World Meteorological Organization

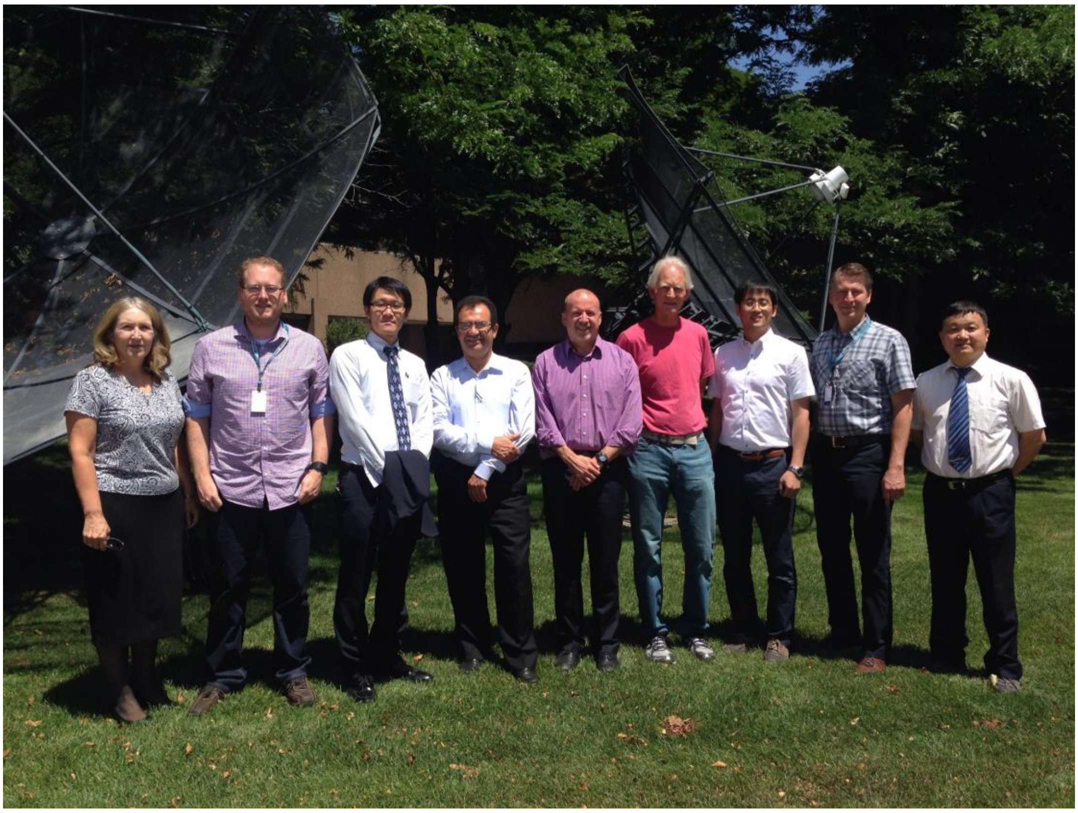
COMMISSION FOR BASIC SYSTEMS

OPEN PROGRAMME AREA GROUP ON INTEGRATED OBSERVING SYSTEMS

First Session of the Task Team on Weather Radar Data Exchange

26-28 July, Boulder, United States

FINAL REPORT



Contents

MEETING AGENDA

1 Organization of the Meeting

1.1 Opening of the session

1.2 Adoption of the agenda

1.3 Working arrangements for the session

1 Guidance From the Chairperson

2.1 Report of the Chairperson

2.2 Status on the formation of a consolidated WMO weather radar group

3 Status of Weather Radar International Data Exchange

4 Review of TT-WRDE Terms of Reference and Work Plan

4.1 Terms of Reference

4.2 Review and Update of the Task Team Work Plan

4.2.1 Deliverable items D1-D4

4.2.2 Meeting items E1 and M1

4.3 Work Plan Task - Work Session

5 Task Team Status, Work Process, Future Meetings & Reporting

6 Any Other Business

7 Close of the Meeting

GENERAL SUMMARY

1. Organization of the Meeting

1.1. Opening of the session

1.1.1. The first meeting of the CBS Open Programme Areas Group on Integrated Observing Systems Task Team on Weather Radar Data Exchange (TT-WRDE) was opened by the Chair of the team, Mr Daniel Michelson, Canada, on 26 July 2016 at 9:00am, at the National Centre for Atmospheric Research (NCAR), Boulder, USA. Mr Michelson welcomed the participants to the Meeting and thanked the host, Mr Mike Dixon for his help in its organisation. Mr Dean Lockett of the WMO Secretariat also welcomed participants and provided some background on the Team, including the reason for, and the process that led to its formation, its history since formation and the expectations in relation to the outcomes of its work plan and activities.

1.1.2. Participants and team members introduced themselves and provided some background on their expertise and interest in the work of the task team. The meeting Participants List is provided within Annex I.

1.2. Adoption of the agenda

1.2.1. The Chair recommended and the Meeting agreed that the agenda as above should be adopted.

1.3. Working arrangements for the session

1.3.1. The participants agreed on the arrangements for the session, which was conducted in English and in plenary throughout.

2. Guidance From the Chairperson

2.1. Report of the Chairperson

2.1.1. Mr Michelson presented his report as Chair of the task team, describing the history of the Team since its formation and outlining the work plan, the expected deliverables and the expected work process to achieve its required outcomes.

2.1.2. The CBS Task Team on Weather Radar Data Exchange (TT-WRDE) had been created in response to anticipated increased demand for weather radar data for assimilation into numerical prediction models, associated with the Global Action (G48) of the CBS Implementation Plan for the Evolution of the Global Observing System (EGOS-IP[1]), calling for wider exchange of weather radar data in support of NWP. In preparing to meet this demand, the overarching goals were to ensure that global meteorological infrastructure, hosted and operated by WMO's Members, was prepared for weather radar data in standard ways, ie. data representation and exchange mechanisms. Intercontinental, inter-regional, and even intra-regional weather radar data exchange were all within scope of TT-WRDE. In some Regional Associations (RA), such data exchange was already well-established, the most comprehensive example being RA-VI (Europe) with EUMETNET OPERA's activities.

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[1] See : http://www.wmo.int/pages/prog/www/OSY/Publications/EGOS-IP-2025/EGOS-IP-2025-en.pdf

2.1.3. The Team was formed in late 2013 by CBS at the request of the CBS Expert Team on Surface-Based Observations, as a response to the recommendations of the WMO Workshop on Weather Radar Data Exchange, held in Exeter, UK, in April, 2013, UK.

2.1.4. The requirements for WRDE gathered at the workshop were an important first deliverable, providing important clarity about expectations on what data are to be exchanged, along with associated details. While the work of the Team has been delayed due to various reasons, preventing an initial meeting, some work had commenced based on the initial work plan developed by the Team's original membership in collaboration by email and remote conferencing. An outcome of the meeting would be to review and update the work plan.

2.1.5. Mr Michelson explained that, while some file formats for exchange of weather radar data had been developed, some becoming de facto standards, there was not yet a recognized WMO information model for weather radar and nor was there a corresponding data model. Therefore an important task of the team initially would be the formulation and recommendation for adoption by WMO of a standard information model and data model for exchange of weather radar data. Once these tasks were complete, the Team could consider the matter of the expression of the data model within an international standard format. However, a most critical aspect was that the information and data models should together guarantee that the same radar data payload could be represented with no loss in information content independently of file format.

2.1.6. An additional important issue for the consideration of the Team was that of data exchange mechanisms and methods. While WMO had well-established infrastructure in place for exchange of observations, TT-WRDE had the mandate to gauge their suitability for real-time exchange of weather radar data, and to make appropriate recommendations. In some regions, significant amounts of radar data were already being exchanged, while in other regions, little or no WRDE was evident. Consequently, requirements for and adoption of international standards for WRDE would likely vary accordingly. Capacity development activities associated with TT-WRDE's technical outputs, e.g. training materials, will be critical in enhancing the technical readiness of WMO's Members.

