Publisher and Data Consumer roles. It provides the following technical functions:

- Real-time or archive data and metadata publishing to WIS2 (Publish), including available data transformation and processing pipelines
- MQTT Message Broker and notification message publication (Subscribe)
- Object storage server providing raw data access (Download)
- OGC API server, providing dynamic APIs and Web services for discovery, access, visualization and processing functionality (APIs)
- Discovery metadata curation / editing tools
- Notification subscription and real-time download of data upon receipt of notifications.
- Provision of system performance and data availability metrics
- The modular design of wis2box makes it simple to extend to meet additional requirements or integrate with existing data management systems.
- wis2box already provides a useful set of functionality and will continue to evolve and develop throughout the WIS2 pilot phase and beyond.

Documentation is published in wis2box documentation.

The project in hosted in GitHub: https://github.com/wmo-im/wis2box

3.3. Implementation and operation of a Global Service

3.3.1. Procedure for registration of a new Global Service

Successful operations of WIS will depend on having a set of Global Services running state of the art IT environments, with a very high level of reliability so that all WIS Users and WIS2 Nodes will be able to access and provide data they need for their duties.

Depending on the nature of the Global Service, the following is considered to be the minimum of centres operating a Global Service, so that collectively, the level of service is 100% (or very close): * Three (3) Global Brokers - Each Global Broker connected to at least two (2) other Global Broker * Three (3) Global Caches - Each Global Cache connected to at least two (2) Global Broker and should be able to download the data from all WIS Nodes providing Core data * Two (2) Global Discovery Catalogues - Each Global Discovery Catalogue connected to at least one (1) Global Broker * Two (2) Global Monitoring Centres - Each Global Monitoring Centre should scrape the metrics from all WIS Nodes and all other Global Service

In addition to the above, WIS architecture can accomodate adding (or removing) Global Services. Candidate WIS Centres should inform their WIS Focal Point and contact the WMO Secretariat to discuss their offer to provide a Global Service.

Running a Global Service is a significant commitment for a WIS Centre. To maintain a very high level of service of WIS, each Global Service will have a key role to play.

WMO Secretariat, based on the current situation of WIS (How many Global Brokers ? A need for additional Cache ?), will propose to the WIS Centre the preferred solution to improve the overall level of service of WIS.

A WIS Centre may decide to run the proposed service or may decide to run another one.

The Manual on WIS, the Guide and other material available will help WIS Centres in deciding the best way forward.

When decided, the WIS Focal Point will inform WMO Secretariat of its preference. Depending on the type of Global Service, WMO Secretariat will provide a checklist to the WIS Centre so that the future Global Service can be included in WIS Operations.

WMO Secretariat will include the new Global Service in the next fast track cycle of WIS Operation. When endorsed by the President of the Infrastructure Commission, the WIS Centre will be included in the list of Global Service operators.

A WIS Centre must commit to running the Global Service for a minimum of four (4) years.

WMO Secretariat and other Global Services will make the required changes to include the new Global Service in WIS Operations.

3.3.2. Performance management and monitoring of a Global Service

3.3.2.1. Service levels, performance indicators, and fair-usage policies

- Each WIS Centre operating a WIS2 Node will be responsible in achieving the highest possible level of service based on their resources and capabilities.
- All Global Services, and in particular Global Brokers and Global Caches, are collectively responsible in making the WIS a reliable and efficient mean to exchange data required for the operations of all WIS Centres. The agreed architecture provides a redundant solution where the failure of one component will not impact the overall level of service of WIS.
- Each Global Service should aim at achieving at least 99.5% availibility of the service they propose. This is not a contractual target. It should be considered by the entity providing the Global Service as a guideline when designing and operating the Global Service.
- A Global Broker:
  - should support a minimum of 200 WIS Nodes or Global Services
  - should support a minimum of 1000 subscribers.
  - should support processing of a minimum of 10000 messages per second
- A Global Cache:
  - should support a mimimum of 100 GB of data in the cache
  - should support a minimum of 1000 simultaneous downloads
  - could limit the number of simultaneous connections from a user (known by its originating source IP) to 5
  - could limit the bandwidth usage of the service to 1Gb/s
- A Global Monitor:
  - should support a minimum of 50 metrics providers
  - should support 200 simultaneous access to the dashboard

    - could limit the bandwidth usage of the service to 100Mb/s
- A Global Discovery Catalogue:
    - should support a minimum of 20000 metadata records
    - should support a minimum of 50 requests per second to the API endpoint

3.3.2.2. Provision of metrics

In the following sections and for each Global Service, a set of metrics is defined. Each Global Service will provide those metrics. They will then be ingested by Global Monitoring Services.

