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Developement of a model based radar Doppler wind generator for de-aliasing and validation purpose

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Introduction

Weather radar so called Doppler weather radar, is a type of radar used to locate precipitation, calculate its motion, and estimate its type (rain, snow etc.). Modern weather radars are mostly pulse-Doppler radar, capable of detecting the motion of rain droplets in addition to the intensity of the precipitation. Both types of data can be analyzed to determine the structure of storms and their potential to cause severe weather, in addition these data could be used as observations in order to initialize the NWP (Numerical Weather Prediction) forecast models. Data assimilation in numerical weather prediction optimally blends observations with an atmospheric model in order to obtain the spatial distribution of atmospheric variables and to produce the best possible model initial state known as the analysis from which to integrate the NWP model forward in time.

Radial wind velocity is one of the products that could be retrieved from radar data and becomes widely used in data assimilation. Injecting such data into atmospheric models has recently received increasing attention due to developments in the use of limited area high resolution numerical models for weather prediction. The radar obtains the radial velocity of target by measuring the impulse phase difference between transmitted and received signals (Doppler-Fizeau effect) [1].However , velocity ambiguity can result in wrong data assimilation and wrong field retrieval. Velocity ambiguities occur when the true velocity exceeds the maximal unambiguous value (-Vmax ,+Vmax) [2], where Vmax is called the Nyquist velocity and expressed as :

$$V_{max} = \frac{\lambda.PRF}{4} \tag{1}$$

Where

PRF is the Pulse-Repetetive Frequency and lambda the radar wavlentgh. Since the 1970s, several methods have been developed to dealias Doppler radial velocity data, such as development of a one-dimensional dealiasing technique or more powerful approach by using data in two dimensions, that is, by searching for aliasing errors along both the radial and azimuthal directions in each sweep (scan) [3].

In our work, the technique consists of modeling the radial Doppler velocities in terms of the two components u and v obtained from a prediction model and interpolating them at the points of observations in the radial direction to the radar beam.

The radar data used for radial velocity are retrieved from OPERA (Operational Programme for the Exchange of Weather Radar Information) database and are stored in HDF5 format, and the forecast fields of U and V wind s componenents are generated from AROME non-hydrostatic mesoscale model. More details about HDF5-ODIM data structure, the AROME model for Austrian domain and technical procedures we followed could be find in the following sections.

1 The OPERA HDF5 radar data structure

HDF is an acronym of Hierarchical Data Format, which can hold a variety of heterogeneous data objects, its structure is similar to directories and files on a computer hard-disk. The meta-data in the file are organized and contained in groups and data are contained in objects called datasets. The meta-data in HDF5 file are called attributes and stores informations about either groups, datasets or data dimensions. In order to improve the radar data exchange between RC-LACE countries, Météo France and other European users of Limited Area Model in Europe, especially for data assimilation, part of agreement was to use radar datasets provided by OPERA hub, which developed a data information model for radar data groups, datasets and attributes contained in HDF5 files[4].

A typical OPERA radar HDF5 file is organized as following : At the top level, the HDF5 file contains the so-called "root" group(the main object in the file). Following it, three groups contain meta-data, these are called *"what"* (object, information model version, and date/time information), *"where"* (geographical information), and *"how"* (quality and optional/recommended metadata). The data are organized in a group called "dataset" which contains another group called "data1" where the actual binary data are found in "data". An example of an OPERA-HDF5 file radar structure containing one radar scan is given in figure 1.

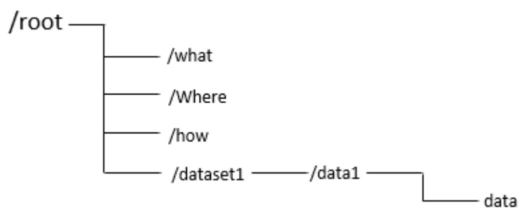

Figure 1: Example of one scan dataset in OPERA-HDF5 file.

A standardized ODIM(OPERA Data Information Model) HDF5 file should have *"how"*, *"what"* and *"where"* attributes at root group and for each dataset, *"how"* and *"what"* are attached to each data and quality group within each dataset.