2.1.7. Mr Michelson informed that the overall objective for TT-WRDE was to formulate and recommend the foundation for global WRDE and that this work would be consolidated together with all other WMO weather radar-related matters as described in agenda item 2.2. below.

2.1.8. In discussion the following points were made:

- Data format for radar data exchange is a critical issue and its resolution and an international standard would be welcome.
- Bilateral and multilateral agreements were in place in between many countries which created administrative overhead.
- Not many NWP centres were assimilating internationally-exchanged radar data, and of those that were, so assimilated QPE or a derivative, while others required and utilised reflectivities.
- Dualpol systems were becoming more prevalent with recognition growing that DP provides better quality and improved QPE estimates, although Members were purchasing DP systems while not having the ability to use them to their optimal capability.
- Data quality was a significant issues for data exchange and there is a requirement by Members for more guidance on weather radar data quality control and processing.

2.2. Status on the formation of a consolidated WMO weather radar group

2.2.1. Mr Dean Lockett, WMO Secretariat, provided the Meeting with a report on the status of the formation within WMO of a mechanism for the international coordination of matters related to weather radar systems, as had been request by Congress (Cg-XVII, June 2015). The Meeting was informed that, since Congress the following had taken place in relation to this:

- The joint meeting of the CIMO Expert Team on Operational Remote Sensing Technologies (ET-ORST) and the CBS Expert Team on Surface Based Observing Systems (ET-SBO), October 2015, Tokyo, Japan, considered the matter and firmly agreed with the proposal for the establishment of a WMO weather radar coordination group. The meeting made a recommendation to CBS and CIMO to form an inter-programme coordination team to be jointly managed by the two technical commissions (TC) and take responsibility for all WMO weather radar related matters, both current and future. The team was recommended to be formed as soon as possible and consist initially of all those weather radar experts within the two TCs. Terms of Reference for the team were proposed.

- The CBS Management Group (CBS-MG) formally addressed the matter of inter-commission coordination of radar activities at its 16th Session (CBS-MG-16, 15-19 Feb, 2016, Geneva). CBS-MG requested the ICT-IOS Chair to liaise with CIMO to propose draft Terms of Reference for a CIMO IPET on WMO weather radar coordination towards their future adoption by both technical commissions.

- The CIMO Management Group (CBS-MG) then addressed the matter at its 14th Session (CIMO-MG-14, 4-8 April, 2016, Offenbach, Germany). CIMO-MG-14 agreed with the decision and recommendation of CBS-MG to approve the formation of the Inter-Programme Expert Team on Operational Weather Radar (IPET-OWR) and proposed updated Terms of Reference. The decision was then submitted to the WMO Executive Council for approval. The CIMO-MG agreed that the initial membership of the IPET should consist of those weather radar experts already within the CBS and CIMO commissions, particularly through the transfer of memberships from CBS/ET-SBO and CIMO/ET-ORST.

- The WMO Executive Council 68th Session, June 2016, approved the formation of the IPET.

3. Status of Weather Radar International Data Exchange

3.1.1. The Chair presented addressed agenda item 3 of the meeting, describing the work that had previously been done prior to and during the ET-SBO Workshop on Weather Radar Data Exchange to list and map those regions and countries where WRDE was currently being undertaken through bilateral and multilateral arrangements and between WMO Members. It was agreed that this information should be maintained by TT-WRDE and updated with more recent information.

3.1.2. The Meeting participants each presented the current known status of their respective regions and countries in WRDE activities. In summary:

- Region I
  - Mr Michelson informed the Meeting that there appeared to be little WRDE being undertaken in African and that the highest priority for African countries remained the installation and maintenance of weather radar networks rather than data exchange.

- Region II

  - Mr Akihito Umehara, Japan, Mr Sunghwa Jung, Republic of Korea, and Mr Li Bai, China, provided presentations to the Meeting on JMA, KMA, CMA and Region II activities relating to WRDE.

  - Mr Umehara's presentation outlined the efforts of JMA towards the development of reginal radar composite and the exchange of its data for Southeast Asia in collaboration with other members of WMO regions II and V. The meeting was informed that:

    - In Southeast Asia, capacity building for improving quality and processing skill of weather radar data was required before addressing WRDE;

    - JMA, in collaboration with TMD and MMD, was working on experimental radar data exchange (using GRIB2 format) with the aim of achieving regional radar composite in Southeast Asia in future; and

    - The Regional radar composite in Southeast Asia would be expected to be one of the outcomes of successful WRDE in Southeast Asia.

  - Various WRDE was being undertaken or being initiated between several countries within Region II and also with countries in Region V including China, Japan, Republic of Korea, Thailand, Vietnam, Malaysia, The Philippines and Indonesia.

- Region III

  - Mr Jose Mauro Rezende, Brazil, reported that, while there were significant sized radar networks operating within Region III, international WRDE activities were limited and the establishment, networking of and data exchange between nationally operated networks and systems was still underway in many countries, including Brazil.

- Region IV

  - Ms Christina Horvat, USA, informed the Meeting that the USA was exchanging radar data bilaterally with a range of countries including Canada, Algiers, Brazil, and others.

- Region V

  - Mr Mark Curtis, Australia, reported that Australia and New Zealand exchanged radar data.

- Region VI

  - Mr Gunther Haase, Sweden, reported that there were many and varied instances of WRDE within WMO Region VI, with the most extensive and organised activity taking place centrally under the OPERA programme within EUMETNET.

  - Within the OPERA programme, participating countries were submitting their radar data to the ODYSSEY system where data from 24 countries and around 150 radars were being processed and then distributed to data users and applications.

  - WRDE was facilitated via the dedicated communications network (RMDCN) maintained by ECMWF for various data exchange activities within and outside of Europe. Much data is provided to Odyssey over the Internet.

- European experience had shown that the communications solution was a critical aspect of WRDE and that various mechanisms and exchange regimes should be considered for viability and efficiency.

- In addition to OPERA programme, most countries creating composites for nowcasting or datastream for assimilation have agreed on bilateral exchange with their neighbours.

3.1.3. **Action 1**: Mr Michelson agreed with the assistance of Team members, to update the tables and maps that were provided within Document 3 and Information Document 5 with a view to publication of the information by the Secretariat within an appropriate technical report format.

4. Review of TT-WRDE Terms of Reference and Work Plan

4.1. Terms of Reference

4.1.1. The Meeting reviewed the current Terms of Reference for TT-WRDE and agreed that they should be revised ahead of provision to the new IPET-OWR for consideration in the context of the reformation of the Team as a sub-group under the IPET. The existing and new proposed Terms of Reference are provided with Annex II.

4.2. Review and Update of the Task Team Work Plan

4.2.1. The Meeting reviewed the work plan of the Team, noting that while the timeline for the activities required considerable adjustment, the activities and tasks should essentially remain the same.

Deliverable Items D1-D4

D1 - Workshop on Regional & Global Exchange of Weather Radar Data

4.2.2. The Workshop on Regional & Global Exchange of Weather Radar Data was completed under the work plan of ET-SBO.

D2 – Development of the Information Model for WRDE

4.2.3. The Chair informed the Meeting that work on the development of the Information Model had commenced and been advanced by several members of the Team working by correspondence. The initial draft completed prior to the meeting, *WMO Weather-Radar Information Model Version 0.3* and provided as Information Document 7, was based on the information models in developed by the EUMETNET OPERA programme and further developed to take into consideration and include requirements and aspects of the netCDF CF (Climate and Forecasting) specification for weather radar developed under the Hierarchical Data Format (HDF) Group.