3.3.3. Global Broker

3.3.3.1. Technical considerations

- As detailed above, there will be at least three (3) instances of Global Broker to ensure highly available, low latency global provision of messages within WIS.
- A Global Broker instance subscribes to messages from WIS Centres, Global Caches and other Global Brokers. The Global Broker should aim at subscribing to all WIS Centres. If this is not possible, for whatever reason, the Global Broker should inform WMO Secretariat so that situation is documented.
- Every WIS Centre or Global Service must have subscriptions from at least two Global Brokers.
- For full global coverage, a Global Broker instance will subscribe to messages from at least two (2) other Global Brokers.
- A Global Broker is built around two software components:
    - An off the shelf broker implementing both MQTT 3.1.1 and MQTT 5.0 in a highly-available setup, typically in a cluster mode. Tools such as EMQX, HiveMQ, VerneMQ are compliant with these requirements. It must be noted that the open source version of Mosquitto cannot be clustered and therefore should not be used as part of a Global Broker.
    - Additional features including anti-loop detection, notification message format compliance, validation of the published topic, and provision of metrics are required.
- When receiviong a message from a WIS Centre or Global Service broker, The metrics `wmo_wis2_gb_messages_received_total` will be increased by 1.
- A Global Broker will check if the topic received is valid (a metadata record must exist for a data under this topic), discarding non-compliant messages and raising an alert. The metrics `wmo_wis2_gb_messages_no_metadata_total` will be increased by 1.
- A Global Broker will validate notification messages against the standard format (see Notification message format and structure), discarding non-compliant messages and raising an alert. The metrics `wmo_wis2_gb_messages_invalid_total` will be increased by 1.
- A Global Broker instance will republish a message only once. Using the message id as defined in WIS Notification Message, the Global Broker will record id of messages already published and will discard subsequent identitical (with the same message id) messages. This is the anti-loop feature of the Global Broker.
- During the pre-operational phase (2024), instead of discarding the message in the two situations

above, processing will continue.

- When publishing a message to the local broker, the metrics `wmo_wis2_gb_messages_published_total` will be increased by 1.
- All aboved defined metrics will be made avalaible on HTTPS endpoints that the Global Monitor will ingest from regularly.
- As a convention Global Broker centre-id will be `tld-centre-name-globalbroker`.
- The figure xxx provides an illustration of the workflow followed by a Global Broker when getting a message.

3.3.4. Global Cache

3.3.4.1. Technical considerations

- The Global Cache will contain copies of real-time and near real-time data designated as "core" within the WMO Unified Data Policy (Resolution 1).
- During the initial stages of the WIS2 pilot phase Global Cache instances will provide open access to their cached content. Access control mechanisms may be added later.
- A Global Cache instance will host data objects copied from NC/DCPCs. These are persisted as files.
- A Global Cache instance will publish notification messages advertising availability of the data objects it holds. The notification messages will follow the standard structure (see 4.3 Notification message format and structure).
- A Global Cache instance will use the standard topic structure in their local message brokers (see WIS2 messages 4.4 Standard topic hierarchy).
- There will be multiple Global Cache instances to ensure highly available, low latency global provision of real-time and near real-time "core" data within WIS.
- Global Cache instances may attempt to download cacheable data objects from all originating centres with "cacheable" content. A Global Cache instance will also download data objects from other instances. This ensures the instance has full global coverage, mitigating where direct download from an originating centre is not possible.
- For full global coverage, a Global Cache instance will download Data Objects and discovery metadata records from other instances.
- Global Cache instance will operate independently of other Global Cache instances. Each Global Cache instance will hold a full copy of the cache – albeit that there may be small differences between Global Cache instances as "data availability" notification messages propagate through WIS to each Global Cache in turn. There is no formal ‘synchronisation’ between Global Cache instances.
- A Global Cache will store a full set of discovery metadata records. This is not an additional metadata catalogue that Data Consumers can search and browse – it provides a complete set of discovery metadata records to support populating a Global Discovery Catalogue instance.
- A Global Cache is designed to support real-time distribution of content. Data Consumers access data objects from a Global Cache instance by resolving the URL in a "data availability" notification message and downloading the file.