Although this structure is similar to one of the standards advised by OPERA (Figure 1), it is not followed by many countries, which make it difficult to create a tool to handle every radar file and use the data for NWP purposes. For further informations and more details about working on OPERA HDF5 radar files structure homogenization see [5]. Since the radar files in Austria don't contains radial velocity product yet, we opted to use radar data produced from the radar station "Silis" in Slovenia (figure 2). In addition, these radar files follows the structure recommended by OPERA, i.e it has *"what"* , *"where"* and *"how"* attributes in root group and attributes *"where"* and *"what"* are attached for each data under dataset group.

The structure of the HDF5 file used to built our de-aliasing model follows the structure given in the figure 2. In this information model , each dataset corresponds to a scan done by the radar, and each scan is perfomed for each elevation angle(12 scans in a file). In addition , under each dataset three parameters are given, the reflectivities (DBZH) , the RHI and the radial velocity (VRAD).

In order to get informations about the geographical emplacement, the quality and the data dimensions, we should parse and read the attributes values of *"what"*, *"where"* and *"how"* groups under each dataset.

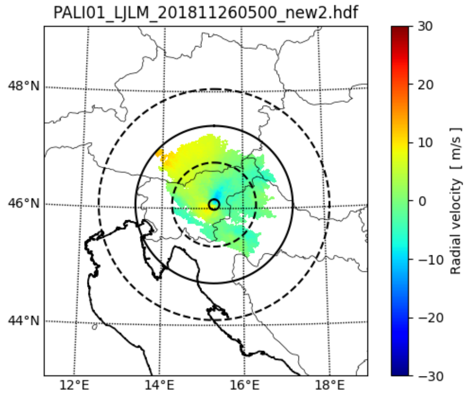

Figure 2: Radar station location used for the model (Radial velocity at 0.5 degree elevation angle)

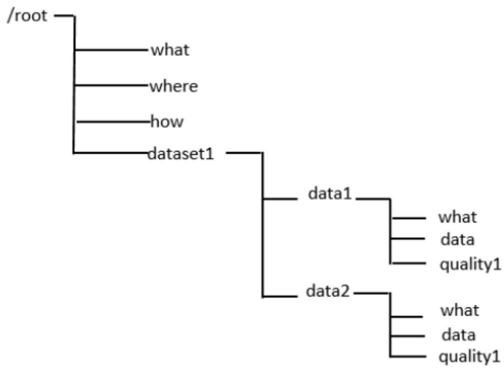

Figure 3: OPERA-ODIM file structure produced in Slovenia.

2 Dedcoding OPERA HDF5 file

Several open-source HDF5 libraries in either FORTRAN , C/C++ and java programming language are available to deal with hdf5 file format, they are mainly supported by the HDFGroup community, but one of the most flexible hdf5 libraries is h5py for python programming language. It lets store a huge amounts of data and easily manipulate them as numpy arrays. It uses widely python dictionary variable type to access hdf5 attributes and dataspaces. In our model, the program written to open and read the data and attributes from hdf5 file is called `decodhdf5.py`, it can be used as module in other scripts or as main program. The main task of the program is to scan and parse the HDF5 radar file, it reads the global how, where and what attributes under the file's root object, then the where and what attributes values under each dataset. The global what, where and how attributes give informations about the radar station, such as coordinates, station height and the name and the WMO radar station identifier. Additional technical informations could be found under these groups, like the software version used to encode the data or the start and the end time of the data production. In order to do computation with the radar data, the program looks for the attributes values of the groups what and where and eventually how under each dataset subgroup. The informations retrieved from the group where under each dataset are described in table 1:

Note that these informations are common to all groups '/datasetN/where', where N is the index of the dataset wich corresponds to every elevation angle scan. The second subgoup to be parsed is the what subroup under each dataset, i.e '/datasetN/data1/what' which contains information about the name of the quantities produced during the scans. The files provided by the radar station 'Silis' in slovenia contains three variables, the logged horizontally-polarized (corrected) reflectivity factor (DBZH), logged horizontally-polarized total (uncorrected) reflectivity factor (TH) and the radial velocity (VRAD).

