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Weather radar data processing: open-source tools

Daniel Wolfensberger, Jordi Figueras i Ventura

Contents

- Introduction
- A typical radar data processing chain
- Radar data file formats
- Open-source software packages

1. Introduction

What is Open-Source Software ?

- A software package is open source if : https://opensource.org
  - Allows **free** (senza pagare) redistribution
  - **Includes the source code** (or it is easily accessible) and allows distribution of both compiled and source code.
  - **Allows modifications** and derived works, allows distributing them under the same terms as the license of the original software
  - No discrimination against persons or groups
  - No discrimination against fields of use (e.g. business, genetic research)
  - No need for any other license (apart from the one of the package) to use it
  - The license is not specific to a product, software within a distribution can be used and distributed independently
  - The license does not restrict the use of other software
  - The license is technology-neutral

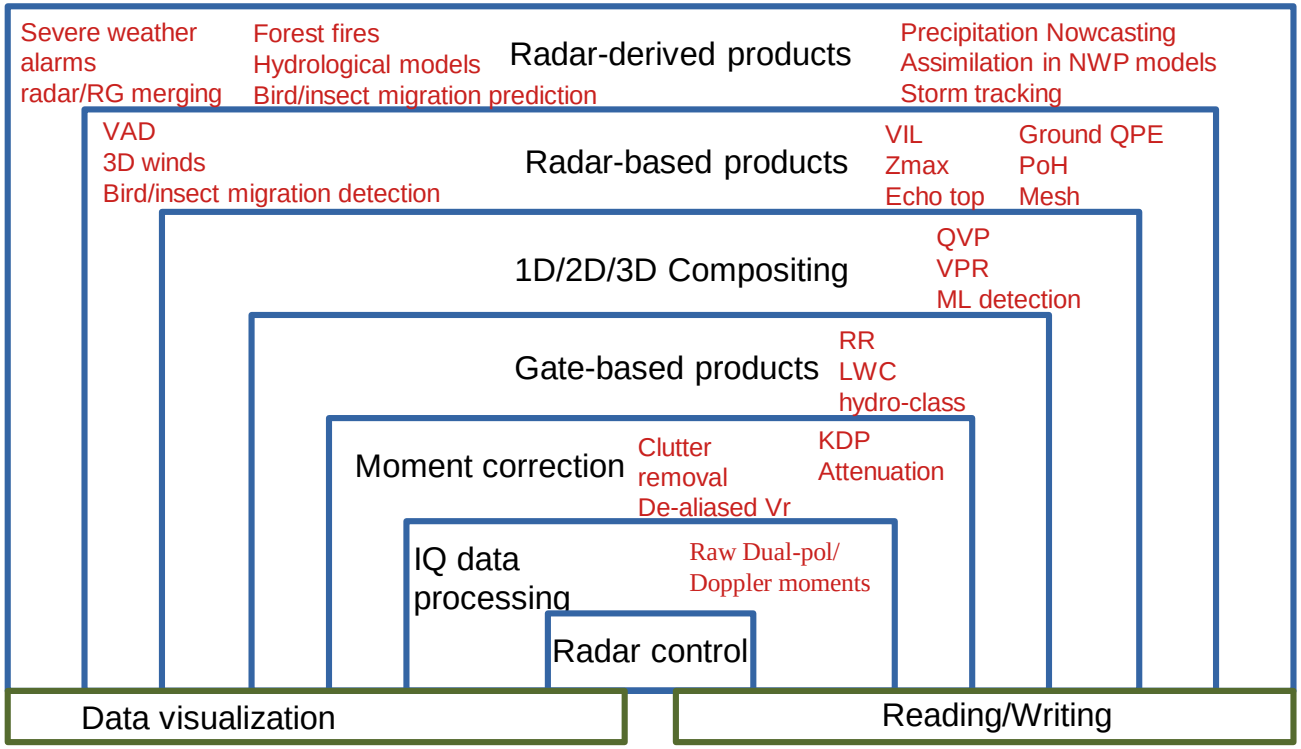
Open source for weather radar ?