4.2.4. The Meeting agreed that the chief outcome of the session was for the Team to review and revise the Version 0.3 draft WWRIM and produce the next version, which should then be considered for submission to the upcoming CBS session (CBS-XVI, November 2016) – see Item 4.3 below.

D3 – Development, specification and approval of standard data exchange formats

4.2.5. The Meeting agreed that the development of standard formats for WRDE would be based on and be undertaken subsequent to the completion of tasks within D2, including both the information and data models. However, the Meeting undertook discussion on various aspects of data exchange formats coming to the following conclusions:

- The Team had a mandate within its ToR to assess the utility and applicability of WRDE formats in addition to BUFR, taking into account that EUMETNET/OPERA has embraced HDF5, and the academic community in the USA has embraced netCDF, as modern solutions that partially meet requirements for GIS compatibility.

- Currently the CF Conventions community was finalising the release of CF Version 2, which contains useful enhancements for representing weather radar data. This means the team has an opportunity to consider the consolidation of ODIM_H5 and netCDF CF format for weather radar data that might be considered for adoption as an international standard. The Meeting discussed how such a format might be developed initially, governed and maintained in the future and what role WMO might play in this activity. It was agreed that, ideally, WMO should play a significant role, particularly in the event that the format was adopted as a WMO standard. It was known that some WMO programmes made use of HDF and netCDF CF for exchange of climate and other meteorological information and that this activity should be researched to determine if it might guide the Team in this matter.

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4.2.6. **Action 2**: The Secretariat to consult within WMO to determine the extent and means for collaboration on NetCDF CF among WMO programmes, work teams and other associated groups.

4.2.7. In relation to BUFR formats for WRDE, the Meeting agreed that while it is indeed possible to encode weather radar data in BUFR, an accumulated wealth of international experience has shown convincingly that doing so is unjustified both technically and in terms of required resources, especially in relation to any foreseen user base. TT-WRDE therefore recommended that ToR (g) not be pursued, and that this recommendation for modification of the ToR be forwarded to IPET-OWR for consideration.

Meeting items E1 and M1

4.2.8. The Chair informed the Meeting that the work plan items E1 and M1 were respectively, the activity to develop the initial draft of the Information Model and the meeting of TT-WRDE currently underway.

4.3. Work Plan Task - Work Session

4.3.1. The Meeting worked in Plenary to review and revise Information Document 7, WMO Weather-Radar Information Model (WRIM) Version 0.3 and identified many corrections and new requirements to be added. It was agreed that the work to produce version 0.4 of the Information Model should be completed shortly following the meeting and included in the final report of the meeting, with the Chair to determine whether that version was suitable to be submitted to CBS-XVI.

4.3.2. **Action 3**: Mark Curtis and Mike Dixon to produce draft Version 0.4 of the Information Model and submit to the Team for review.

4.3.3. **Action 4**: Chair-TT-WRDE to finalise draft Version 0.4 and, if agreed by the Team, submit to the Secretariat for submission to CBS-XVI.

4.3.4. WRIMM Version 0.4 as finalised under item 4.3.1 and Actions 3 and 4 is provided within Annex IV.

5. Task Team Status, Work Process, Future Meetings & Reporting

5.1.1. The Meeting agreed that the Team would likely meet again in 2017 subsequent to the transfer of the role of the Team to the CIMO IPET-OWR and would meanwhile endeavour to meet regularly by teleconference to further the tasks of the work plan.

6. Any Other Business

6.1.1. No other business was addressed.

7. Close of the Meeting

The Chair thanked all participants for their input to the session and the meeting was closed around 3pm of the 28 July, 2016.

ANNEX I

List of Participants

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ANNEX II

Terms of Reference of Task Team on Weather Radar Data Exchange

(Version July, 2014)

a) Gather requirements for information (data, metadata, products, timeliness and frequency) from weather radars to be exchanged globally on a regular basis along with requirements on recommended transmission methods.

b) Develop and document a data model based on the requirements.

c) Identify and recommend appropriate data formats for operational and scientific exchange.

d) Express the data model using approved data formats, taking into account the considerable progress achieved by EUMETNET OPERA in harmonizing operationally exchanged real-time weather radar data with the OPERA Data Information Model (ODIM).

e) Coordinate with IPET-MDRD and IPET-DRMM to ensure that the data model and data representations are consistent and compatible with WMO standards and practices.

f) Make recommendations on requirements for documentation and training materials to support WMO Members in the application and use of the data model and data representations to be used for the global exchange of weather radar information to support data users.

g) Using ODIM_BUFR as a basis, develop, review and coordinate approval of required BUFR sequences for global exchange of radar data.

h) Elaborate compliance between ODIM_H5 and netCDF CF Conventions, especially regarding GIS compatibility.

Proposed New Terms of Reference of IPET-OWR Sub-Group on Weather Radar Data Exchange

(Proposed by CBS/TT-WRDE, July 2016)

a) Gather requirements for information (data, metadata, products, timeliness and frequency) from weather radars to be exchanged globally on a regular basis along with requirements on recommended transmission methods.

b) Develop and document a data model based on the requirements.

c) Identify and recommend appropriate data formats for operational and scientific exchange.

d) Express the data model using approved data formats, taking into account the considerable progress achieved by EUMETNET OPERA in harmonizing operationally exchanged real-time weather radar data with the OPERA Data Information Model (ODIM).

e) Coordinate with IPET-MDRD and IPET-DRMM to ensure that the data model and data representations are consistent and compatible with WMO standards and practices.

f) Make recommendations on requirements for documentation and training materials to support WMO Members in the application and use of the data model and data representations to be used for the global exchange of weather radar information to support data users.

g) Elaborate compliance between ODIM_H5 and netCDF CF Conventions, especially regarding GIS compatibility.

ANNEX III

Work Plan for the TT-WRDE for the period 2014 – 2016 (Version 1)

Main Deliverables

D1. Requirements on weather radar data to be exchanged globally [ToR 1]
D2. Information model for weather radar data [ToRs 2,5]
D3. Recommended file formats for operational and scientific exchange [ToRs 3,4,7,8]
D4. Recommendations on requirements for documentation and training materials to support WMO members [ToR 6]

There is not a one-to-one mapping of terms of reference to deliverables. This is because some of the terms of reference are formulated in a way that can be accommodated together, as referred to above.
The main deliverables can be realized by breaking them down into the following tasks, which also include team and group meetings.

No.	Task	Deliverable/Activity	Due	Responsible	Status	Comment
D1	**Gathering of requirements** Workshop on Regional & Global Exchange of Weather Radar Data [ToR 1]	Workshop report	April 2013	Chair ET-SBO and Secretariat	Done	Lots of valuable information in the workshop report, which can be updated periodically.
D2.1	**Information model strategy** New vs. existing model [ToR 2]	Strategic decision A focus on existing model(s), e.g. ODIM, will be simpler, yet this acknowledges that a single standard is likely to be unachievable. In contrast, a dedicated effort to create a new data model, possibly based on existing ones, would attempt to achieve the objective of a single standard.	Q4 2014	Chair TT-WRDE in consultation with TT members, Chair ET-SBO and Secretariat		Some discussion will be required, remotely (email, maybe on-line meeting)