- There is no requirement for a Global Cache to provide a "browse-able" interface to the files in its repository allowing Data Consumers to discover what content is available. However, a Global Cache may choose to provide such a capability (e.g., implemented as a "Web Accessible Folder", or WAF) along with adequate documentation for Data Consumers to understand how the capability works.

TODO: to be completed

3.3.4.2. Practices and procedures

The following procedures will be described here once validated through testing during the WIS2 pilot phase: * Assigning a Global Cache to a NC or DCPC * Lifecycle management of discovery metadata records stored in the Global Cache.

TODO: to be completed

3.3.5. Global Discovery Catalogue

3.3.5.1. Technical considerations

- The Global Discovery Catalogue provides Data Consumers with a mechanism to discover the Datasets of interest, as well as, how to interact with and find out more information about those Datasets.
- The Global Discovery Catalogue implements the OGC API – Records – Part 1: Core standard.
- The Global Discovery Catalogue advertises the availability of Datasets and how/where to access them or subscribe to updates, it does not advertise the availability of individual Data Objects that comprise a dataset (i.e., data files).
- A single Global Discovery Catalogue instance is sufficient for WIS2.
- Multiple Global Discovery Catalogue instances may be deployed for resilience.
- Global Discovery Catalogue instances operate independently of each other – each Global Discovery Catalogue instance will hold all discovery metadata records. There is no need to synchronise between Global Discovery Catalogue instances.
- A Global Discovery Catalogue is populated with discovery metadata records from a Global Cache instance – receiving messages about availability of discovery metadata records via a Global Broker.
- A Global Discovery Catalogue should connect to more than one Global Broker instance to ensure that no messages are lost in the event of a Global Broker failure. A Global Discovery Catalogue instance shall discard duplicate messages as needed.
- A Global Discovery Catalogue will validate discovery metadata records against the WMO Core Metadata Profile version 2 (WCMP2), discarding non-compliant records and raising an alert.
- A Global Discovery Catalogue will update discovery metadata records it receives to add links for subscription URLs at Global Broker instances.
- A Global Discovery Catalogue should applying faceting capability as specified in the cataloguing considerations of the WCMP2 specification as defined in OGC API - Records.

- A Global Discovery Catalogue shall provide human-readable Web pages with embedded markup using the schema.org vocabulary, thereby enabling search engines to crawl and index the content of the Global Discovery Catalogue. Consequently, Data Consumers should also be able to discover WIS content via third party search engines.
- A Global Discovery Catalogue shall periodically assess the discovery metadata provided by NCs and DCPCs against a set of key performance indicators (KPIs) in support of continuous improvement. Suggestions for improvement are shared with the originating NC or DCPC and their primary GISC.
- A Global Discovery Catalogue shall generate and store a zipfile of all WCMP2 records once a day, that shall be made be accessible via HTTP.
- A Global Discovery Catalogue shall then publish a WIS2 Notification Message on its centre-id's metadata topic (i.e. `origin/a/wis2/centre-id/metadata`, where `centre-id` is the centre identifier of the Global Discovery Catalogue)`.

TODO: to be completed

3.3.5.2. Practices and procedures

The following procedures will be described here once validated through testing during the WIS2 pilot phase:

- Alerting originating NC or DCPC about malformed or non-compliant discovery metadata records
- Providing feedback to NC and DCPC about how to improve their discovery metadata
- Removing discovery metadata for a Dataset on request
- 'Bootstrapping' a Global Discovery Catalogue instance from the Global Cache

TODO: to be completed

3.3.6. Global Monitor

3.3.6.1. Technical Considerations

- WIS standardises how system performance and data availability metrics are published from WIS nodes and Global Services.
- For each type of Global Service, a set of standard metrics have been defined. Global Services will implement those metrics and provide an endpoint for those metrics to be scraped by the Global Monitor
- The Global Monitor will collect metrics as defined in the OpenMetrics standard.
- The Global Monitor will monitor the 'health' (i.e., performance) of WIS2 Node as well as Global Service instances.
- The Global Monitor will provide a Web-based 'dashboard' that displays the WIS system performance and data availability. The WIS Operations and Management team, in close collaboration with the Global Services will define the content of the dashboard.
- The Global Monitor, through the metrics provided, will be able to detect issues. In this case, Global Monitor will publish a Notification Message in the monitoring topic, as define by the WIS