- Since the late 2000s (and even before) there has been a number of major open-source projects released (see e.g. https://openradarscience.org).
- Some of them are in a mature stage and are widely used in an **academic** (mostly) but also **operational environment**
- Most make use of modern tools (e.g. github, conda, docker) and practices (e.g. Continuous Integration, automatic tests) that make them easy to evolve and deploy
- Most are backed by major weather services or academic institutions
- Projects **are not competing among them** but collaborating : Best practices and inter-operability are discussed regularly and joint open-source courses have been organized for years at major radar conferences (AMS, ERAD)

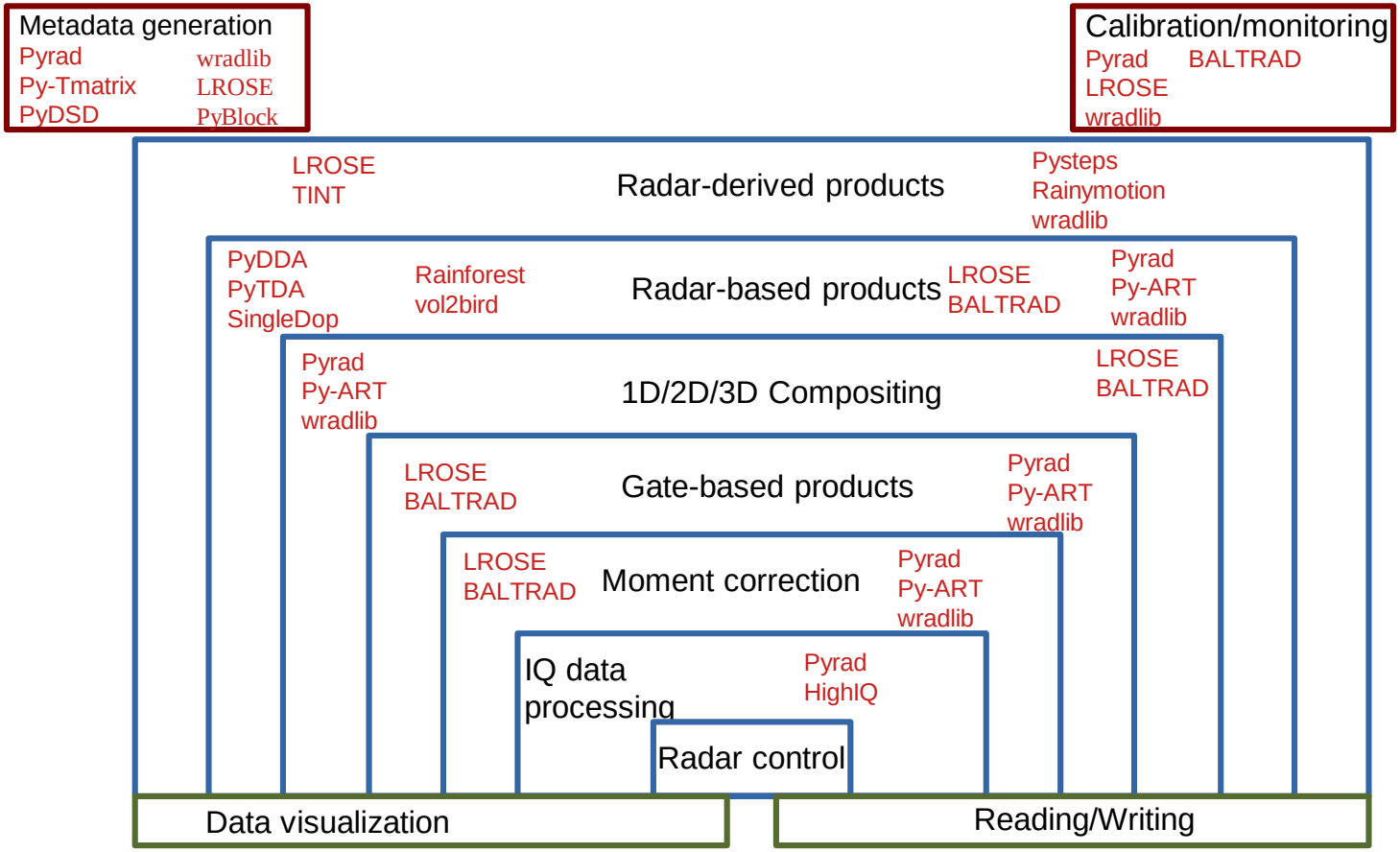
The weather radar business

Metadata generation
Beam blockage
Scattering simulations
PSDs

Calibration/monitoring
Solar monitoring
Sphere calibration
Inter-comparison

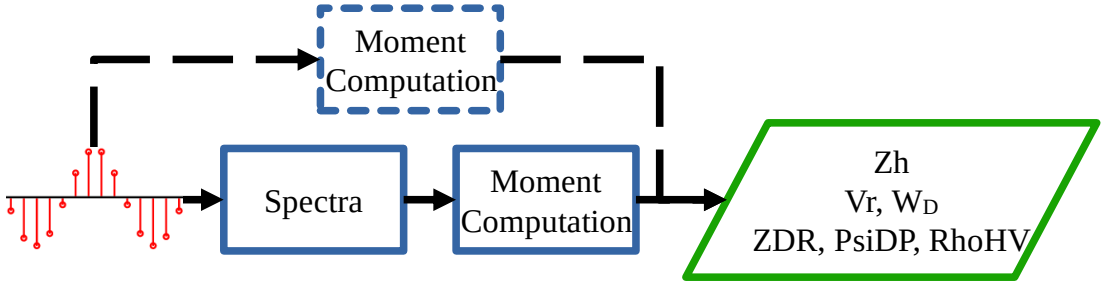


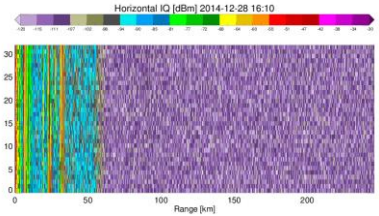
The weather radar business

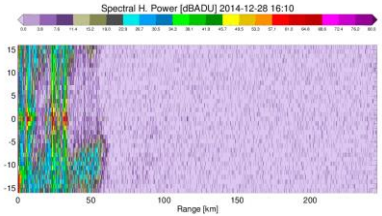


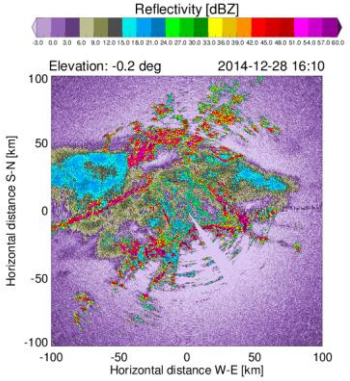
2. A typical radar data processing chain