No.	Task	Deliverable/Activity	Due	Responsible	Status	Comment
D2.2	**Create information model** Logistics: see Task E1 [ToR 5]	Document an information model that can act as a single global standard for weather radar data.	Q2 2015	Chair TT-WRDE with a small expert group comprising TT members, invited experts and support from Secretariat		Contingent on D2.1
D2.2.1	**Mapping exercise** WxR <—> WIGOS Metadata Profile [ToR 5]	Document required WxR metadata and the degree to which they may be accommodated in the WIGOS Metadata Profile, along with recommendations based on identified limitations with the latter.	Q1 2015	Chair TT-WRDE with TT members		Some guidance already available from TT-WMD workshop output.
D3.1	**Select file format(s)** [ToR 4]	Strategic decision Based on D2, target file format(s) with which the information model is to be represented.	Q2 2015	Chair TT-WRDE with TT members.		Some guidance already available from D1 output. Contingent on D2.
D3.2	**Express information model using file format(s)** [ToR 4]	Documentation Based on the outputs from D2 and D3, represent the information model using selected data format(s)	Q4 2015			Contingent on D2.2 and D3.1
D3.2.1	**WMO-compliant BUFR for weather radar** [ToR 7]	Documentation Reviewed, coordinated and approved BUFR sequences for global exchange of radar data		IPET-DRMM, based on information gathered in TT-WRDE		Dependent on D3.1

No.	Task	Deliverable/Activity	Due	Responsible	Status	Comment
D3.2.2	**Compliance between ODIM_H5 and CF Conventions** [ToR 8]	Documentation Elaborated interoperability, especially regarding GIS compatibility	Q4 2015	Chair TT-WRDE with TT members		Dependent on D3.1
D4	**Documentation and training materials** [ToR 6]	Documentation, presentation slides, data, possibly also software	Periodically starting Q3 2015	Chair TT-WRDE with TT members		Based on D1-D3
E1	**Expert meeting**	Documented single-standard information model, in mature draft form. One full week of work together in a small, efficient group.	Q1 2015	Chair TT-WRDE and Secretariat		
M1	**Group meeting**	TT coordination and updated work plan	Q3 2015	TT-WRDE and Secretariat		

Work Plan for the TT-WRDE (draft Version 2, TT-WRDE-1, July 2016)

Main Deliverables

D1. Requirements on weather radar data to be exchanged globally [ToR (a)]
D2. Information model for weather radar data [ToRs (b),(e)]
D3. Recommended file formats for operational and scientific exchange [ToRs (c),(d),(g),(h)]
D4. Recommendations on requirements for documentation and training materials to support WMO members [ToR (f)]

There is not a one-to-one mapping of terms of reference to deliverables. This is because some of the terms of reference are formulated in a way that can be accommodated together, as referred to above.
The main deliverables can be realized by breaking them down into the following tasks, which also include team and group meetings.

No.	Task	Deliverable/Activity	Due	Responsible	Status	Comment
D1	**Gathering of requirements** Workshop on Regional & Global Exchange of Weather Radar Data [ToR (a)]	Workshop report	April 2013	Chair ET-SBO and Secretariat	Done	Lots of valuable information in the workshop report, which can be updated periodically.
D2.1	**Information model strategy** New vs. existing model [ToR (b)]	Strategic decision A focus on existing model(s), e.g. ODIM, will be simpler, yet this acknowledges that a single standard is likely to be unachievable. In contrast, a dedicated effort to create a new data model, possibly based on existing ones, would attempt to achieve the objective of a single standard.	Q4 2014	Chair TT-WRDE in consultation with TT members, Chair ET-SBO and Secretariat	Done	Some discussion will be required, remotely (email, maybe on-line meeting) Decision made to develop a new IM based on existing models (chiefly ODIM_H5 and CfRadial).

No.	Task	Deliverable/Activity	Due	Responsible	Status	Comment
D2.2	**Create information model** Logistics: see Task E1 [ToR (b),(e)]	Document an information model that can act as a single global standard for weather radar data. G.Haase & C. Horvat to be added as co-authors. Version 0.4 to be produced by 15 Aug. 2016 for submission to CBS for information.	Q4 2016 15 Aug 2016	Chair TT-WRDE with a small expert group comprising TT members, invited experts and support from Secretariat	Underway	Contingent on D2.1 Version 0.3 reviewed and commented at TT-WRDE-1
D2.2.1	**Mapping exercise** WxR <--> WIGOS Metadata Profile [ToR (e)]	Document required WxR metadata and the degree to which they may be accommodated in the WIGOS Metadata Profile, along with recommendations based on identified limitations with the latter.	Q1 2015	Chair TT-WRDE with TT members		Some guidance already available from TT-WMD workshop output. Task to be deferred until considered by IPET-OWR
D3.1	**Select file format(s)** [ToR (c),(d)]	Strategic decision Based on D2, target file format(s) with which the information model is to be represented. Require a document to be produced that describes the analysis and justification for the decision and also describes how the format would be defined, maintained and governed (operations and science).	Q4 2016 Q1 2017 Q1 2017	Chair TT-WRDE with TT members.	Underway	Some guidance already available from D1 output. Contingent on D2. Tentatively decision appears to be pointing to NetCDF CfRadial/CF 2.0 solution. The solution for polar representation would evolve

No.	Task	Deliverable/Activity	Due	Responsible	Status	Comment
		Perform necessary tests required to support the decision.				CfRadial 1.4 with features from ODIM_H5. (Most of work for this task is here). The solution for Cartesian would be based on existing CF 1.6/ future CF 2.0.
D3.2	**Express information model using file format(s)** [ToR (d)]	Documentation Based on the outputs from D2 and D3, represent the information model using selected data format(s)	Q2 2017			Contingent on D2.2 and D3.1
D3.2.1	**WMO-compliant BUFR for weather radar** [ToR (g)]	Documentation Reviewed, coordinated and approved BUFR sequences for global exchange of radar data		IPET-DRMM, based on information gathered in TT-WRDE		Dependent on D3.1 Based on D3.1, this may no longer be relevant, subject to referral to IPET-OWR.
D3.2.2	**Compliance between ODIM_H5 and CF Conventions** [ToR (h)]	Documentation Elaborated interoperability, especially regarding GIS compatibility	Q2 2017	Chair TT-WRDE with TT members		Dependent on D3.1 This will be assured by D3.1 and D3.2 and the existing GIS compatibility of CF.

No.	Task	Deliverable/Activity	Due	Responsible	Status	Comment
D4	**Documentation and training materials** [ToR (f)]	Documentation, presentation slides, data, possibly also software	Periodically starting Q3 2017	Chair TT-WRDE with TT members		Based on D1-D3
E1	**Expert meeting**	Documented single-standard information model, in mature draft form. One full week of work together in a small, efficient group.	Q1 2015	Chair TT-WRDE and Secretariat	Done.	Completed through TT-WRDE-1 (Jul 2016)
M1	**Group meeting**	TT coordination and updated work plan	Q3 2015	TT-WRDE and Secretariat	Done.	Completed through TT-WRDE-1 (Jul 2016)

ANNEX IV

WMO Information Model for Radial Radar and Lidar Data

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9 August 2016

Abstract

This document describes an information model for the representation of weather radar and scanning lidar data, metadata, and products. While effort has been made to be general, the weather radar technology in question is assumed to be that commonly used in real-time operations throughout the world: scanning X, C, and S-band systems. Emphasis is placed on comprehensive information representation in the instrument's native polar coordinate system. The representation of data quality is also of central importance. Cartesian surfaces, and other geometries to which radar/lidar information may be derived are not addressed here.

This information model is independent of any data model or file format by which an implementation of the information model may be achieved. Instead, the objective is for this information model to act as common ground for such practical implementation, thereby ensuring that data files are as complete as possible, while also facilitating interoperability among file formats by ensuring that the same information is represented irrespective of file format.

Release Notes

Version 0.4, 9th August 2016

Major revision incorporating changes from TT-WRDE-1

Version 0.3, 29th June 2016

Draft ready to circulate to TT-WRDE

Version 0.2, 20th June 2016

First draft after iteration

Version 0.1, 17th May 2016

First draft, polar data only

Introduction

TODO

- Information model for the exchange of weather radar and lidar data – known collectively as Pulsed Polar Systems (PPS).
- Various levels of PPS data: time series, polar referenced, Cartesian products. This information model addresses only the representation of polar referenced PPS data.
- Ambiguity of term "scan". In common vernacular can be used to mean alternatively an entire volume of radar sweeps, or a single sweep at a single elevation angle. For this reason use of the term scan is avoided by this document in favour of the unambiguous terms "volume" and "sweep".

