Potential for use of radar data for climate monitoring

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1 Introduction

Many NMHSes have now archives of over 10 years of radar data, and there is growing need to use this data also for climate monitoring. This implies an additional archival and documentation requirement on top of those that had been addressed for the canonical use of radar systems for real-time purposes like warning.

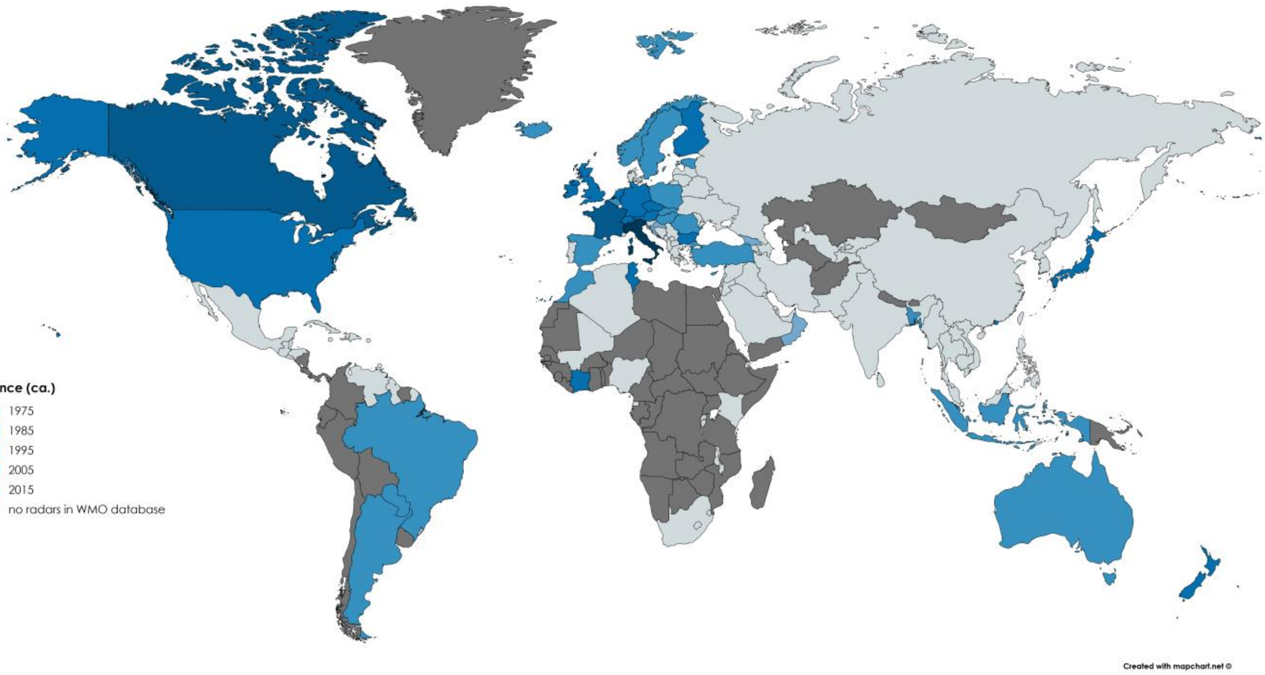

Figure 1:Approximated length of radar data archives in different WMO member countries.
Note that the entire country is coloured even if there are archives by no more than one radar.

Through WMO and GCOS a Task Team has been initiated leading discussions between climate researchers and radar experts, and preparing recommendations for mandatory and suitable data and metadata to be archived for climate monitoring purposes. This serves the baseline information to develop accepted guidelines and standards, with a view on the rather limited lifetimes of radar systems being shorter than those of stations and the characteristic climate time scale of 30yrs. Therefore it is essential to keep not only the metadata describing the latest hardware and processing, but also a history of important hardware changes such as from non-Doppler to Doppler radars to allow for a full retrieval of the essential information also decades after the measurements had been taken and to avoid false interpretations of apparent trends which come from changes in equipment, not changes in climate.

The phenomena to be monitored with weather radars include in addition to precipitation also severe mesoscale phenomena such as hailstorms and tornadoes.

The central parameter is horizontal reflectivity, ZH, which is basis of precipitation estimates. The other key parameters have importance for improving the quality of precipitation estimates and as independent variables for process and climate studies. As for the extreme precipitation, radar systems are the only instruments that can claim to fully resolve and fetch the scale of such meteorological events giving their unique capacity to study their developments during the first decades where climate change impacts the hydrometeorology.

2 Recommendations

2.1 What data to save

The task team recommends that radar data for climate monitoring shall be saved as Level 2 files, ie 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. (Full definition of radar data levels by WMO's Inpert-Programme Expert team of Operational Weather Radars, IPET-OWR, is as Annex 1)

While it is acknowledged, that there are still single polarization radars in use and data saved from non-Doppler radars, the key parameters listed are

- Equivalent reflectivity factor (DBZH)
- Radial velocity of scatterers away from instrument (VRAD)
- Doppler spectrum width (WRAD)
- Log differential reflectivity H/V (ZDR)
- Correlation Coefficient (RHOHV)
- Differential phase (PHIDP)

For ease-of-use, archive managers can be tempted to save Level 3 products such as rainfall rate or hydrometeor classification. As processing algorithms develop over years, maintaining homogeneity in the time series is challenging, and for reprocessing purposes saving also the Level 2 data is strongly recommended. The difference in amounts of stored data is not significant. 3D data are 10-30 times larger than 2D, but it is very easy to compress (e.g. zip). In OPERA, 150 radars produce 1-2 Gb a day for reflectivity, and even if we include all parameters the dataset grows to 10 Gb a day. Problem is not the disk space, but the management of data.