The infomations given in the subgroup what are specific to each mesured quantity and are described in

Table 1: Attributes description under ”where” group of dataset.

attributes	**description**
a1gate	Index of the first azimuth gate radiated in the scan.
elangle	Antenna elevation angle (degrees) above the horizon.
nbins	Number of range bins in each ray.
nrays	Number of azimuth rays (gates) in the object.
rscale	The distance in meters between two successive range bins
rstart	The range (km) of the start of the first range bin.

table 2: Note that the program `decodhdf5.py` looks only for the parameter “Radial velocity” (VRAD) and its

Table 2: Attributes description under ”what” group of each dataset.

attributes	**description**
gain	Coefficient “a” in y=ax+b used to convert to unit. Default value is 1.0.
offset	Coefficient “b” in y=ax+b used to convert to unit. Default value is 0.0.
undetect	Value used for areas radiated but nothing detected.
quantity	Mesured parameter (example reflectivity DBZH)

meta-data. For more informations and description of the OPERA-ODIM model radar file see the reference [4].

3 Geographical localization of the radar radial velocity

The Doppler radar measures both precipitation and wind. The radar emits a short pulse of energy, and if the pulse strike an object (raindrop, snowflake, bug, bird, etc), the radar waves are scattered in all directions. A small portion of that scattered energy is redirected, this reflected signal is then received by the radar during its listening period. The measurements are along rays and each ray is divided on bins (gates). For the OPERA radar files model, the number of rays is usually 360 rays, and the number of bins can have different values (from 52 to 249 bins) depending on the elevation angle of scan and the radar beam range (figure 4). The native projection of the radar observations is a polar grid, one observation point for each ray, or azimuth and bin (distance radar-target). The main task during building our model of wind de-alising is the interpolation of the values of the two wind's components U and V from the model forecast to the observations points. Therefore, the polar radar observations must be converted to a latitude/longitude grid. Furthermore, to completely localize the radar pixel in space, the altitude of the radiated target is calculated. The python program `pixe2coord.py` was written as module to convert the azimuths and bins to latitude, longitude coordinates and calculates the height of the observation point depending on the elevation angle of the scan. Assuming the Earth is round, the radar beam in vacuum would rise according to the reverse curvature of the Earth. However, the atmosphere has a refractive index which diminishes with height, due to its diminishing density. This bends the radar beam slightly toward the ground and with a standard atmosphere this is equivalent to considering that the curvature of the beam is 4/3 the actual curvature of the Earth (figure 5). Depending on the elevation angle of the antenna and the other considerations, one can calculate the height above ground of the target using the formula(2) [6] :

$$H = \sqrt{r^2 + ke.Re^2 + 2.r.Re.sin(\phi)} - ke.Re \tag{2}$$

where

- r : Distance radar-target.
- ke : 4/3 earth radius coeifficient in middle latitudes.
- Re : Earth radius.
- ϕ: Elevation angle above the radar horizon.

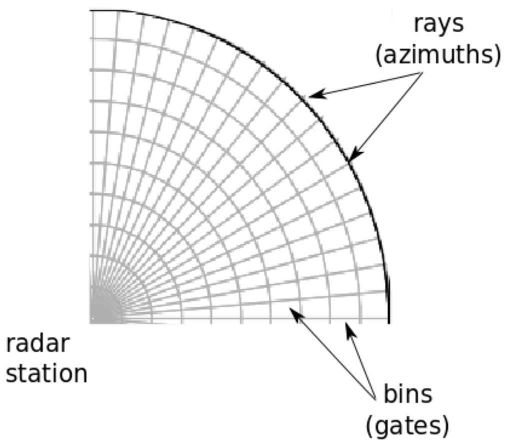

Figure 4: Observation points.

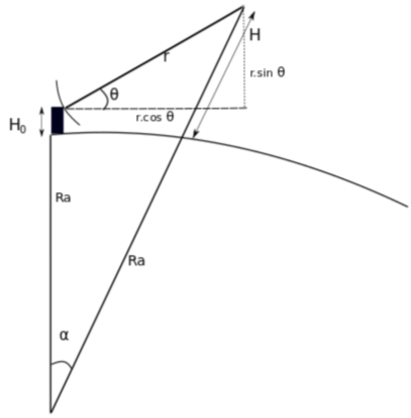

Figure 5: Altitude of a radar pixel.

