COMMISSION FOR BASIC SYSTEMS

World Meteorological Organization
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Inter-Program Expert Team on Data Representation Development (IPET-DD)
Zagreb, Croatia 18-20 February 2019

IPET-DD-1
Agenda Item 7.1

17 January 2019

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Adoption of CfRadial 2.0 as a WMO standard representation of radial weather radar data

Purpose

This document contains outputs of IPET-OWR related to representation of weather radar data in radial coordinates. More specifically, as part of the main scope of IPET-OWR's work, an Operational Weather Radar Best Practices Guide (BPG) is being prepared, designed to provide advice and guidance to WMO's Members on all aspects related to operational weather radar. Part G of this BPG addresses "Data representation and exchange", and it is this part that is provided here.

The purpose of submitting Part G of the BPG to IPET-DD is for IPET-DD to vet the data representation content of Part G as part of the process aiming at having these IPET-OWR outputs adopted as an official WMO standard for use by Members for the purposes of international data exchange. Acknowledging that preparations are underway for WMO Congress to be held in June 2019, any recommendations related to this data representation for decision-making to be submitted to Congress would need to be formulated at IPET-DD-1 to meet deadlines. Feedback from IPET-DD to IPET-OWR is also solicited to help align and strengthen these weather-radar related outputs.

Weather radar and data representation

There is a legacy of weather radar data representation that should be provided to the meeting participants as necessary context, to help explain why and how IPET-OWR has arrived at its outputs. A presentation will be prepared for the meeting that will give this clarity. A fundamental aspect of this is that weather radar is only now emerging as a global resource under WMO's coordination and governance, with high priority, and data representation is central to this process. Community buy-in is critically important for this to succeed, and such buy-in has been secured due to the data representation outputs themselves having been evolved from previous/existing successes.

BPG Part G

The document provided here contains five sections. These are:

1. Publishing Radar Site Metadata
2. Selection of Radar Products for Data Exchange
3. Representation of Weather Radar Data
4. Licensing of Exchanged Data
5. Methods of Data Exchange

While the most relevant of these sections is Section 3, all of Part G is provided for completeness. Within Section 3, there is sub-section 3.5 “File Naming Convention” that is given without any knowledge of previously existing or planned file naming conventions that have been formulated by WMO and intended as Regulatory Material. This Section 3.5 does not need to be considered as an integral part of weather radar data representation.

Section 3 refers to an Information Model, a Data Model, and a CfRadial 2 file format specification. These are provided as supporting INF documents (see below).

It should be noted that BPG Part G, in its current draft form, is deliberately unformatted pending finalization of its contents. Following this, it is expected that all of the BPG will receive a proper WMO look and feel.

Supporting INF documents

Three such information documents are provided:

1. Information model for radial radar and lidar data (IM), submitted as INF_7.1a
2. Data model for radial radar and lidar data (DM), submitted as INF_7.1b
3. CfRadial 2.0 specification (CfR2), submitted as INF_7.1c

These documents are referred to by Part G of the BPG. The IM and DM are both outputs of IPET-OWR, and are thus owned and governed by WMO. CfR2 is a community output to which IPET-OWR has contributed.

NetCDF data formats

CfR2 itself is not governed by WMO, but the way in which it is applied by WMO’s Members for the purposes of international data exchange is proposed to be governed by WMO. While this proposal is the main focus of IPET-OWR’s participation at IPET-DD-1, there is a larger scope and discussion about the relation between Climate and Forecasting (CF) Conventions (based on netCDF) and WMO data representation standards into which CfR2 contributes.

IPET-OWR

Operational Weather Radar Best Practices Guide

Part G: Data Representation and Exchange

Contents

1 Publishing Radar Site Metadata

The metadata describing a weather radar site is an important technical resource that is maintained by the operating member. When this metadata is also made available externally, it can form part of a valuable global resource.

1.1 WMO Radar Database

The WMO supports a database of weather radar site metadata called the "WMO Radar Database". This database provides a centralized repository of information about the status and design of most operational weather radar networks globally. Figure 1 shows the locations of radar sites which have entries in the database as of November 2018. This represents over 900 sites worldwide.