IQ data processing

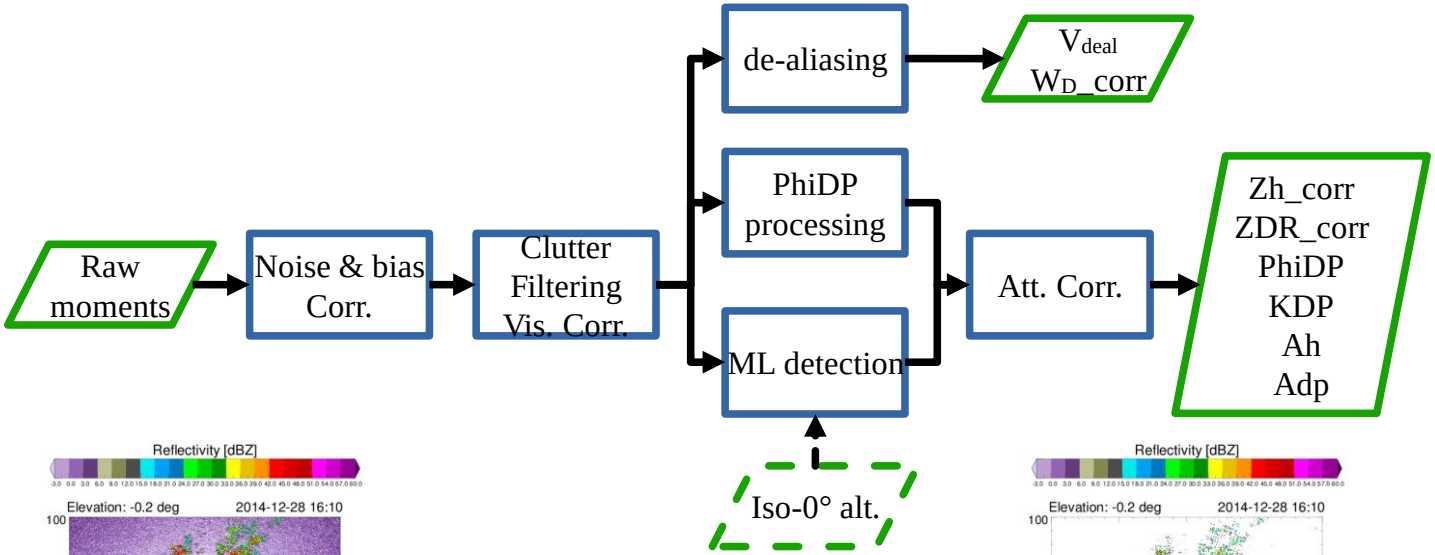


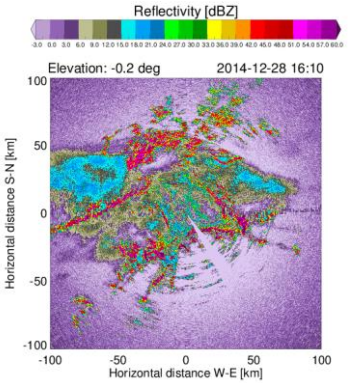


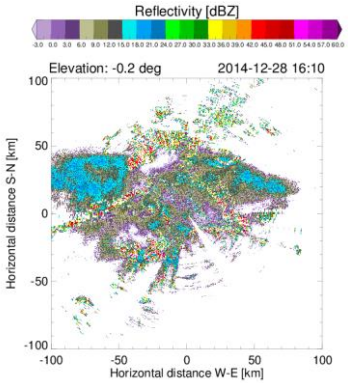




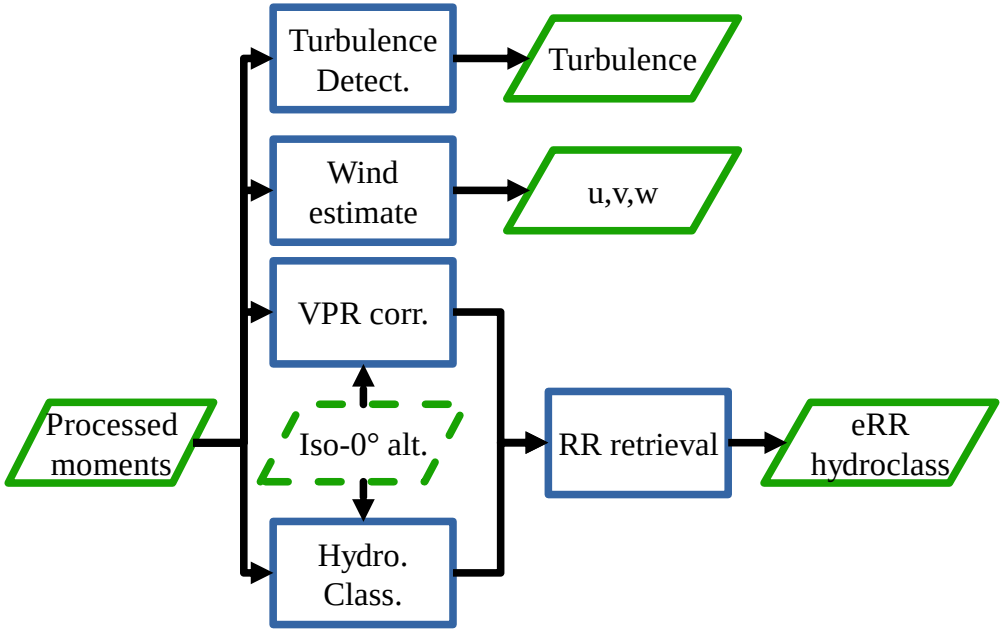
Moment correction

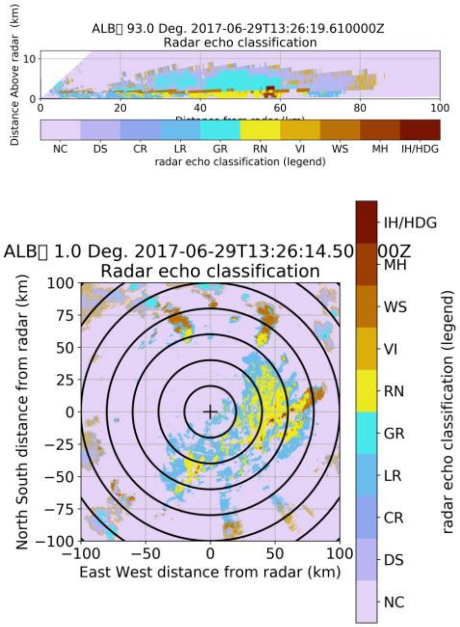




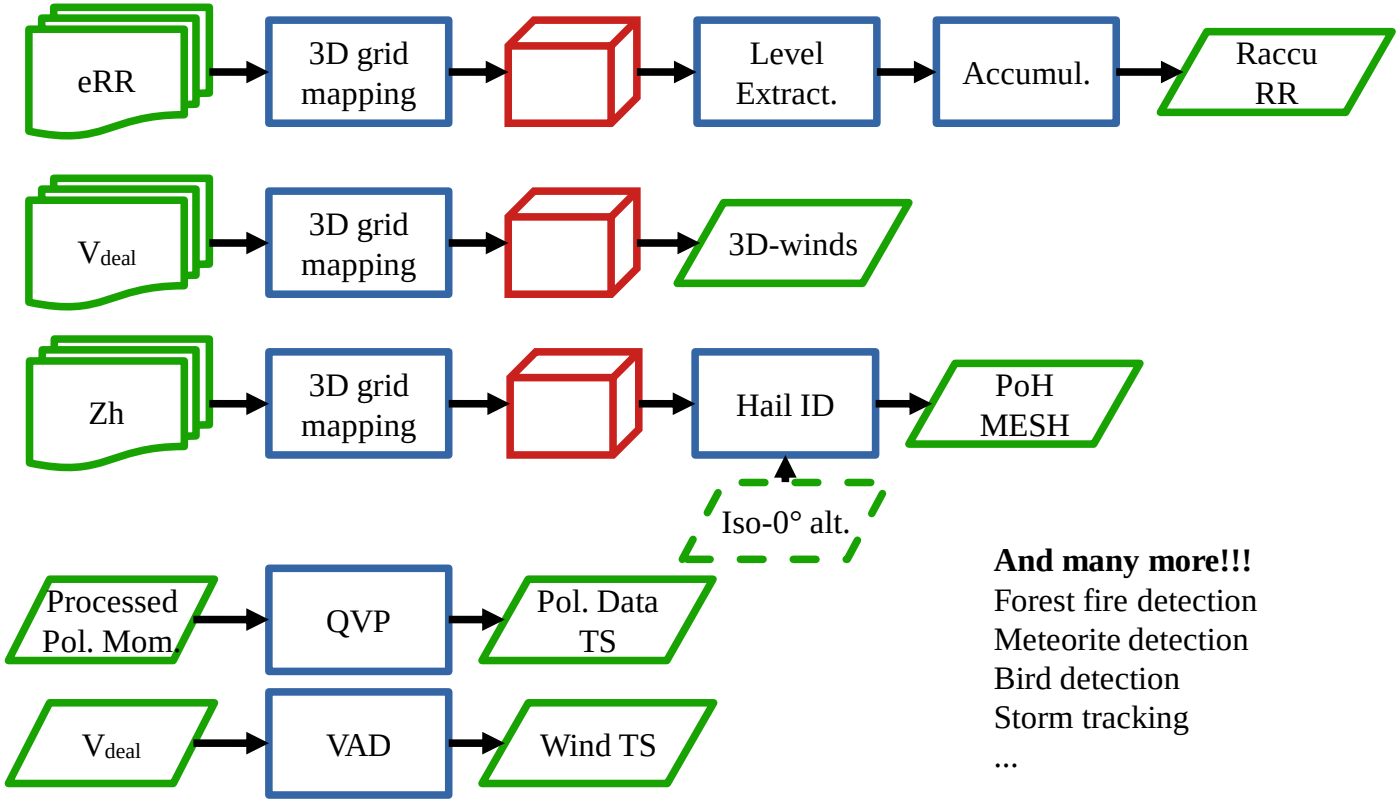


Gate-based products





Radar-based products



And many more!!!
Forest fire detection
Meteorite detection
Bird detection
Storm tracking
...

3. Radar data file formats

Radar Data Formats

- Radar data takes different formats at each processing stage:
  - IQ data: Time series of complex numbers
  - Moments: Polar coordinates (azimuth, elevation, range)
  - Composites: Cartesian/geo-referenced grids
  - Radar-based products: Grids but also time-height, time-range, etc.
  - Radar-derived products: ??????
- There is no formally accepted standard yet for radar data at any stage
- Most radar manufacturers and major Met services use their own proprietary formats
- There are 3 de-facto standards for moment data file formats:
  - ODIM_H5
  - CfRadial
  - NEXRAD-AR2