The latitude and longitude of a bin at a given distance from the radar (*n*rscale*) and given azimuth angle (theta) are calculated using the formulas (3) and (4) [6]:

$$lat = arcsin(sin(lat_0) * cos(\frac{d}{Re}) + cos(lat_0) * sin(\frac{d}{Re}) * cos(\theta)) \tag{3}$$

$$lon = lon_0 + antan2(sin(\theta) * sin(\frac{d}{Re}) * cos(lat_0), cos(\frac{d}{Re}) - sin(lat_0) * sin(lat)) \tag{4}$$

where

- d : distance radar-bin on the ground.
- lat_0 : latitude of the radar station.
- lon_0 : longitude of the radar station.
- θ : azimuth of a given ray.

4 Prepartion of AROME forecast FA file

To simulate the radial velocities at the observation points, the forecast model file used is in format FA from AROME (Application de Recherche Operationnelle Meso-Echelle) forecast model, the Austrian AROME domaine extends from lat=44.14,lon=6.29 in low left corner to lat=50.56 ,lon=21.49 for upper-right corner, with 2.5Km resolution (600x432 grid points) and 90 levels. The forecast models usally use the hybrides coordinates for altitude, but the radar data observations heights are in meter, therefore a Fortran program was written (Florian Meier) and compiled within gmkpack utility to create a new binary called `heighttomod.x` in order to convert the altitude from hybride coordinates into meter. The Program reads the fields TEMPERATURE, HUMI.SPECIFI at all the model levels and the SURFPRESSURE, SPECSURFGEOPOTEN at the ground perfroms some calculations and writes the levels heights in meter under CLOUD_WATER field name.

5 Interpolation of the model wind to observation points

At this step of building a radar radial velocity generator model, the task consists of the creation of an observation operator that can simulate the observations from the model at the radar pixels locations, this poduces the model counterpart of the observed quantity (figure 6).

The building of this operator involves three steps:

- Interpolation of the NWP model horizontal wind components u and v to the observation location.

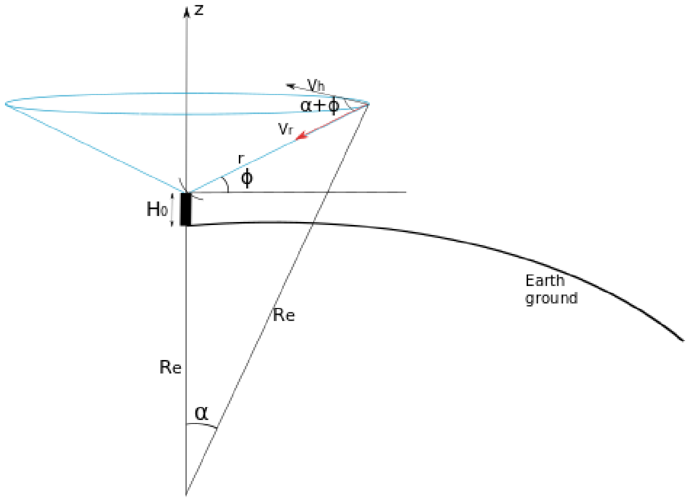

Figure 6: Production of radial velocity at a given observation point.

- Projection of the interpolated NWP model horizontal wind towards the radar , this quantity is called Vh and is calculated using the relation(5) [7]:

$$V_h = u.sin(\theta) + v.cos(\theta) \tag{5}$$

- Projection of V_h in (5) on the slanted direction of the radar beam.

$$V_r = V_h.cos(\phi + \alpha) \tag{6}$$

where

$$\alpha = arctan(\frac{r.cos(\phi)}{r.sin(\phi) + Re.4/3 + H_0}) \tag{7}$$

The main program `RadVS.py` (Radar Doppler Velocity Simulator) is written in python, calls the modules `decodhdf5.py` to read data from HDF5 file and `pixe2coord.py` to perfome the necessary geographical transformation (polar coordinates to latitude/longitude). The U,V wind components and model heights from AROME FA file are read using EpyGrAM utility.

The execution time of iterations over all the model grid points and levels (432x600 and 90 levels) is to long ,in addition, the interpolation is done for each elevation angle. In order to speed-up the program runtime, a FORTRAN routine called `doppsim.f90` is written, which is converted to python module and called from the main program `RadVS.py`.