Stages or levels of data processing

Definition of various stages of processing, starting from I/Q data through to polar product representation. TBD.

Object Model

This section introduces the core object types which are described by the information model. The primary data content of each object type is described, along with its relationship to other object types. Individual instances of each of the object types may be further described through the use of object metadata. Standard metadata for each of the object types is listed in Section 0, however a user of the information model is free to associate additional user-defined metadata with any object.

Overview

The object model is implemented as a simple hierarchy of types. The type at each level of the hierarchy is strictly a collection of the type(s) at the next lower level. An example of this arrangement is illustrated in *Figure 1*.

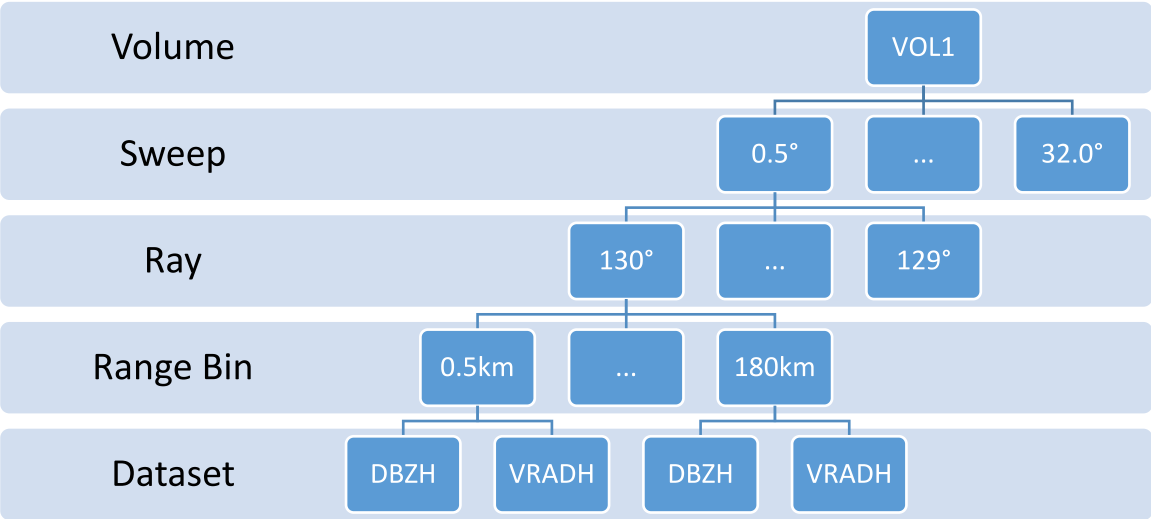

Figure 1. Object Model Hierarchy. Horizontal sweep-based example shown.

This nested arrangement of object types provides a conceptually simple, yet highly flexible scheme for the organisation of PPS data. The model is able to serve the needs of both common operational and highly specialised research scanning strategies. *Figure 2*, *Figure 3* and *Figure 4* show how the model may be used to represent standard operational PPI[2], RHI [3] and vertically pointing scan strategies respectively.

[2] Plan Position Indicator. It represents a complete 0-360° sweep of data. In this document, the PPI is always preserved in polar coordinates.

[3] Range-Height Indicator.

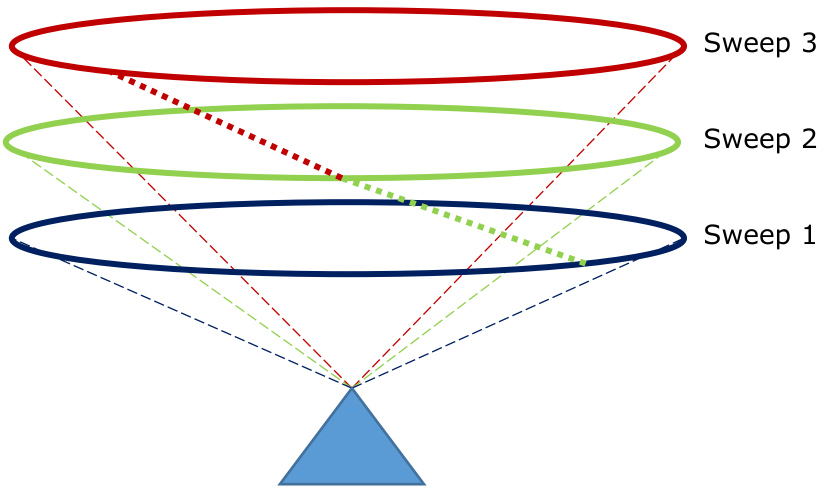

Figure 2. Horizontal sweep-based volume. One sweep per elevation angle. Heavy dotted lines represent rays recorded while antenna is in transition to target elevation angle for each sweep. Such transition rays are not normally exchanged, but are useful to represent in a scientific context.

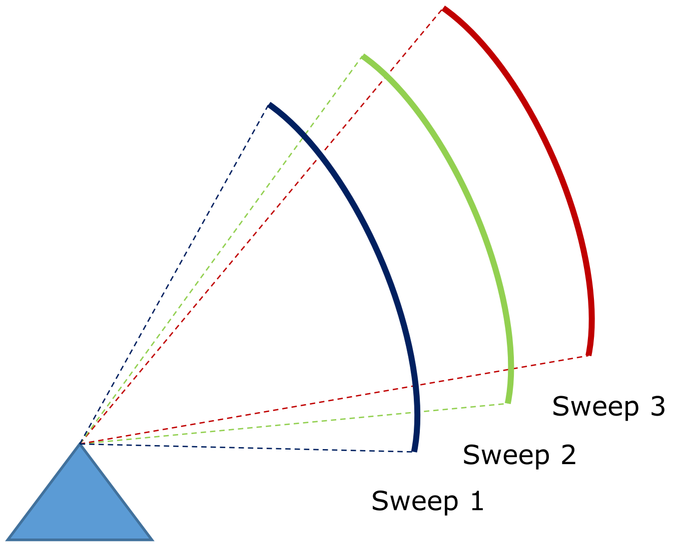

Figure 3. RHI based volume. One sweep per azimuth angle.

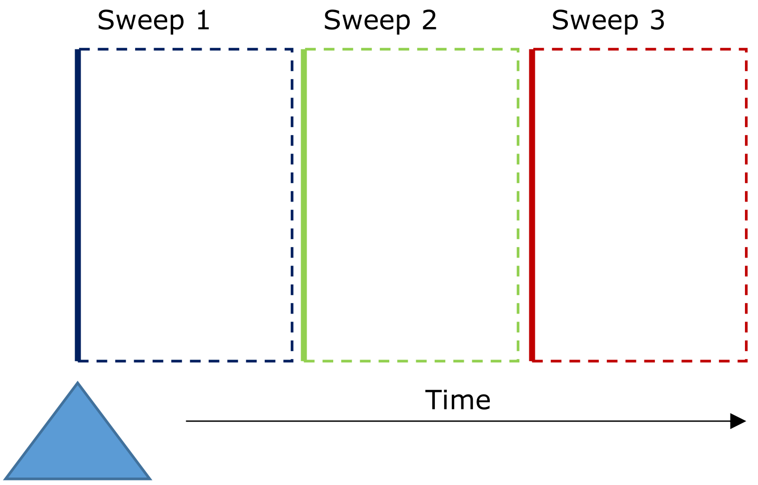

Figure 4. Vertical Pointing based volume. Volume divided into sweeps by time windows.