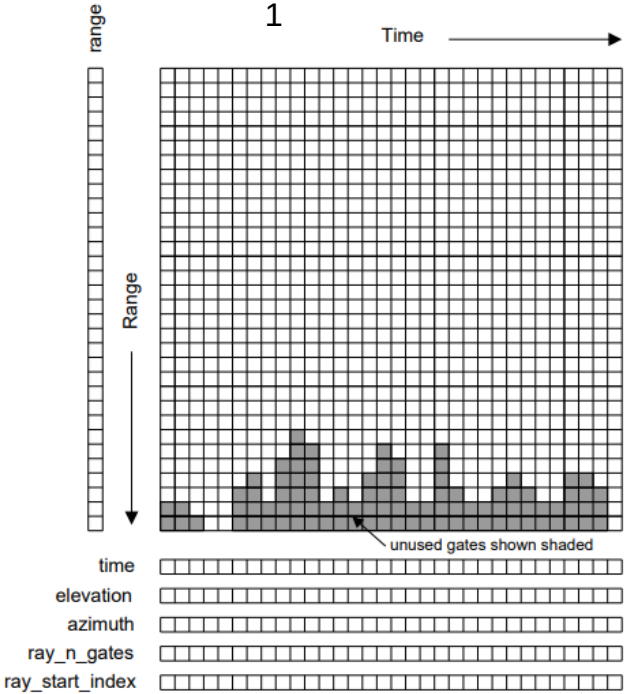
CFRadial

- NetCDF Climate and forecast (CF) Conventions for RADAR and LIDAR data in polar coordinates
- Based on Network Common Data Form (NetCDF)
- Maintained by NCAR
- De-facto standard for the research community
- Two major versions:
  - CfRadial Version 1: (Since 2010) Classic model using NetCDF3 => Py-ART data model
    - Data stored in regular 2D (time, range) format
    - Metadata: range, time, elevation, azimuth, (ray_n_gates, ray_start_index)
  - CfRadial version 2: (Since 2016) uses NetCDF4 (based on HDF5) and groups
    - Hierarchical grouping volume=>sweep=>dataset (time, range)
    - Candidate for WMO radar data standard (FM301)

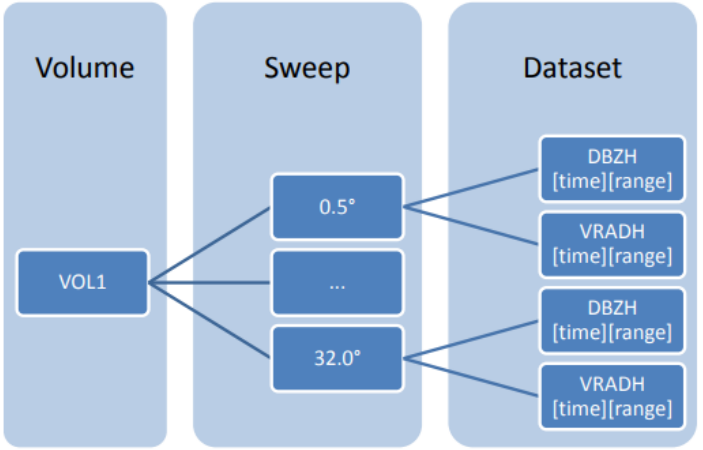
Readers: xradar, wradlib, BALTRAD, Py-ART (V1), LROSE, Pyrad (V1 and (partially) V2)

CFRadial

CFRadial 1



CFRadial 2

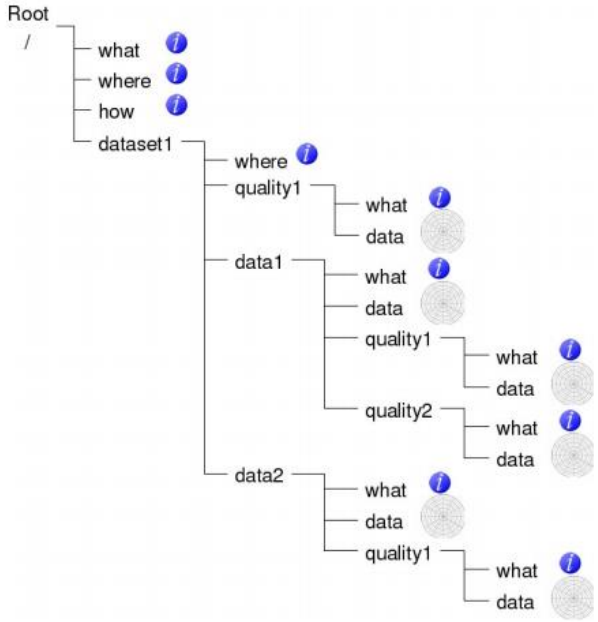


ODIM_H5

- OPERA Data Information Model for HDF5
- Based on HDF5
- Maintained by the OPERA programme of EUMETNET
- European standard for the exchange of radar data
- Defined for exchange of polar AND Cartesian data
- Uses groups