Operations and Monitoring team. TODO: to be completed

3.4. Operations

Chapter 4. PART III

4.1. Information management

4.1.1. Introduction

4.1.1.1. Background

The efficient and effective provision of services relying on meteorological, climatological, hydrological and oceanographic information depends on a reliable information infrastructure. This infrastructure should be guided by community best practices and standards, including recommendations and requirements on sourcing, securing, managing, archiving, exchanging, and providing easy access to information. These terms and activities can be grouped under the term "information management" and this part of the Guide aims to provide high-level guidance on those activities. This is done by identifying and describing the fundamental principles of good information management and by highlighting the different stages of the information management lifecycle.

Note: The term "information" is used in a general sense and includes data and products.

4.1.1.2. Scope

High-level guidance on information management practices that apply in the context of information related to the Earth system is provided in this part of the Guide. Detailed technical information, such as specification of data formats or quality control and assurance methods, is provided in other parts of the Guide and in other WMO publications. These are referenced where applicable.

The principles of information management are described in Section 6.2. Section 6.3 describes the information management lifecycle through the identification of five focus areas. These are:

1. Planning, information creation and acquisition. Creation of information using internal and external data sources and the acquisition of information from various sources.
2. Representation and metadata. Standards to represent metadata, data and information are of primary importance to enable interoperability and long-term usability of the information.
3. Publication and exchange of information. The creation and publication of discovery metadata in a standardized format enabling users to discover, access and retrieve the information.
4. Usage and communication. Publication of guidance material on the use of published information, including on the limitations and suitability of the information and any licensing terms.
5. Storage, archival and disposal. Policies and procedures for business continuity and disaster recovery, as well as retention and disposal.

4.1.1.3. Intended audience

This guidance is primarily aimed at personnel within WMO centres, with responsibility for planning and undertaking the creation or acquisition, stewardship, exchange and provision of

information related to the Earth system.

Specifically, the guidance has five main target audiences across the information lifecycle:

1. Information producers or creators (those who produce or acquire the information - they need to ensure the scientific quality of the underpinning information).
2. Information managers (those who manage information).
3. Information providers or publishers (those who publish the information - they are responsible for the provision of the information, and for ensuring that appropriate access is enabled, licensing agreements are in place, etc.).
4. Service providers (those who disseminate the information - they are responsible for ensuring information availability and maintaining capability for easy and secure access to the information).
5. Information consumers (those who utilize the information - they need to understand the restrictions, rights, responsibilities and limitations associated with the information together with the suitability for intended usage or purpose).

4.1.2. Principles of information management

Effective management of information is essential for WMO Centres to deliver operational services and information that is authoritative, seamless, secure and timely. The principles below underpin this management across the full information lifecycle and provide a framework for information management. The principles are independent of information type and are largely independent of technology, they are therefore expected to remain stable over time.

4.1.2.1. Principle 1: Information is a valued asset

- An information asset is information that has value. This value may be related to the cost of generating and collecting the information, a value associated with the immediate use or a value associated with the longer term preservation and subsequent reuse of the information.
- 10.2.1.2 This value should be recognizable and quantifiable and the asset should have an identifiable lifecycle. Risks associated with, and to, an information asset should also be identified. As such, information management must be considered an integral part of a WMO centre’s responsibilities and needs to be adequately resourced over the full lifecycle of the information.

4.1.2.2. Principle 2: Information must be managed

- An information asset must be managed throughout its lifecycle, from creation to use to eventual disposal, in a way that makes it valuable, maximizes its benefits and reflects its value in time and its different uses.
- Information managers must consider the entire information lifecycle, from identifying needs and business cases to creating, quality assurance, maintenance, reuse, archiving, and disposal. Careful consideration must be given to disposal, ensuring that information is destroyed only when it has ceased to be useful for all categories of users.
- Professionally qualified and adequately skilled staff with clear roles and responsibilities should

apply a sound custodianship framework concerning security, confidentiality and other statutory requirements of different types of information.

4.1.2.3. Principle 3: Information must be fit for purpose

- Information should be developed and managed in accordance with its function and use for internal and external users.
- WMO Centres should regularly assess information to ensure that it is fit for its purpose and that processes, procedures, and documentation are adequate.
- Processes should be consistent with the general provisions and principles of quality management as described in the WMO Technical Regulations (WMO-No. 49).