Object storage model

The object model introduced by *Figure 1* provides a clear hierarchy of PPS data which outlines the conceptual relationships of the data types involved. When PPS data must be practically stored and exchanged, generally accepted practice is to group ray and range bin data together on a per-dataset basis so that the ray and range bin objects are implied rather than explicitly represented. This allows for efficient storage of each dataset as a simple two-dimensional array. As such, implementations of this information model are expected to store PPS data according to the refined model illustrated in *Figure 5*.

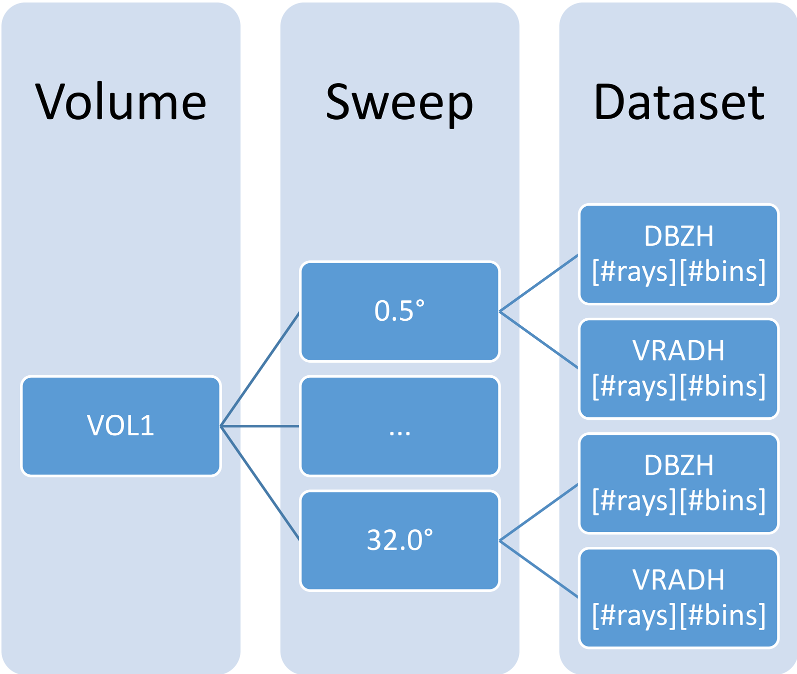

Figure 5. Object model hierarchy as refined for efficient storage. Horizontal sweep-based example shown.

The structure of the refined object model imposes some homogeneity restrictions on the ray, range bin and dataset objects:

- Metadata for the implied ray and range bin objects must be stored at the sweep level.
- The number of range bins must be uniform for each ray in a sweep.
- Metadata applied to a range bin must apply to the same range bin (by index) of every ray in the sweep.
- Metadata applied to a dataset must apply to all rays and range bins in the sweep.
- Each dataset must supply a value for every ray/range bin in the sweep. Should a dataset not be available for a particular ray/range bin, then a special value indicating missing data must be stored.

Volume Object

A volume is the top level object represented by the information model. A volume represents a collection of logically associated PPS data. Typically, although not necessarily, these data will represent a continuous or near-continuous series of observations acquired from the instrument. Often, volumes of a similar structure will be produced at fixed intervals to fulfil operational needs.

Sweep Object

The PPS data which comprises a volume are divided into a number of logical groups called sweeps. A single sweep represents a subset of data in the volume over which certain fundamental conditions such as frequency, pulse width and commanded fixed angle remain constant. For a full list of conditions which must remain constant for the duration of a sweep refer to Section 0.

Typical examples of sweeps include the PPI and RHI where either the elevation or azimuth angle is fixed while the other varies. Vertically pointing instruments, or scan strategies where both the elevation and azimuth angle change continuously could be represented by breaking the volume into sweeps based on time – i.e. containing all of the rays in a given time interval. In such a case a volume may only contain a single sweep.

Independently of the volume, a horizontal sweep scanning less than 360° represents a sector.

Ray Object

The ray represents a collection of data which are considered to be at a single elevation and azimuth angle from the instrument. The propagation of the radiated pulses and reflections through time allows the time of observation to be related to a distance from the instrument along the propagation path. This allows a ray to be considered as a collection of data over distance (rather than over time).

Range Bin Object

The subset of data within a ray which are considered to be representative of the same short observation time window are known as a range bin, or bin. The fact that the data are representative for a time window means that they are also representative for a continuous span of distance, known as slant range, along the ray.

Range bins within a ray may be of varying lengths; however the pattern of bin lengths must always be consistent within a sweep. This implies that the structure (length and number of range bins, as well as contained datasets) of each ray in a single sweep must be identical. This restriction is imposed to allow for efficient representation of sweep objects within implementing data models and file formats as simple two-dimensional arrays.

Dataset Object

A single range bin may contain any number of datasets which represent various quantities associated with that bin. The quantities may be values observed by the instrument, values inferred by signal processing, or even quality control or analytical metrics added by downstream systems. Section 0 enumerates commonly used dataset quantities; however, a user of the information model is free to define any number of custom dataset quantities.

The number and type of datasets available for a bin must always be consistent within a sweep. This restriction is imposed to allow for efficient representation of sweep objects within implementing data models and file formats as simple two dimensional arrays.

Two subclasses of dataset object are supported by the information model. Each dataset will either be a scalar, or spectrum dataset.

Scalar dataset

A scalar dataset is one for which a single numerical value is stored per range bin. This is the most common type of dataset and is used to represent both standard observed moments (e.g. reflectivity, Doppler velocity, spectral width) and quality control metrics (e.g. percent beam blockage by topography).

Spectrum dataset

A spectrum dataset is one for which a vector of numerical values, representing a spectrum, is stored per range bin. This type of dataset is infrequently used within operational networks; however, they are more common within research and scientific contexts, and specifically with some vertically-pointing radars.

Standard Metadata

This section describes the metadata which may be associated with each of the objects detailed in section 0.

Overview

Mandatory metadata

The level of metadata available from a PPS varies greatly by system and operator. This information model therefore imposes very few requirements on which metadata must be made available. Only metadata which is absolutely necessary for accurate time referencing and geographic referencing of the data is considered mandatory. For the sake of completeness, however, providing as much additional metadata as possible is highly recommended as they are inevitably useful in supporting science.

Mandatory metadata is indicated in the tables of this section using shaded background.

Fundamental types

All metadata applied to an object must be either a whole number, a real (floating-point) number, a Boolean, or a character string. In this document, these are referred to as "integer", "real", "Boolean", and "string" respectively. An "enum" is a special constant integer value used for identification purposes. The depth (number of bits or bytes) of the numerical types is not specified, nor is the character encoding of strings. Such determinations are the responsibility of the implementing data model and file format representation. Rather, the information model specifies the minimum precision with which certain metadata must be stored. Implementers are free to store metadata at a precision which exceeds the stated minimum.

It is also possible for metadata to consist of an array of any of the fundamental types. In such situations the type for the metadata will list the fundamental type name followed by '[n]'.

Unit conventions

Geographic coordinates

Longitude and latitude coordinates shall be expressed in decimal-degree format with positive longitudes towards the east and positive latitudes towards north.

Polar coordinate system angles

Azimuthal angles shall be expressed as clockwise from true north (0°). Elevation angles shall be expressed as positive above the horizontal plane (0°).

Times

Several different methods of defining and representing a point in time are relevant for use with PPS data. Time-based metadata shall be specified according to the following two classifications:

- **Absolute** or **relative** time. An absolute time is a time point defined according to an external time standard (such as UTC). A relative time is defined as an offset from a known absolute time.
- **Low-precision** or **high-precision** time. A low-precision time must be represented with precision of at least seconds. A high-precision time must be represented with a precision of at least nanoseconds.

For example, the time associated with a volume start may be specified as a low-precision absolute time. A conforming implementation could store this time as an ISO 8601 string representing the UTC time of the product (e.g.: "2016-07-26T09:00:00Z").