The algorithme consists of finding the closest model grid-points to the radar observation points in a rectangle (0.04 degree in latitude and 0.06 in longitude directions), then takes the value of the nearest point by calculating the distances between observation point and the model grid-points found in the rectangle. Once the point is found in the horizontal plan, the upper-air model value is found by interpolating the values between two successive levels enclosing the pixel height. The value of U and V model components are computed by linear interpolation using the formula (8) :

$$u = \frac{(ph - h_l).(u_{l-1} - u_l)}{h_{l-1} - h_l}), v = \frac{(ph - h_l).(v_{l-1} - v_l)}{h_{l-1} - h_l}) \tag{8}$$

Where

- ph : Altitude of a radar pixel found between two model levels.
- $u_l, v_l, u_{l-1}, v_{l-1}$: The model wind componenets at two successive levels.
- h_l, h_{l-1} : The model heights at two successive levels.

6 First model implementation

The first test of the model was done for the date of 26-11-2018 at 05 hour UTC, by taking a radar file from the station cited above (Silis station in Slovenia), the AROME forecast file used is the second term produced by a 03 UTC forecast network. The main program `RadVS.py` is executed by a PBS job script on one CPU. The number of scans (between 12 and 60) could be relatively big, therefore a python function was added in order to minimize the execution time by assigning a process for each elevation angle found, the job takes approximatively one minute to process all the radar elevations.

Preliminary results after implementation of the model are presented on a polar grid showed on figures (7) and (8). The data are displayed in PPI mode (Polar Plane Indicator) for the two first elevation angles.