4.1.2.4. Principle 4: Information must be standardized and interoperable

- Information must be stored and exchanged in standardized formats to ensure wide usability in the short and long term. It is essential for long-term archiving that information is stored in a form that can be understood and used after several decades.
- Standardization is essential for structured information such as dataset definitions and metadata to support interoperability.
- Interoperability is essential for users to utilize information through different systems and software. Open standards help ensure interoperability with their openness and wide adoption across various communities.
- Which standards to use depends on the user community and organizational policies. Interoperability requirements should be considered when selecting the standard for internal use and broader dissemination.
- The use of closed and proprietary standards is strongly discouraged.

4.1.2.5. Principle 5: Information must be well documented

- WMO centres should comprehensively document information processes, policies, and procedures to facilitate broad and long-term use.
- WMO centres should keep documentation up to date to ensure full traceability of processes along the information lifecycle, particularly for its creation.
- Previous versions of the documentation should be retained, versioned, archived and made readily available for future use. In addition, versions should be assigned a unique and persistent identifier for future unambiguous identification.

4.1.2.6. Principle 6: Information must be discoverable, accessible and retrievable

- Information should be easy to find through the Web, and for this purpose, the publisher should share discovery metadata with a catalogue service. The catalogue service should include a Web Application Programming Interface (API) to be used by other applications in order to offer user-tailored search portals.
- For information to be easily retrievable once discovered, it should be accessible using standard data exchange protocols.

4.1.2.7. Principle 7: Information should be reusable

- In order to maximize the economic benefits of an information asset it should be made as widely available and as accessible as possible.
- The WMO Unified Data Policy encourages the reuse of data and information through the open and unrestricted exchange of core WMO data. The WMO encourages the free and unrestricted exchange of information in all circumstances.10.2.7.3 The publisher should provide an explicit and well-defined license for each information item or dataset as part of the associated metadata.
- The Findable, Accessible, Interoperable and Reusable (FAIR) data principles promote open data with the ultimate goal of optimizing reuse of data. These principles should be followed where possible.

Note: Information on the FAIR data principles can be found at: FAIR Principles - GO FAIR [6]

4.1.2.8. Principle 8: Information management is subject to accountability and governance.

- Information management processes must be governed as the information moves through its lifecycle. All information must have a designated owner, steward, curator and custodian. These roles may be invested in the same person but should be clearly defined at the time of creation. A WMO centre with responsibility for managing information must ascertain:
- information management practices, procedures and protocols, including well-defined roles, responsibilities and restrictions on managing the information;
- definition and enforcement of appropriate retention policy, taking into account stakeholder needs and variations in value over the information lifecycle;
- licensing and defining and enforcing any access restrictions.
- The designated owner should have budget and decision-making authority about preservation and data usage, including passing ownership to another authority.

4.1.3. The information management lifecycle

4.1.3.1. Overview

All information should be subject to a well defined and documented lifecycle. The governance of this process is often referred to as the information management lifecycle and this process helps organizations manage information throughout its full lifecycle, from planning, creation and acquisition through usage and exchange to archival and disposal.

The following sections describe two overarching themes, governance and documentation, that apply to all stages of the information lifecycle and then provides high level guidance split into 5 aspects:

- Planning, creation and acquisition
- Representation and metadata
- Publication and exchange
- Usage and communication

- Storage, archival and disposal

Governance covers the rules that apply to managing information in a secure and transparent manner, documentation covers the act of recording the reasons for, and detail of, all operations in the information management process.

4.1.3.2. Overarching requirements

Governance

- Information management governance defines a set of organizational procedures, policies and processes for the management of information. This includes defining accountabilities and compliance mechanisms.
- Effective governance helps ensure that all aspects of the information management process are conducted in a rigorous, standardized and transparent manner and that the information are secure, accessible and usable.
- WMO centres should establish a board or leadership group to develop and regularly review such a governance structure and ensure compliance with its requirements.

Documentation

- Documentation describing the who, what, why, when, where and how various actions are undertaken in the management of information is required to ensure the traceability and integrity of the information and to ensure operations can continue if key staff leave.
- This documentation is required for all aspects of the information lifecycle and should be clear, well communicated, regularly updated, and easy to find. Guidance to the documentation should be provided to new staff taking on responsibilities for information management and be a key component of training.