Conversely, the data acquisition time associated with a ray may be specified as a high-precision time relative to the volume start time. A conforming implementation could store this time as a real representing the number of nanoseconds offset from the volume start time.

User-defined metadata

Users of the information model are free to apply custom metadata to any information model object provided that the metadata does not already have a standard representation listed in this document.

Application restrictions

The following conditions are imposed on the application of metadata to information model objects:

- Standard metadata listed in this section must be associated only with the object type under which they are listed. It is not permissible, for example, to apply metadata for a sweep to individual range bins. This implies that metadata for an object is constant throughout that object and applicable to all contained objects. Should it be necessary to break this condition, the PPS data should be split into several sweeps and/or volumes.
- Metadata applied to a range bin applies to the same ordinal range bin in every ray of the containing sweep.
- Metadata applied to a dataset applies to every range bin in every ray of the containing sweep.

These restrictions are imposed to allow for efficient representation of sweep objects within implementing data models and file formats as simple two-dimensional arrays.

Volume Object Metadata

Product information

Table 1. Product information.

ID	Description	Type	Unit	Precision
	Instrument type, distinguishing between “radar” and “lidar”	string	-	-
	Site identifier, e.g. WIGOS identifier (see below)	string	-	-
	Volume start time	time	absolute	low
	Volume end time	time	absolute	low
	Scan strategy name	string	-	-
	Instrument identifier (e.g. WSR-88D)	string	-	-
	Whether instrument has malfunctioned	Boolean	-	-
	Instrument error message	string	-	-
	Whether acquired data are simulated	Boolean	-	-

The WIGOS identifier[4] structure consists of four parts. The part of the structure called “Local identifier” is the only part consisting of characters. Following the ODIM convention (Michelson et al., 2014), it is suggested as a best practice, but not required, 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).

[4] http://wis.wmo.int/page=WIGOS-Identifiers

[5] http://www.iso.org/iso/country_codes

Geographical reference information

For moving platforms, the metadata in this section relate to the position of the instrument at the start of data acquisition, which applies to the first ray of the volume.

Table 2. Geographical reference information.

ID	Description	Type	Unit	Precision
	Site longitude	real	degrees	0.000001°
	Site latitude	real	degrees	0.000001°
	Site altitude above geodetic datum. For a scanning instrument this is the center of rotation of the antenna.	real	m	1m
	Site altitude above ground level	real	m	0.1m
	Geodetic datum name	string	-	-
	Magnetic declination at site, positive clockwise	real	degrees	0.001°
	Whether platform is moving	Boolean	-	-

Radar characteristics

The metadata in this section only apply to instrument type 'radar'.

Table 3. Radar characteristics.

ID	Description	Type	Unit	Precision
	Nominal antenna gain H	real	dBi	
	Nominal antenna gain V	real	dBi	
	Antenna beam width H	real	degrees	
	Antenna beam width V	real	degrees	
	Bandwidth of radar receiver	real	s-1	
	Frequency	real	Hz	

Lidar characteristics

The metadata in this section only apply to instrument type 'lidar'.

Table 4. Lidar characteristics.

ID	Description	Type	Unit	Precision
	Beam divergence (transmit side)	real	milliradians	
	Field of view (receive side)	real	milliradians	
	Aperture diameter	real	cm	
	Aperture efficiency	real	percent	
	Peak power	real	watts	
	Pulse energy	real	joules	

Sweep Object Metadata

Sweep characteristics

Table 5. Sweep characteristics.

ID	Description	Type	Unit	Precision
	Sweep mode, ie. Plan Position Indicator (PPI), Range-Height Indicator (RHI), Vertical, and Sun scan.	enum	-	-

	Other specialized sweep modes are permitted.			
	Target fixed angle (elevation angle for PPI mode, azimuth angle for RHI mode)	real	degrees	0.01°
	Target scan rate	real	degrees/s	
	Polarization mode, ie. Horizontal, Vertical, Horizontal-vertical alternating, Horizontal-vertical simultaneous, and Circular. Other specialized polarization modes are permitted.	enum	-	-
	PRT mode, ie. Fixed, Staggered, and Dual. Other specialized PRT modes are permitted.	enum	-	-

Radar calibration

The metadata in this section only apply to instrument type 'radar'. A separate set of radar calibration metadata may be supplied for each pulse width used. For single polarization radars, only the horizontally polarized metadata are relevant.

Note H and V indicate horizontal and vertical polarization respectively. Co-polar indicates transmit and receive on the same polarization. Cross-polar indicates transmit and receive on opposite polarization, with the receiving polarization listed. (i.e. H cross-polar = transmit V, receive H)

Table 6. Radar calibration metadata.

ID	Description	Type	Unit	Precision
	Pulse width	real	seconds	
	Derived antenna gain H	real	dBi	
	Derived antenna gain V	real	dBi	
	Nominal transmit power H	real	dBm	
	Nominal transmit power V	real	dBm	
	2-way waveguide loss measurement plane to feed horn H	real	dB	
	2-way waveguide loss measurement plane to feed horn V	real	dB	
	2-way radome loss H	real	dB	
	2-way radome loss V	real	dB	
	Receiver filter bandwidth mismatch loss	real	dB	
	Receiver filter bandwidth mismatch loss H	real	dB	
	Receiver filter bandwidth mismatch loss V	real	dB	
	Radar constant H	real	dB	
	Radar constant V	real	dB	
	Probert Jones correction	real	-	
	Measured noise level H co-polar	real	dBm	
	Measured noise level V co-polar	real	dBm	
	Measured noise level H cross-polar	real	dBm	
	Measured noise level V cross-polar	real	dBm	
	Measured receiver gain H co-polar	real	dB	
	Measured receiver gain V co-polar	real	dB	
	Measured receiver gain H cross-polar	real	dB	

	Measured receiver gain V cross-polar	real	dB	
	Reflectivity at 1km for SNR=0dB H co-polar	real	dBZ	
	Reflectivity at 1km for SNR=0dB V co-polar	real	dBZ	
	Reflectivity at 1km for SNR=0db H cross-polar	real	dBZ	
	Reflectivity at 1km for SNR=0db V cross-polar	real	dBZ	
	Calibrated sun power H co-polar	real	dBm	
	Calibrated sun power V co-polar	real	dBm	
	Calibrated sun power H cross-polar	real	dBm	
	Calibrated sun power V cross-polar	real	dBm	
	Noise source power H	real	dBm	
	Noise source power V	real	dBm	
	Power measurement loss in coax and connectors H	real	dB	
	Power measurement loss in coax and connectors V	real	dB	
	Coupler loss into waveguide H	real	dB	
	Coupler loss into waveguide V	real	dB	
	ZDR correction	real	dB	
	LDR correction H	real	dB	
	LDR correction V	real	dB	
	System PhiDP as seen in drizzle close to the radar	real	degrees	
	Calibration test power H	real	dBm	
	Calibration test power V	real	dBm	
	Computed receiver slope H co-polar	real		
	Computed receiver slope V co-polar	real		
	Computed receiver slope H cross-polar	real		
	Computed receiver slope V cross-polar	real		

Lidar calibration

No calibration metadata for lidar instruments are currently identified.

Table 7. Lidar calibration metadata.

Ray Object Metadata

Ray characteristics

Table 8. Ray characteristics.