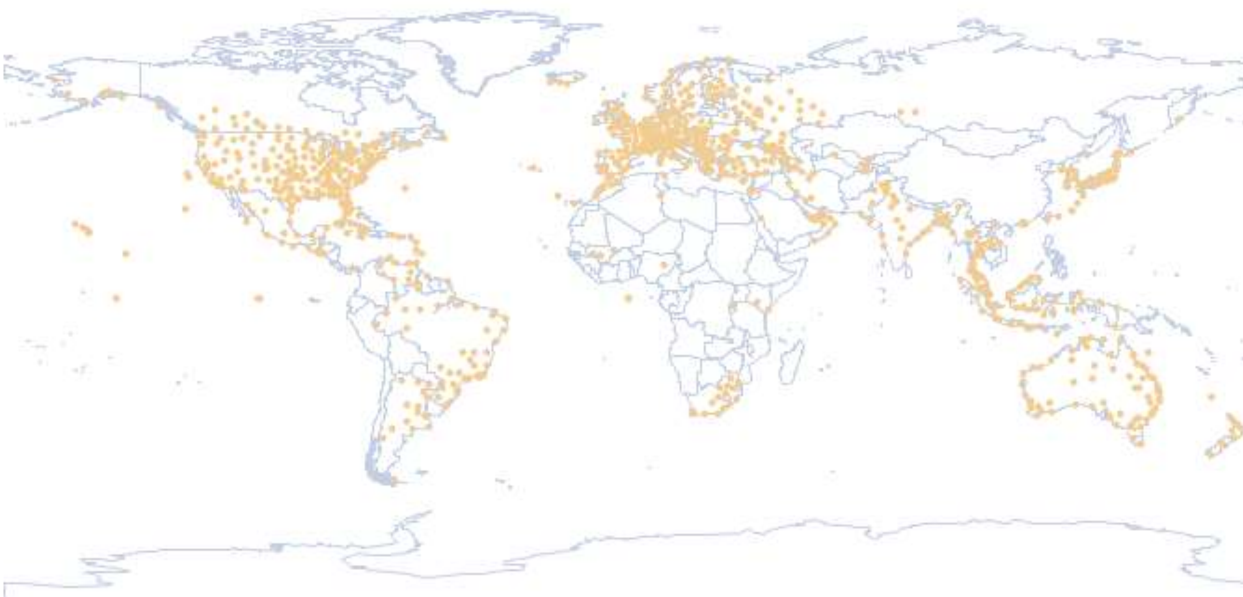

Figure 1 Location of weather radars according to existing entries in the WMO Radar Database, November 2018

The stated reasons for establishing the WMO Radar Database are:

- Presenting a comprehensive web-based database for network planning information and resource allocation for all members
- Assisting in wide spread international exchange of radar data
- Gathering radar information to protect radio-frequency spectrum allocation
- Presenting common issues/problems and potential solutions

The submission of radar site metadata to the WMO Radar Database is encouraged as a best practice. This allows members to discover international radar sites of interest and may aid in the establishing of data exchanges.

1.2 Site metadata versus scan metadata

The metadata associated with a radar site is a subset of the metadata which is associated with individual radar scans. Site metadata is used to describe aspects of the radar system that do not generally change scan to scan. This includes metadata related to the infrastructure, instrument, signal processing, and available products. These metadata tend to be long lived and typically change infrequently. Examples include the manufacturer, tower height, and beam width.

In contrast to site metadata, the metadata associated with an individual scan may change every scan, or even during a scan. Examples include the scan start time, pulse repetition frequency and range resolution. A subset of the site metadata will also typically be included with each scan to avoid the need for separate lookup of fundamental properties such as the antenna location and beam width.

Due to its infrequently changing nature, one of the major challenges faced by the WMO Radar Database is keeping the site metadata up to date. Metadata is often published once when the radar is setup and then allowed to go stale. It is considered best practice to ensure that the WMO Weather Radar Database is updated in a timely manner whenever radar site metadata changes.