4.1.3.3. Aspects of the information management lifecycle

Planning, information creation and acquisition

Before the creation or acquisition of new information a business case and information management plan should be developed, covering both the input information sources and any derived information. The plans should include:

- Why the information is required
- How it will be collected or created
- How it will be stored
- Whether it will be exchanged with other users and under what policy
- Where it should be submitted for long term archival
- Key roles and responsibilities associated with the management of the information

For externally sourced data the plans should include where the information has come from and what the licensing terms are.

Once information has been acquired it should be checked to ensure that the contents and format are as expected. This may be done using a compliance checker or validation service. Once these checks have been performed the information content should also undergo quality control checks using well documented procedures to identify any issues. A record of the checks should be kept and any issues detected should be documented and feedback to the originators. It is also important to subscribe to updates from originators so any issues identified externally can be taken into account.

Information created rather than acquired should undergo the same processes as the acquired information. The information created should undergo quality control and the resulting files checked against the specified format requirements. The results of the processes and checks should be documented.

To ensure traceability and reproducibility the information and documents at this, and subsequent stages, should be version controlled and clearly labelled with version information. Similarly, software, or computer code, used to generate or process information should be version controlled with the version information recorded in the documentation and metadata. Where possible, software should be maintained within a code repository.

Representation and metadata

The formats used to store and exchange information should be standardized to ensure its usability, both in the short and long term. It is essential that the information can be accessed many years after archival if required. To ensure this usability, the format and version information should be recorded in the metadata record for the information and should be included in the information where the format allows.

Information exchanged on the WMO Information System and between WMO centres is standardized through the use the formats specified in the WMO Manual on Codes (WMO-No. 306, Volume I.2) and the Manual on the WMO Information System (WMO-No. 1060). This includes the GRIB and BUFR formats for numerical weather prediction products and observational data and the WIS Core Metadata Profile for discovery, access and retrieval metadata. The format for the exchange of station and instrumental metadata, the WIGOS Metadata Data Representation, is also defined in the WMO Manual on Codes (WMO-No. 306, Volume I.3).

These formats have been developed within the WMO community to enable the efficient exchange of information between WMO centres and for the information to be interoperable between centres and systems. The formats, including detailed technical information, have also published openly through the WMO manuals, enabling use of the formats and information by other communities, promoting reuse of the information.

The WMO formats specified in the manuals are subject to strong governance processes, and changes to the formats can be traced through the versions of the manuals. The code tables and controlled vocabularies are also maintained in a code repository. To enable future reuse, the technical information, including detailed format specifications, should be archived alongside information for future access. This includes any controlled vocabulary, such as BUFR tables or WIGOS metadata code lists, associated with the format.

Publication and exchange of information

To maximize the benefits and return on investment in the acquisition and generation of

information there needs to be a clear method as to how the information will be published, exchanged and accessed by users.

Information is published on the WMO Information System through the creation of discovery metadata records. These records are publicly searchable and retrievable via WMO cataloguing services, providing access to the records via the Web and via a Web Application Programming Interface (API). The metadata records should include information on how to access the described datasets and services (see also 10.3.3.3.4) and how to subscribe to receive updates and new data.

Guidance on the creation of these discovery metadata records is included in Part V of this Guide. Technical regulations are provided in the Manual on the WMO Information System (WMO-No. 1060). Before exchange and publication the metadata should be assessed using the WMO Core Metadata Profile Key Performance Indicators to ensure usable and high quality metadata in addition to metadata that conforms with the technical standard.

Note: Further information on the Key Performance indicators can be found on the WMO Community Website at https://community.wmo.int/activity-areas/wis/wis-metadata-kpis

The Web standards and protocols used should be adequately documented to enable users to find and retrieve the information. This should be possible both manually and automatically via machine-to-machine interfaces and should be standardized between centres.

Updates to the information exchanged on the WIS, including the publication of new information or the cessation of previously exchanged information, is published in the WMO Operational Newsletter.