Readers: xradar, wradlib, Py-ART, Pyrad, BALTRAD, LROSE

ODIM_H5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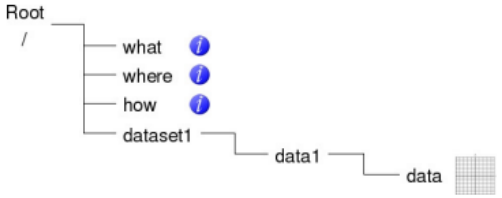
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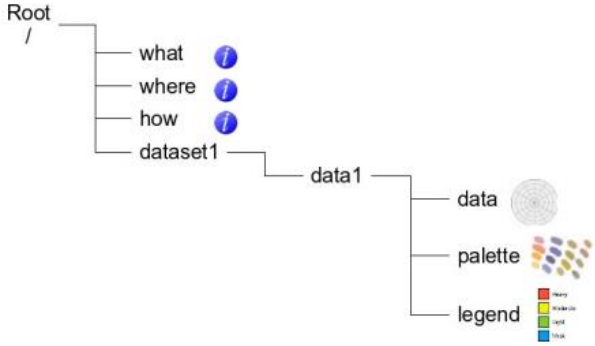
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NEXRAD-AR2 data

- Data from the US Weather radar network
- NEXRAD Level-II (Base) Data: reflectivity, mean radial velocity, spectrum width, (differential reflectivity, correlation coefficient, differential phase)
- NEXRAD Level-III Products: More than 75 products

Readers: xradar, wradlib, Py-ART, Pyrad (level II), LROSE

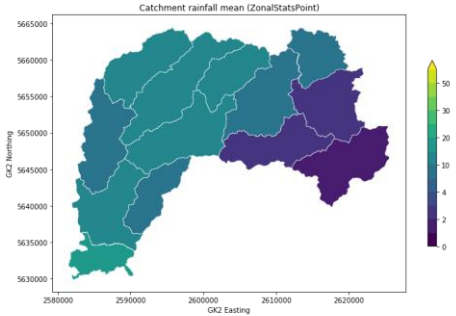
4. Open source software packages

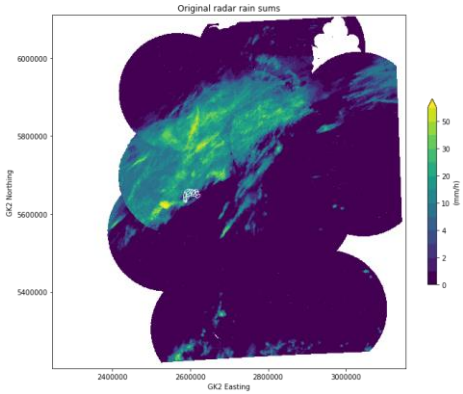
Wradlib

Philosophy : Keep the magic to the minimum (and let the user decide)

- One of the oldest packages (2011)
- Open platform for collaborative development of algorithms
- Python-based
- Linux/Windows/Mac
- Flat data model that allows maximum flexibility to interact with the data. xarray readers available
- Comprehensively addresses the full radar processing chain
- Mainly geared to interactive use in research but used in operations too
- Easy to install (PyPI, conda, Docker Hub)

https://wradlib.org





Wradlib functionality

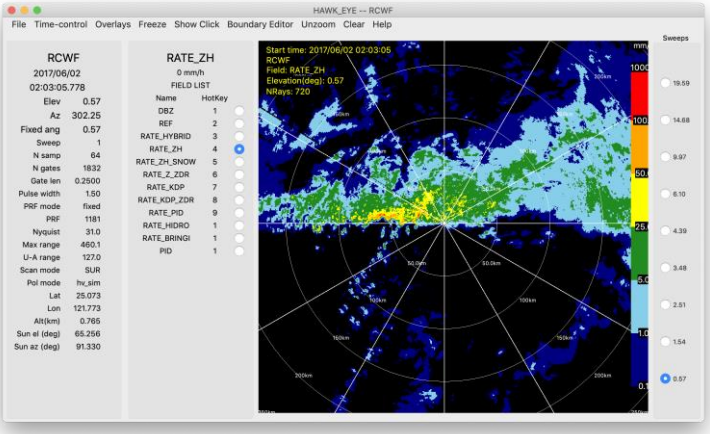
Module	Functionality	Comments
adjust	Gage adjustment	
atten	Attenuation Correction	Hitschfeld, PIA from KDP
classify	Hydrometeor Classification	Fuzzy logic classifier
clutter	Clutter Identification	
comp	Composition	Multiple Radar compositing
dp	Dual-Pol and Differential Phase	KDP retrieval, texture computation, de-polarization ratio computation
georef	Georeferencing	
io	Raw data I/O	Many readers, some put data in xarrays
ipol	Interpolation	Interpolation functions
qual	Data Quality	Beam blockage calculations, Bright band contamination
trafo	Data Transformation	e.g. linear to dB
util	Utility Functions	Despeckle, derivate, etc.
verify	Verification	Comparison between radar-base precipitation and ground truth
vis	Visualization	PPI, RHI, etc.
vpr	Vertical Profile of Reflectivity	Create and work with 3D grids
zonalstats	Zonal Statistics	
zr	Z-R Conversions	