1.3 Recommendations

1. Ensure that an appropriate National Focal Point for Weather Radar Metadata is nominated and listed within the WMO Country Profile Database
2. Submit weather radar site metadata to the WMO Weather Radar Database
3. Review and update entries in the WMO Weather Radar Database regularly

1.4 References

Turkish Meteorological Service (TMS) on behalf of World Meteorological Organization (WMO), 2018: WMO Radar Database, http://wrd.mgm.gov.tr/

World Meteorological Organization (WMO), 2018: Country Profile Database (National Focal Point for Weather Radar Metadata), https://www.wmo.int/cpdb/workgroups/view/crm_FP%20WR

2 Selection of Radar Products for Data Exchange

Operational weather radar systems can output many different products. These range from very low-level data such as a time series of samples measured by the receiver through to very high-level data such as multi-radar composite rainfall grids.

It is important that the correct level of weather radar data be targeted for exchange at the international level. If data exchanged is too low-level it will be very difficult to work with and utilize effectively. If the data exchanged is too high-level, then valuable information may be omitted which reduces its usefulness for applications.

2.1 Weather radar data levels

The WMO Information Model for Radial Radar and Lidar Data defines the basic levels of weather radar data shown in Table 1.

Table 1 Weather radar data levels

Level	Description
0	Data at full resolution as received at the sampling rate of the receiver. Generally only available internal to the system. Special equipment may be required to measure and record such data.
1	Data in sensor units also known as "time series" or "I/Q" (in-phase and quadrature) data. Produced and processed by the instrument's signal processor. Generally not recorded except for limited durations on operational radars. Commonly recorded on research radars.
2	Derived radar variables or moments (reflectivity, radial velocity, differential reflectivity, etc.) at full resolution after aggregation and filtering. Organised in polar coordinates by rays, range bins and quantities. Also, known as "sweep" and “volume scan" data.
3	Radar products which are derived primarily from level 2 data. May be in the level 2 polar coordinates (particle ID, quality metrics, etc.), or in other coordinates systems such as vertical profiles or Cartesian grids (CAPPI, rain rate estimates, etc.).
4	Higher order products which may include data from multiple measurements. This includes products which composite multiple radars (mosaics) as well as those that blend data from other sources (satellites, rain gauges, NWP etc.).

In most operational radar networks, the Level 2 polar data is the lowest level of data which is widely available. This data corresponds to radar moments, such as reflectivity, which are organized in polar coordinates relative to the instrument (elevation, azimuth and slant range). Advanced and emerging applications such as direct assimilation for numerical weather prediction (NWP) require access to data at this level since it is the closest to 'raw' observations. For this reason, Level 2 data is considered the most suitable for international exchange purposes.

In addition to Level 2 data it may be beneficial to offer Level 3 and 4 radar products for exchange. These products may provide ready-to-use information such as Cartesian reflectivity composites or rainfall estimates. Access to such products is considered particularly helpful for users that are unable or do not wish to generate their own radar products from raw Level 2 data.

2.2 Granularity of representation

Representations of Level 2 weather radar data generally provide a high degree of flexibility with regard to granularity of storage. Scan data may be stored on a per-data type, per-sweep, per-volume, or even multi-volume basis. For example, a single volume scan might be stored as a set of single sweep files, or an entire day of volumes might be archived within a single file.

The choice of how granular to make a data exchange requires careful consideration. If the data is stored in large batches (e.g. multiple volumes per file) a large amount of latency will be introduced, limiting its usefulness in operational contexts. Similarly if the data is stored at a high level of granularity (e.g. one file per-data type, per-sweep) then exchanges become complex and a large burden is placed on downstream users to reassemble the data into whole volumes.

For the purpose of international data exchange, it is recommended to exchange data on a per-volume basis. This is a natural level of granularity for many radar applications while also facilitating reasonably low latency transfers for operational use. Where very low latency exchange is required the data could also be made available on a per-sweep or per-data type basis.

2.3 Recommendations

1. Prefer to exchange data as Level 2 (polar) data rather than higher order products
2. Prefer to exchange data on a per-volume basis
3. Offer Level 3 and 4 products for exchange as an auxiliary service when appropriate

2.4 References

Michelson D, Curtis M., Dixon M., Haase G., Horvat C., Joe P., Umehara A., 2018: WMO Information Model for Radial Radar and Lidar Data. Version 1.3. WMO IPET-OWR. 20pp

3 Representation of Weather Radar Data

The adoption of a common representation for weather radar data is important for the successful implementation of international data exchange at a large scale. While Level 2 radar data is generally output from a radar in a manufacturer specific format, exchanging data in these formats is problematic. The formats may not have openly available descriptions, require proprietary tools to work with, or not include enough metadata for downstream applications. The use of a common exchange format reduces the complexity of exchange mechanisms and eases the use of received data.