Note: The newsletter is available from: https://community.wmo.int/news/operational-newsletter

Usage and communication

For information to have value it must inform users, aid knowledge discovery and have impact through informed decision making. Ensuring that the user can make effective use of the information is an important step in the information management lifecycle. This takes two forms:

1. Provision of suitable information within the discovery metadata (See 10.3.3.4), enabling users to discover and access the information and to assess whether it meets their requirements. This should include licensing information.
2. Provision of user guides and documentation on the suitability of the information for different uses, including any technical caveats or restrictions on the use of the information.

For common types of information the guides may be generic or link to standard documentation. Information on the observations available from the WMO Integrated Global Observing System is provided within the Manual and Guide to the WMO Integrated Global Observing system, WMO-No. 1160 and WMO-No. 1165 respectively. This includes information on the expected uses and quality of the data, either directly or through links within. Similarly, information on the data and products available through the Global Data Processing and Forecasting System is provided in the Manual on the Global Data Processing and Forecasting System (WMO-No. 485).

For non-standard and specialist products targeted user guides may be more appropriate. These should include a plain text summary for the non-technical user and should also be accessible and

retrievable via a link within the discovery metadata. Any user guide should be in addition to the technical documentation described under Planning, information creation and acquisition (see 10.3.3.1).

Updates and the availability of new information should be announced and published via the WMO Operational Newsletter (see 10.3.3.4.6). Other communication methods may also be used but these should not be in place of the operational newsletter. It is also recommended to allow users to subscribe to receive updates directly.

The discovery metadata should include a valid point of contact, enabling users to provide feedback and ask questions about the information provided.

Storage, archival and disposal

The type of storage used should be appropriate to the type of information stored. Core information exchanged operationally should be stored and made available via high-availability and low latency media and services. For some operation critical information, such as hazard warnings, there is a requirement for the end-to-end global distribution of the information to be completed in two minutes. For other operational data there is a requirement for the global exchange to be completed in 15 minutes.

The storage requirements for non-operational services and information may be different but the guidance provided in this section applies equally. Further information on the performance requirements is provided within the WIS Technical Specifications listed in the Manual on the WMO Information System (WMO-No. 1060).

Backup policies and data recovery plans should be documented as part of the information management plan. These should be implemented either before or when the information is created or acquired and should include both the information and the associated metadata. The backup and recovery process should be routinely tested. Specific guidance on the expectations and requirements for WMO centres is provided under the operational guidance in Part VII of this Guide.

Business rules governing the access to and modification of the information should be clearly documented in the information management plan. This must include the clear specification of roles and responsibilities of those managing the information. Information on who can authorize the archival and disposal of the information and the processes for doing so should be included. The roles associated with an information resource are standardized as part of the WIS Core Metadata Profile, see Part V of this Guide for further information.

The archival and long-term preservation of an information resource should be identified and included in the information management plan. This may be at a national data centre and/or a WMO centre. The WMO centres are recommended for globally exchanged core data and include those centres contributing to the Global Atmosphere Watch, the Global Climate Observing System and the Marine Climate Data System (see Manual on Marine Meteorological Services, WMO-No. 558), as well as the WMO World Data Centres and those defined in the Manual on the WMO Information System (WMO-No. 1060) and those defined in the Manual on the Global Data Processing and Forecasting System (WMO-No. 485).

Earth system information, especially observational data, are often irreplaceable. Other information, whilst technically replaceable, is often costly to produce and therefore not easily

replaceable. This includes output from numerical models and simulations. Before an information resource is marked for disposal careful consideration must be given to whether long term archival or disposal is more appropriate. This consideration must follow a clearly defined process documented in the information management plan.

When an information resource is marked for disposal the reasons for disposal, including the outcome of the consultation with stakeholders and users, must clearly be documented. The disposal must be authorized by the identified owner and custodian of the information. The information on the disposal must be included in the metadata associated with the information resource. The metadata must be retained for future reference.

4.1.4. Other considerations

4.1.4.1. Technology and technology migration

Information managers must be aware of the need to ensure that the technologies, hardware and software used do not become obsolete and must be aware of emerging data issues. This topic is discussed further in the WMO Guide to Emerging Data Issues (WMO-No. 1239).

4.1.4.2. Information security

Further information on information security and best practices can be found in the WMO Guide to Information Technology Security (WMO-No. 1115).

[6] https://go-fair.org

Chapter 5. PART IV

5.1. Security

This section will introduce some concepts on the measures a publisher or a global service can implement to decrease the risk of cyber attacks.

Chapter 6. PART V

6.1. Competencies