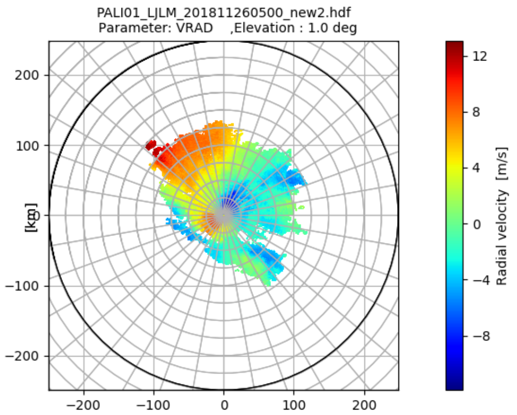

Figure 7: Observed Radar radial velocity *(1.0 degree elevation)*

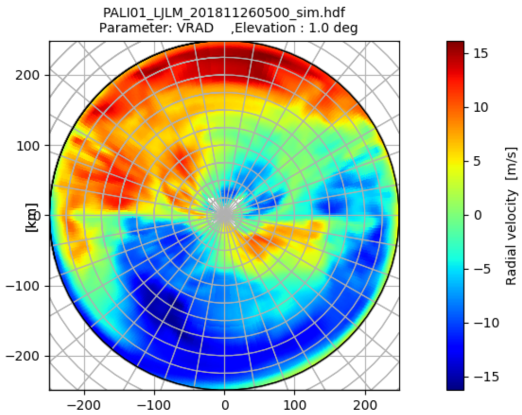

Figure 8: Simulated Radar radial velocity *(1.0 degree elevation)*

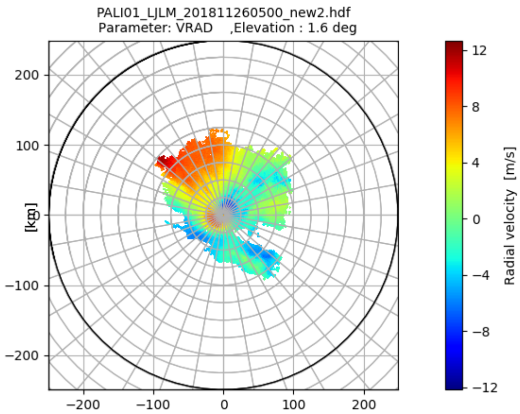

Figure 9: Observed Radar radial velocity *(1.6 degree elevation)*

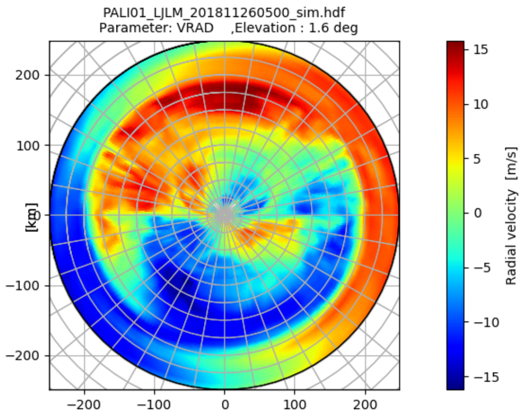

Figure 10: Simulated Radar radial velocity *(1.6 degree elevation)*

The observed Doppler velocity plotted on PPI mode(0.5 degree elevation angle) shows that there is serious aliasing (figure 7), it could be seen that there is velocity foldings between the 20 and 110 degree azimuths with a minimal Nyquist velocity equal to -8 m/s, we can distinguish areas where the wind velocity values change suddently from 0 m/s to minimal(-8 m/s) in a very close area.
The figure 8 shows the simulated radial velocity for 0.5 degree elevation angle, The plot shows that the aliasing areas have been removed and the both maximal and minimal velocity values increase from -8 m/s,+12 m/s to -/+ 20 m/s. Furthermore, it becomes easier to distingish the wind direction (south-east to noth-west), the plot shows a zero line between the droplets towards and faraward the radar beam, which was not the case when the velocity alising accurs. In the other hand, as it's displayed in figure 10, the velocity field is smooth and

contains no holes, it's caused by the assumptions we made to don't take in account the areas corresponding to no-values or undetect flaged regions in the observed velocity field (figure 8). The figues (9,10) show observed

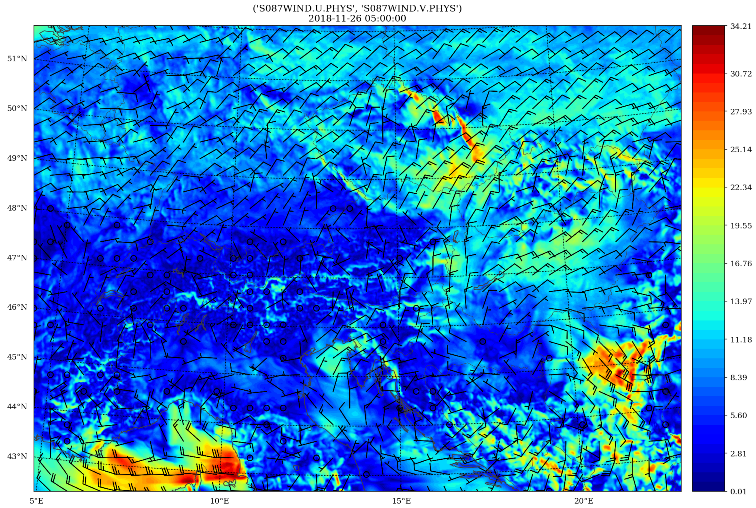

Figure 11: AROME forecast of wind speed and direction at level 87 for 26-11-2018 at 5 UTC.

and simulated velocity for 1.6 elevation angle, in this case the velocity is strongly aliased for observed field (between 30 and 110 degree azimuths), compared to the PPI in the figure 10, the valocity values are de-aliased and the maximal unambiguous velocity increases slightly to -/+ 18 m/s. However, it is bit diffcult to distingish the wind direction especially in the areas near than the radar station, this is mainly caused by the orography of the site. For radar ranges between 110 and 250 km the beam becomes relatively far from the earth ground (6 to 7km height), thus a wind shear could be seen at the first model levels.

Conclusion

During the externship, a model for de-aliasing Doppler radar wind velocity was developed. The model called RadVS (Radar Doppler Velocity Simulator) takes wind values from a NWP model and simulate radial wind velocity at the radar space. It was written by mixing python and FORTRAN programming languages.The sample radar file we used is produced in Slovenia (included in the Austrian AROME domain). First tests of the model produces smooth and almost uniforme wind fields with unambigous velocity values that could be used for de-alising the radar recieved from the radar stations. In the other hand, for a more sophisticated modelling and realistic assumptions, other parameters could be taken into account such as, the areas with no-value or flaged as undetect, the clutters, the vertical wind for high elevation angles and the broadning of the radar beam far from the radar station.

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