The WMO Information Model for Radial Radar and Lidar Data defines a model for Level 2 weather radar data which is suitable for use as a common exchange format. It describes the key objects, relationships and metadata that must be represented in a conceptual form, independent from the concrete implementation details.

The WMO Data Model for Radial Radar and Lidar Data elaborates on the Information Model by introducing logical, structural and representational constraints. These constraints[1] form a bridge between the conceptual Information Model and the concrete description of an implementing file format or protocol.

3.1 CfRadial 2 file format

CfRadial 2 is an extension to the NetCDF Climate and Forecast (CF) Metadata Conventions which addresses the issue of representation of polar radar and lidar data. Together with the underlying NetCDF file format, CfRadial 2 establishes a concrete file-based implementation of the WMO Information Model for Radial Radar and Lidar Data, and the associated Data Model.

Files in the CfRadial 2 format are self-describing[2] which means that they can be understood without the need for external information. In a context where files are to be exchanged internationally, this is an advantage over table driven codes such as BUFR and GRIB. This also eases the use of radar data in climate related applications where long-term archives are required.

CfRadial 2 is an extensible format which allows users to store non-standard data and metadata in the file while maintaining full compatibility with applications. This facilitates maximal retention of information during the conversion from the native Level 2 data format output by the instrument.

It is recommended as best practice that CfRadial 2 be used as the common international exchange format for Level 2 weather radar data.

3.2 Mandatory scan metadata

The Information Model, Data Model and CfRadial File Format specify a minimum set of metadata that must be included with each data file for the purpose of basic data integrity. Table 2 lists these metadata and several others which are to be considered mandatory for international exchange purposes. Within this table:

[1] Examples include encoding of strings as UTF-8, and permissible data packing and compression schemes.

[2] Self-describing in this context means that information needed to understand the contained datasets is provided within the file itself. This includes information such as quantity names, units, valid ranges etc.

- **IMID** provides the identifier of the metadata within the WMO Information Model for Radial Radar and Lidar Data.
- **Description** provides the description of the metadata as listed in the Information Model.
- **CfRadial** provides the name of the equivalent dimension, variable or attribute which implements the metadata within the CfRadial 2 format.

The inclusion of comprehensive metadata beyond those identified by Table 2 is strongly encouraged.

Table 2 Mandatory weather radar metadata

IMID	Description	CfRadial
	Volume metadata	
1.0	Instrument type, distinguishing between "radar" and "lidar"	instrument_type
1.1	Site identifier, WIGOS identifier (see below)	instrument_name
1.2	Volume start time	time_coverage_start
1.3	Volume end time	time_coverage_end
2.0	Site longitude	longitude
2.1	Site latitude	latitude
2.2	Site altitude above geodetic datum. For a scanning instrument this is the center of rotation of the antenna.	altitude
2.3	Geodetic datum name	
3.2	Antenna beam width H	radar_beam_width_h
3.3	Antenna beam width V	radar_beam_width_v
3.5	Frequency	frequency
	Sweep metadata	
5.1	Target fixed angle	fixed_angle
5.4	PRT mode	prt_mode
5.5	Distance to centre of first range bin	meters_to_center_of_first_gate
	Ray metadata	
8.0	Elevation angle	elevation
8.1	Azimuth angle	azimuth
8.2	Time of acquisition (relative to volume start time)	time
8.8	Pulse repetition time(s)	prt
8.9	Nyquist velocity	nyquist_velocity
	Range bin metadata	
11.0	Length of range bin	meters_between_gates
	Dataset metadata	
12.0	Dataset identifier (user specified)	variable name
12.1	Quantity name	standard_name
12.2	Quantity units	units
12.3	Quantity value used to indicate missing data	_FillValue
12.4	Quantity value used to indicate no signal	_Undetect
13.0	Identifiers of datasets which are qualified by this dataset	qualified_variables

The site shall be identified (IMID 1.1) by its WIGOS identifier, the structure of which consists of four parts[3]. The part of the structure called "Local identifier" is the only part consisting of characters. Following the ODIM NOD identifier convention (Michelson et al., 2014)[4], it is suggested as a best practice that the local identifier be harmonized to a five-character string, where the first two characters are the member country's ISO 3166-1 alpha 2 ccTLD[5] code (lower case), and the latter three characters are freely-selectable (also lower case).