LROSE

Philosophy : High quality building blocks for complex workflows

- Based on legacy of NCAR and CSU tools
- Fast native cross-platform applications
- Mostly C++
- Linux/Mac/partially Windows
- Many stand-alone tools
- Stores data in CF/Radial

http://lrose.net/



LROSE tools

Function	Tools
Convert	RadxPrint: Print file properties and determine if it is supported by Radx RadxConvert and RadxBufr: Conversion from 25 formats to CfRadial
Display	HawkEye
Quality Control	14 tools: compare merge and filter fields Detect sun hits and analyse them
Grid	Radx2Grid
Echo	23 tools: KDP and Attenuation Particle Identification, hydrometeor classification Rain rate and rainfall accumulation Beam blockage estimation Convective/stratiform Mesocyclones Refractivity and moisture Titan (Thunderstorm Identification, Tracking, Analysis and Nowcasting)
Wind	5 tools: VAD Multi-Doppler retrieval Vortex Optical Flow

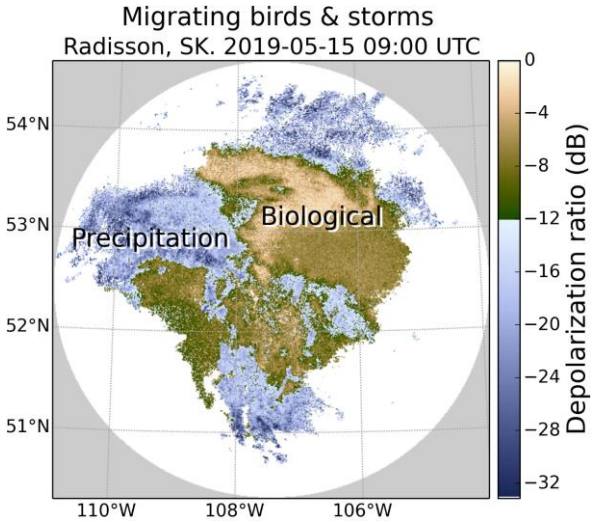
BALTRAD

Philosophy : Advanced Weather Radar Network

- Heritage from the Nordic Network NORDRAD. Partly funded by the EU. BALTRAD and BALTRAD+ projects (2009-2014). 13 partners in 10 countries
- Real-time data exchange and data processing
- Sub-packages written in different languages
  - Data exchange: JAVA
  - Data processing: C and Python
- Linux/Mac
- Distributed networking, partners exchange polar
- data and process them using a common toolbox
- Uses ODIM-H5

Docu: https://baltrad.github.io/

Code: https://github.com/baltrad



BALTRAD packages

Package	Environment	Description
baltrad-db	Python, Java	Database manager subsystem
BaltradDex	Java	Distribution and Exchange subsystem
baltrad_wms	OGC Map Server	Web map services
bbufr	C, Python	BALTRAD interface to EUMETNET OPERA's BUFR Software
beamb	C, Python	Beam blockage correction
beast	Java	Task manager/scheduler subsystem
bRopo	C, Python	Anomaly (non-precipitation echo) detection and removal
GoogleMapsPlugin	Python	Creation of PNG images to use in Google Maps
node-installer	Python	Installation wizard
OdimH5	Java	Data injector using ODIM_H5 and Rainbow file formats
RAVE	C, Python	Product generation framework and toolbox
baltrad_wrwp	C, Python	Wind products
baltrad-ppc	C, Python	Polarimetric processing chain

Other useful meteorological software

Py-TROLL : satellite data processing

WRF: weather Research and Forecasting Model

MetPy: weather data visualization

Metview: Meteorological workstation

MetWork Framework: Useful modules to build meteorological applications


GRAZIE !
MERCI!
THANK YOU !
GRÀCIES!

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

MeteoSchweiz
Operation Center 1
CH-8058 Zürich-Flughafen
T +41 58 460 91 11
www.meteoschweiz.ch

MeteoSvizzera
Via ai Monti 146
CH-6605 Locarno-Monti
T +41 58 460 92 22
www.meteosvizzera.ch

MétéoSuisse
7bis, av. de la Paix
CH-1211 Genève 2
T +41 58 460 98 88
www.meteosuisse.ch

MétéoSuisse
Chemin de l'Aérologie
CH-1530 Payerne
T +41 58 460 94 44
www.meteosuisse.ch