2.2 What about metadata

Data alone is not useful, if it is not accompanied with a sufficient set of metadata. Minimum and goal sets of metadata parameters have been defined e.g. by WMO WIGOS and IPET-OWR (Annex 2). For use of climate studies, there is has one strong recommendation: save history of metadata.

Because a lifetime of a radar is 10-20 years, most climatologically interesting time series would be containing data from different instruments at the same places. Even if the instrument has not been replaced, typically several upgrades have been implemented, so the present metadata is not describing the oldest data. Dates and types of major changes (such as from non-Doppler to Doppler capability, from single to dual polarization) should be indicated carefully. The logs of such changes is typically saved separately from the data; if not earlier then at least in data rescue projects these should be connected. The engineering logs may connect other information also useful for data use, such as calibration records. Combining these with the actual data is an important task to support the climatological studies. We are facing a risk of interpretation of changes in instruments or data processing to trends or seasonal variation of climate. (Have you heard the anecdote of three-year cycle of wind speed, which proved to be the maintenance interval of Wild anemometers? A counterpart in radar world is yet to be found - or not.)

2.3 We have some very old data

Existing archives are a treasure at risk. Data rescue projects and digital archiving are not only interest of radar meteorologist, our entire society is thinking what to do with old data formats and old physical media such as magnetic tapes.

For reprocessing of data, it is advisable to save intermittent products comparable to Level 2 data, including at least minimal metadata with a posteriori analysis. It is likely, that the reprocessing will be a repeated activity, and the goal is that the most cumbersome issues such as reading old data formats can be repeated only once. Bear in mind,that the technology needed for reading very old media (such as magnetic tapes) may not be available in the future decades.

Homogenization and potential reanalysis of archives containing several years and several radars is an effort of several man months, not something one can do in his/her spare time. For example, the operational Australian radar archive consists of approximately 800 years of data across more than 50 sites. Consolidation, quality control and post-processing of multiple archive sources has required several months of full-time work and remains an ongoing effort.

3 Examples of data use

Climatologists have already published local and regional climatological studies based on national radar archives. The analyzed parameters include

- High-resolution maps of annual average precipitation and frequency of precipitation rate (Fairman et al, 2015)
- Exceedance probability of 1h rainfall (Overeem et al., 2009)

- Relative frequency of severe weather as a function of time of day (Brimelow et al., 2014)
- Hovmöller diagram of > 40 dBZ (longitunal average) (Chen et al, 2012)
- Distribution by numbers of significant tornado events for convective mode by season (Grams et al., 2012)
- Number of hail days detected in the period 2003-2012 (Lukach et al, 2017)
- Hourly radar-derived hail frequency (normalized) for the entire domain and six sub-regions in the Alps. (Nisi et al. 2015)
- Distribution of the GEV parameters derived from satellite (HRC and CHRC) and radar datasets. (Marra et al. 2017)
- Rose diagrams of thunderstorm movement distributions for different months (Liu et Li, 2016)
- Climatology of progressive derecho events for the warm season (May–August) of 1996–2013. (Guastini & Bosart, 2016).

This is by no means a comprehensive list, just examples of what all can be studied with radar data time series! A mosaic of corresponding figures from these articles is included in the poster.

4 Conclusions and next steps

The team recommends, that while everyone saves the data you are measuring now, they also think if it can be read and understood in 2050, improve your documentation, and document the link between your data and supporting technical metadata (such as maintenance and upgrade logs).

Those who have existing archives, should think about the data you have saved over the years, especially think if it can be read and understood in 2050, and probably plan a data rescue project. Improving the documentation and document the link between your data and supporting technical metadata (such as maintenance and upgrade logs) should be done as soon as possible – not only the storage media are fading, but also the people who were responsible for changes such as Doppler upgrade projects, are soon getting retired in many countries.

This would also be a great subject for an international project to plan and prototype a portal with uniform access for different archives.

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Annex 1: Proposed Standard Definitions for Weather Radar Data Levels

The table below is proposed by WMO IPET-OWR as the standard wording to describe 'levels' of weather radar data.

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.).

5 Annex 2. Draft for Mandatory Weather Radar Metadata for International Exchange by IPET-OWR

This table lists weather radar related metadata which are considered mandatory for the international exchange of weather radar data. The metadata are listed according to their definition in the WMO Information Model for Radial Radar and Lidar Data. An additional column 'CfRadial' identifies the corresponding dimension, variable or attribute name which implements the metadata within the CfRadial 2.0 file format. Note that this is still work in progress.

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[1]. 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)[2], 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[3] code (lower case), and the latter three characters are freely-selectable (also lower case).

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

[2] 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.

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