3.3 Identification of Weather Radar Quantities

The CfRadial 2 file format imposes no direct restriction on the naming of the variables used to store individual radar quantities. Rather, it specifies only a standard name attribute which identifies the basic physical quantity stored. For example, CfRadial makes no distinction between corrected and uncorrected[6] reflectivity even though the difference is significant within an operational context.

To ensure that exchange of commonly used operational quantities, a naming convention is established for the dataset variables within a CfRadial file. Table 3 identifies common operational quantities and provides the names that must be given to variables containing them when CfRadial 2 is used for international exchange. Within this table:

- **IMID** provides the identifier of the quantity within the WMO Information Model for Radial Radar and Lidar Data. This number is provided for reference only.
- **Identifier** provides the name which must be used as the field data variable name (short_name) within a CfRadial 2 file. This value corresponds to the IMID 12.0 "Dataset identifier" metadatum.
- **Quantity** provides the value which must be used for the standard_name attribute within a CfRadial 2 file. This value corresponds to the IMID 12.1 "Quantity name" metadatum.
- **Description** provides the value which should be used for the long_name attribute within a CfRadial 2 file. This value has no corresponding metadatum within the Information Model.

Table 3 Standard Radar Quantity Identifiers

IMID	Identifier	Quantity	Description
16.0	DBZH	radar_equivalent_reflectivity_factor_h	Equivalent reflectivity factor H
16.0	DBZV	radar_equivalent_reflectivity_factor_v	Equivalent reflectivity factor V
16.1	ZH	radar_linear_equivalent_reflectivity_factor_h	Linear equivalent reflectivity factor H
16.1	ZV	radar_linear_equivalent_reflectivity_factor_v	Linear equivalent reflectivity factor V
16.0	DBTH	radar_equivalent_reflectivity_factor_h	Total power H (uncorrected reflectivity)
16.0	DBTV	radar_equivalent_reflectivity_factor_v	Total power V (uncorrected reflectivity)

[3] http://wis.wmo.int/page=WIGOS-Identifiers
[4] Michelson D.B., Lewandowski R., Szewczykowski M., Beekhuis H., and Haase G., 2014: EUMETNET OPERA weather radar information model for implementation with the HDF5 file format. Version 2.2. EUMETNET OPERA Output O4. 38 pp.
[5] http://www.iso.org/iso/country_codes
[6] Total power

16.1	TH	radar_linear_equivalent_reflectivity_factor_h	Linear total power H (uncorrected reflectivity)
16.1	TV	radar_linear_equivalent_reflectivity_factor_v	Linear total power V (uncorrected reflectivity)
16.2	VRADH	radial_velocity_of_scatterers_away _from_instrument_h	Radial velocity of scatterers away from instrument H
16.2	VRADV	radial_velocity_of_scatterers_away _from_instrument_v	Radial velocity of scatterers away from instrument V
16.3	WRADH	radar_doppler_spectrum_width_h	Doppler spectrum width H
16.3	WRADV	radar_doppler_spectrum_width_v	Doppler spectrum width V
16.4	ZDR	radar_differential_reflectivity_hv	Log differential reflectivity H/V
16.5	LDR	radar_linear_depolarization_ratio	Log-linear depolarization ratio HV
16.6	LDRH	radar_linear_depolarization_ratio_h	Log-linear depolarization ratio H
16.7	LDRV	radar_linear_depolarization_ratio_v	Log-linear depolarization ratio V
16.8	PHIDP	radar_differential_phase_hv	Differential phase HV
16.9	KDP	radar_specific_differential_phase_hv	Specific differential phase HV
16.10	PHIHX	radar_differential_phase_copolar_h _crosspolar_v	Cross-polar differential phase
16.11	RHOHV	radar_correlation_coefficient_hv	Correlation coefficient HV
16.12	RHOHX	radar_correlation_coefficient_copolar_h _crosspolar_v	Co-to-cross polar correlation coefficient H
16.13	RHOXV	radar_correlation_coefficient_copolar_v _crosspolar_h	Co-to-cross polar correlation coefficient V
16.14	DBM	radar_received_signal_power	Log power
16.15	DBMHC	radar_received_signal_power_copolar_h	Log power co-polar H
16.16	DBMHX	radar_received_signal_power_crosspolar_h	Log power cross-polar H
16.17	DBMVC	radar_received_signal_power_copolar_v	Log power co-polar V
16.18	DBMVX	radar_received_signal_power_crosspolar_v	Log power cross-polar V
16.19	SNR	radar_signal_to_noise_ratio	Signal-to-noise ratio
16.20	SNRHC	radar_signal_to_noise_ratio_copolar_h	Signal-to-noise ratio co-polar H
16.21	SNRHX	radar_signal_to_noise_ratio_crosspolar_h	Signal-to-noise ratio cross-polar H
16.22	SNRVC	radar_signal_to_noise_ratio_copolar_v	Signal-to-noise ratio co-polar V
16.23	SNRVX	radar_signal_to_noise_ratio_crosspolar_v	Signal to noise ratio cross polar V
16.24	NCP	radar_normalized_coherent_power	Normalized coherent power
16.25	RR	radar_estimated_precipitation_rate	Rain rate
16.26	REC	radar_scatterer_classification	Radar echo classification