ID	Description	Type	Unit	Precision
	Elevation angle	real	degrees	0.01°
	Azimuth angle	real	degrees	0.01°
	Time of acquisition (relative to volume start time)	time	relative	high
	Width of ray (dwell)	real	degrees	0.01°
	Measured scan rate, positive clockwise and/or ascending	real	degrees/s	
	Whether the antenna is in transition to fixed angle during this ray	Boolean	-	-
	Whether geographic reference information for moving platforms has been applied to correct the elevation and azimuth angles	Boolean	-	-
	Pulse width	real	seconds	

	Pulse repetition time(s)	real[n]	seconds	
	Nyquist velocity	real	m/s	
	Unambiguous range	real	m	
	Number of samples used to compute moments	integer	-	-

Moving platform geographic reference information

The shaded metadata of this section are only required for moving platforms.

Table 9. Moving platform geographic reference information.

ID	Description	Type	Unit	Precision
	Latitude of the instrument	real	degrees	0.000001°
	Longitude of the instrument	real	degrees	0.000001°
	Altitude of the instrument above the geodetic datum. For scanning PPS, this is the center of rotation of the antenna.	real	m	1m
	Heading of the platform relative to true north, looking down from above	real	degrees	0.01°
	Roll about longitudinal axis of platform. Positive is left side up, looking forward.	real	degrees	0.01°
	Pitch about the lateral axis of the platform. Positive is up at the front.	real	degrees	0.01°
	Difference between heading and track over the ground (drift). Positive drift implies track is clockwise from heading, looking from above. Not applicable to land-based moving platforms.	real	degrees	0.01°
	Angle between the PPS beam and the vertical axis of the platform (rotation). Zero is along the vertical axis, positive is clockwise looking forward from behind the platform.	real	degrees	0.01°
	Angle between the radar beam (when it is in a plane containing the longitudinal axis of the platform) and a line perpendicular to the longitudinal axis (tilt). Zero is perpendicular to the longitudinal axis, positive is towards the front of the platform.	real	degrees	0.01°
	East/west velocity of the platform. Positive is eastwards.	real	m/s	
	North/south velocity of the platform. Positive is northwards.	real	m/s	
	Vertical velocity of the platform. Positive is upwards.	real	m/s	
	East/west wind at the platform location. Positive is eastwards.	real	m/s	
	North/south wind at the platform location. Positive is northwards.	real	m/s	
	Vertical wind at the platform location. Positive is upwards.	real	m/s	
	Rate of change of heading	real	degrees/s	
	Rate of change of roll of the platform	real	degrees/s	
	Rate of change of pitch of the platform	real	degrees/s	

Radar monitoring

Table 10. Radar monitoring metadata.

ID	Description	Type	Unit	Precision
	Measured transmit power H	real	dBm	
	Measured transmit power V	real	dBm	
	Noise measured at the receiver when connected to the antenna with no noise source connected	real	dBm	
	Noise measured at the receiver when connected to the noise source which is disabled	real	dBm	
	Noise measured at the receiver when it is connected to the noise source which is enabled	real	dBm	

Range Bin Object Metadata

Table 11. Range bin object metadata.

ID	Description	Type	Unit	Precision
	Range to center of bin	real	m	1m
	Length of bin	real	m	1m

Dataset Object Metadata

Basic dataset information

Table 12. Basic dataset information.

ID	Description	Type	Unit	Precision
	Dataset identifier (user specified)	string	-	-
	Quantity name (see section 0)	string	-	-
	Quantity units	string	-	-
	Quantity value used to indicate missing data	real	-	-
	Quantity value used to indicate no signal	real	-	-
	Whether dataset is represented by discrete values	Boolean	-	-
	Discrete values used in dataset	real[n]	-	-
	Labels for discrete values used in dataset	string[n]	-	-
	Whether dataset is a quality dataset	Boolean	-	-
	Identifiers of quality datasets which qualify this dataset	string[n]	-	-

Quality dataset information

In addition to the basic dataset information, the following metadata are defined for datasets which are used to represent a quality metric.

Table 13. Quality dataset information.

ID	Description	Type	Unit	Precision
	Identifiers of datasets which are qualified by this dataset	string[n]	-	-
	Identifier of the algorithm that generated the dataset (see below)	string	-	-
	Arguments or configuration provided to the algorithm that generated the dataset	string[n]	-	-
	Literature reference to the algorithm that generated	string	-	-

	the dataset

It is suggested, although not required, that quality algorithm identifiers take the form of "org.name" where 'org' is a short mnemonic identifying the original source of the algorithm, such as an organization or researcher, and 'name' is a short identifier for the algorithm itself. This arrangement allows a single organization to provide a common prefix for all algorithms it has developed, thereby preventing name clashes with other algorithms used for a similar purpose.

Examples of algorithm identifiers in the suggested format are provided in Table 14 below.

Table 14. Example algorithm identifiers.

Identifier	Organization	Algorithm
bom.spike	Bureau of Meteorology	External emitter detection algorithm
smhi.beamb	Swedish Meteorological and Hydrological Institute	BALTRAD beam blocking analysis algorithm
ncar.pid	National Center for Atmospheric Research	Particle Identification Algorithm
nssl.hca	National Severe Storms Laboratory	Hydrometeor Classification Algorithm

Note that the intention of the algorithm identifier metadata is to allow data exchange of quality output by unambiguously identifying the algorithm used to produce it. This identifier should not be used to identify the particular software the algorithm was implemented within, configuration used, nor the organization executing it unless these factors cause incompatibility with the output of the original implementation.

Spectrum dataset

Table 15. Spectrum dataset metadata.

ID	Description	Type	Unit	Precision
	Value represented by each point in the spectrum	real	Hz	-
	Length of FFT used to compute the spectrum	int	-	-
	Length of averaging block used to compute the spectrum	int		

Standard Datasets

The following table lists standard datasets associated with polar pulsed systems. Users of the information model are free to use custom datasets which are not listed here.

Scalar quantities

Table 16. Scalar quantities.

ID	Description	Unit
	Equivalent reflectivity factor	dBZ
	Linear equivalent reflectivity factor	Z
	Radial velocity of scatterers away from instrument	m/s
	Doppler spectrum width	m/s
	Log differential reflectivity H/V	dB
	Log-linear depolarization ratio HV	dB
	Log-linear depolarization ratio H	dB
	Log-linear depolarization ratio V	dB
	Differential phase HV	degrees
	Specific differential phase HV	degrees/km
	Cross-polar differential phase	degrees
	Cross-correlation ratio HV	
	Co-to-cross polar correlation ratio H	
	Co-to-cross polar correlation ratio V	
	Log power	dBm
	Log power co-polar H	dBm
	Log power cross-polar H	dBm
	Log power co-polar V	dBm
	Log power cross-polar V	dBm
	Linear power	mW
	Linear power co-polar H	mW
	Linear power cross-polar H	mW
	Linear power co-polar V	mW
	Linear power cross-polar V	mW
	Signal-to-noise ratio	dB
	Signal-to-noise ratio co-polar H	dB
	Signal-to-noise ratio cross-polar H	dB
	Signal-to-noise ratio co-polar V	dB
	Signal to noise ratio cross polar V	dB
	Normalized coherent power (also known as signal quality index)	
	Corrected equivalent reflectivity factor	dBZ
	Corrected radial velocity of scatterers away from instrument	m/s
	Corrected log differential reflectivity HV	dB
	Radar estimated rain rate	mm/hr
	Rain rate	kg/m2/s
	Radar echo classification	-

Spectrum quantities

Table 17. Spectrum quantities.

ID	Description	Unit

	Spectrum of co-polar H
	Spectrum of co-polar V
	Spectrum of cross-polar H
	Spectrum of cross-polar V
	Cross spectrum of co-polar H
	Cross spectrum of co-polar V
	Cross spectrum of cross-polar H
	Cross spectrum of cross-polar V

References

Dixon M., Lee, W-C., Rilling B., Burghart C., and Van Andel J., 2013: CfRadial Data File Format. Proposed CF-compliant netCDF Format for Moments Data for RADAR and LIDAR in Radial Coordinates. Version 1.3. EOL, NCAR. 66 pp.

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.