3.4 Encoding of Radar Quantity Values

CfRadial 2 can store radar quantities at a range of bit depths using a linear offset and gain encoding scheme. This type of encoding is common within the native formats used by weather radars, with quantities typically being stored as either 8-bit or 16-bit integers.

When converting data from a native format produced by the instrument into CfRadial 2 it is recommended to preserve the existing encoding scheme if possible. This ensures that an exact representation of the original values is retained.

The radar quantities PHIDP, PHIHX, KDP and RR should always be represented with a depth of at least 16 bits. This is due to the increased need for precision in these types.

3.5 File Naming Convention

To simplify handling of data from multiple sources, a simple naming convention for exchanged files is recommended. This convention is based on the WIGOS identifier of the radar instrument, a timestamp, and a user defined product identifier. The addition of a user defined product identifier allows for the output of multiple files from a single radar at the same time. If a single product is output by the radar the identifier of "vol" is recommended. In this convention files are named using the format "**WIGOS_timestamp_product**.nc" where:

- **WIGOS** is the WIGOS station identifier for the radar
- **timestamp** is the UTC product time in ISO 8601 basic format (YYYYMMDDThhmmssZ)
- **product** is a user defined product name

An example of how the file name is constructed is shown in Figure 2.

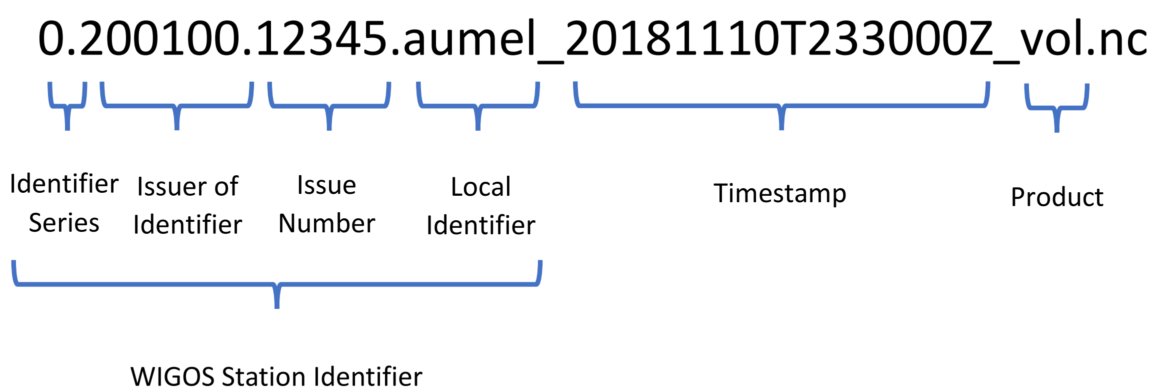

Figure 2 Example of radar data file naming convention

3.6 Recommendations

1. Represent Level 2 weather radar data for exchange using the CfRadial 2 file format
2. Store all data associated with a radar volume in a single file
3. Include the metadata identified by Table 2 in every file
4. Include all available metadata which is identified by the CfRadial 2 specification in every file
5. Included the following radar quantities in every file, where available based on the capabilities of the radar: DBZH, DBTH, VRADH, WRADH, ZDR, RHOHV, PHIDP

6. Store radar quantities in the file with the same encoding (bit depth) as output by the instrument when possible
7. Store the radar quantities PHIDP, PHIHX, KDP and RR with a depth of at least 16 bits
8. Name files for exchange according to the convention established in 3.5

3.7 References

Michelson D, Curtis M., Dixon M., Haase G., Horvat C., Joe P., Umehara A., 2018: WMO Information Model for Radial Radar and Lidar Data. Version 1.3. WMO IPET-OWR. 20pp

Curtis M., Dixon M., Michelson D., 2018: WMO Data Model for Radial Radar and Lidar Data. Version 1.0. WMO IPET-OWR. 20pp

Dixon M., Curtis M., Michelson D., Hardin J., Kehoe K., Haimov S., 2018: CfRadial2 Data File Format. Version 2.0. NCAR. 59pp

World Meteorological Organization, 2015: Manual on the WMO Integrated Global Observing System, 2015 edition updated in 2017, WMO. 97pp

4 Licensing of Exchanged Data

An important consideration when exchanging data of any form is the license under which access to the data is granted. The data license that is used governs the conditions on how the data may be used and redistributed, as well as issues such as attribution and legal disclaimers.

It is recommended that weather radar data be exchanged as 'open data' with as few restrictions on the use and redistribution of the data as possible.

The data produced by operational weather radar networks is often seen as a significant national resource with exploitable commercial value. Given this, it is expected that licensing of data as 'open data' will not always be possible due to political and commercial considerations. In such cases, extra care must be taken to ensure that restrictions and conditions imposed on the use of the data are clearly stated.

Where open data exchange is permitted, it is recommended that the Creative Commons[7] license be used. There are several variants of the Creative Commons license that are available. The most open variant is the public domain or 'CC0' license. This license waives all copyright claims over the data, allowing its use and redistribution for any purpose without requiring attribution to the original source. Another common variant is the attribution, or 'CC BY' license. This version also allows use and redistribution for any purpose provided that the original source of the data is attributed.

Where it is possible to exchange data under an open data license, it is recommended that either the CC0 or CC BY licenses be used since these permit the least encumbered use of the data.

4.1 Recommendations

1. Make weather radar data available under an open data license where possible.
2. Prefer to license open data with the Creative Commons license either as public domain (CC0) or with attribution condition (CC BY).
3. Ensure that data license conditions are clearly stated and known to all parties when open data license is not possible.
4. Identify the data license within the metadata of each exchanged file.

4.2 References

Creative Commons, 2018: About The Licenses, https://creativecommons.org/licenses/

[7] https://creativecommons.org/

5 Methods of Data Exchange

When using CfRadial 2 to represent Level 2 radar data as recommended, the data payload takes the form of plain files. This allows operational data exchanges to be established using generic IT facilities which are not directly related to weather radar systems. The exact choice and design of an exchange mechanism must consider a range of technical, financial and legal requirements and may often be performed by IT or communications experts rather than radar experts.

5.1 Considerations for the design of exchange mechanisms

This section highlights some of the key factors that should be considered when designing an operational weather radar data exchange.

5.1.1 Security

Security of the mechanism is a major concern for any data exchange. Some of the key characteristics of a secure exchange mechanism include:

- **Authentication** – Connections may be authenticated to ensure that data is exchanged with the correct end point.
- **Encryption** – The data may be encrypted during transport. This is particularly important to ensure that data is not accessed outside of the terms of its license.
- **Signing** – Digital signatures may be provided to allow integrity checking of the received data.
- **Auditing** – Activity of the exchange may be logged to provide later analysis of security events.

5.1.2 Resilience

An exchange mechanism suitable for use within an operational environment must be highly resilient. Some of the characteristics to consider include:

- **Reliability** – The mechanism should not be prone to failure and may be designed to meet a specific availability requirement imposed by the operational environment.
- **Redundancy** – A redundant data flow may be established to ensure that data remains available for use operationally if the primary exchange fails for any reason.
- **Recovery** – In the event of an outage or failure, consider how the mechanism should recover. This includes return to service procedures and issues such as the resending of missed data.
- **Monitoring** – The mechanism may provide facilities for monitoring to ensure correct function, acceptable performance, and to assist with diagnosis of problems.

5.1.3 Performance

The operational environment that is being supported by the exchange mechanism will dictate the required performance characteristics of the exchange. The primary considerations are:

- **Latency** – For most operational environments radar data must be delivered promptly if it is to be useful. The time between the data acquisition and delivery to the remote end of an exchange should therefore be a key consideration. This consideration extends beyond the latency of the exchange mechanism itself. All sources of latency between the radar instrument and the exchange (e.g. internal radar network, data processing chain) may contribute.
- **Throughput** – The mechanism must be designed to ensure that it is capable of transferring the required quantity of files over time (while maintaining an acceptable latency). The throughput

requirement will vary greatly between exchanges depending on the number of radars, frequency of transmission, size of data files, number of clients etc.

- **Quality of Service** – The size of Level 2 radar data can change significantly based on factors such as weather conditions, scanning strategy and data processing. This means that the peak size of data files may be significantly larger than the average case. Where the throughput of a mechanism cannot be guaranteed under absolute worst case conditions (all files near peak size), a Quality of Service (QoS) feature may be provided to ensure that the most important data is prioritized.

5.1.4 Connection model

The style of connection used by the exchange mechanism is an important consideration as it impacts the design of receiving systems:

- **Active or Passive** – In an active connection model, the receiving end of a data exchange is explicitly notified when new data is available, while in a passive model the receiver must periodically check (or poll) for the presence of new data.
- **Push or Pull** – In a push model, the transfer of an individual data payload is initiated by the sender and 'pushes' data to the receiving system. In a pull model, the transfer of a payload is initiated by the receiver who 'pulls' the data from the sending system.

The choices between active/passive and push/pull are independent and can be used to create a variety of exchange mechanisms. An example of each combination is described below:

- A publish/subscribe mechanism, where a receiver initially subscribes to a data flow and then automatically receives new data over a TCP connection as soon as it becomes available, is an example of an **Active Push** mechanism.
- A notify/pull mechanism, where the receiver subscribes to a data flow and then automatically receives notifications of new data availability over a TCP connection, but must then collect the payload itself (e.g. from a FTP server), is an example of an **Active Pull** mechanism.
- A sender which uses FTP to automatically transfer files to a known remote host when they become available is an example of a **Passive Push** mechanism.
- A sender which publishes files to an FTP server without otherwise notifying receivers is an example of a **Passive Pull** mechanism.

5.2 Recommendations

1. FTP[8] should be avoided due to its security vulnerabilities. This is particularly sensitive, and potentially impactful, to Members who experience challenges with capacity related to IT expertise. While it may not be reasonable to expect current message switching system solutions using FTP to be replaced in the short term, future WMO Information System (WIS) mechanisms for real-time data exchange should not be built on top of FTP.
2. Members should consider the desired resilience and performance characteristics of the exchange when choosing between passive and active data exchange. Active mechanisms provide useful control and monitoring, at the expense of system complexity and overhead.

[8] Note that the subject of this recommendation is the File Transfer Protocol (FTP), which is distinct from other similarly named technologies such as Secure File Transfer Protocol (SFTP).

3. WMO data exchange mechanisms should be designed to accommodate weather-radar data payloads using the data representations proposed by IPET-OWR.
4. Members wishing to exchange weather-radar data should use WMO data exchange mechanisms that are designed to accommodate weather-radar data payloads.
5. Private (secure) networks can be used as an alternative to the Internet for additional safety and stability. Such networks, e.g. the Regional Meteorological Data Communication Network (RMDCN) in Europe, are private TCP/IP networks with regulated bandwidth designed for peer-to-peer data transfer. The Global Telecommunications System (GTS) is used by many European Members over the RMDCN.
6. Alternative/redundant routing of data should be considered in exchange methods in order to increase the likelihood that data are successfully exchanged. For example, in a network with three nodes A, B, and C, where all nodes exchange data with the others, if the connection between nodes B and C is broken, data from these two nodes are routed through node A in order to reach each other. So-called multicasting or gridded methods may be a means of achieving such network robustness.

5.3 References

Michelson D., Curtis M., 2017: Weather radar data exchange methods. WMO IPET-OWR. 4pp