Radar Reflectivity Data Assimilation

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1. Summary

Development in NWP leads to high resolution models, which need more accurate initial conditions. In other words, high-resolution modelling needs high-resolution data assimilation. Classical observations such as SYNOP or TEMP have not enough density to catch e.g. local convection etc. Radar measurements provide a sufficient density of data, but this observation type is not implemented in the ARPEGE/ALADIN/AROME forecasting system yet. In this report, I will show our first steps in the implementation of radar reflectivity. I will introduce the prepared data-flow, followed by the first work done in implementation.

2. Data-flow for radar reflectivity

To have well-working radar-reflectivity assimilation, we have to pass the following three steps :

- pre-processing,
- screening,
- variational assimilation.

2.1 Pre-processing

Radar reflectivity should be available from different radar sites in common BUFR format. For some radars we will have volume data divided to single elevations, for others only 2D data (one elevation or one product). BUFR file contains reflectivity values for each radar elevation defined on a 512x512 Cartesian/cone-shaped 1 km grid. BUFR file with the associated flag pixel values should be provided for each elevation as well. We have to be aware that the Nth pixel for each elevation of a radar have not the same (lat., lon.) location. The projection on the Cartesian cone-shaped grid is only *x=r*sin(azimuth)* and *y=r*cos(azimuth)* (*r* is distance on beam) at each elevation. That means, we can have significant differences in latitude and longitude between the lowest and the highest elevations for the Nth pixels. These BUFR files should be archived for future re-pre-processing in case of changes in model geometry or resolution.

In pre-processing, first quality check should be performed. What does it mean ? We should check wrong data, wrong beams, too noisy data and also occurrence of anomalous propagation or bright band or strong attenuation. Perhaps we will need some model fields for this preliminary check, e.g. temperature for bright-band check.

Next step in pre-processing should be "translation" to common, and "understandable" by the model, format for all radars. It means we should prepare ODB files. Here we will need other additional information about radar site, such as beam width in degrees, etc. Next, at least the following information should be stored in ODB :

- radar reflectivity (dBZ)
- horizontal position (degree)
- vertical position (m)
- vertical width of beam at observation point (m)
- elevation (degree)
- starting time of elevation (time)

Reflectivity data will be stored in ODB as pixel vertical reflectivity (PVR) messages - in vertical profiles (columns) of reflectivity for each point in radar horizon. Each radar should be processed separately. It can be very interesting to put some additional variable for each column, containing the cloud-top value from different sources than model, e.g. satellite observations. This can help in 1D-Var to set the maximal height where model column will be modified because of observed reflectivity.

Thinning of much more dense radar data (horizontal resolution 0.5 – 1 (2) km) should be performed here, because thinning in screening is very expensive (call for whole observation operator is performed). Radar data can be thinned only to the gridpoint. The nearest gridpoint is suggested, because it has no sense to mix different cloud types in averaging.

2.2 Data flow in screening

In this part, it is supposed that we have radar-reflectivity data in ODB file and we are working with 4D screening to have access to required physical fields. The main aim of this section is to design a data-flow for reflectivity to obtain functional monitoring system for this observation type. That means, we need to have direct, one-way observation operator - just reflectivity simulator from model data. Reflectivity will be treated as other observations.

The specification of a new type of observation must be prepared and then a new table for this observation should be created in OBSTABS. We need to set all parameters for reflectivity processing. The new subroutine for setting can be called SURADAR and should be called from SUOBS as well. In the future, further settings necessary for radar Doppler wind measurement can be added to this subroutine.

For reflectivity simulation, we need to have some physical fields such as mixing ratio from hydrometeors (for rainwater and ice for ALADIN), information about hydrometeors' size distribution and dry air reference density and temperature. We need to define new GOMSNOW, GOMRAIN, etc. arrays in YOMMVO for these purposes. These arrays will be filled in MPOBSEQ subroutine from buffer. Buffer is filled in COBS and COBS is called from SCAN2MDM. Model data will be then horizontally interpolated to the observation point (SCAN2MDM -> COBSLAG -> OBSHOR -> SLINT).

In next step, under OBSV, vertical "interpolation" of model fields will be performed. We have to be more careful about this interpolation, because for some reflectivity observations we will need interpolation, but for the rest the average is necessary, depending on radar beam width at observation point.

For monitoring of reflectivity, a new subroutine REFLSIM for simulating reflectivity should be called from HOP. Then all the necessary values for *Jo* can be calculated and stored. In HOP, we must be as generic as possible, following the usual way as other observations are processed. All differences should be put into the subroutine REFLSIM to avoid problems of maintenance of HOP at ECMWF. This should be still consulted with ECMWF. It is important to have the reflectivity-simulating subroutine REFLSIM, because REFLSIM will be called from two different places : from HOP for monitoring and from HREFL for 1D-Var (see 2.3.1), otherwise the code will be duplicated.

Last step is to compute all statistics in subroutine SCREEN.

2.3 Variational assimilation

Real assimilation of radar reflectivity will be done indirectly, in two steps. First, we need to retrieve T and q profiles from reflectivity profile. Second, these T and q profiles should be assimilated as a specific set of pseudo-TEMP or pseudo-SATEM observations.

2.3.1 Computation of (T, q) vertical profiles

Computation of T and q profiles will be performed in another step of screening and can be done in parallel with the monitoring described in section 2.2. For this purpose the 1D-Var method will be used.

Again, assuming 4D-screening (model is running with its physics), we have two possible solutions :

a) Save model physics and call 1D-Var retrieval from inside of observation operator for reflectivity HREFL, before HOP. This solution can be used for 3D screening as well, because physical fields can be read from external file.
b) Call 1D-Var retrieval from inside the model physics, through a specific interface. Below this interface, 1D-Var must also be able to call the reflectivity simulator and read adequate information from ODB tables.

At the end of screening, the model reflectivity equivalent from monitoring as well as T and q profiles from 1D-Var retrieval are stored in the ODB tables.

Some observation error standard deviation σ_o must also be set for the 1D-Var retrieval. This could be derived from comparison of the retrieved profiles with usual data such as radiosondes.

2.3.2 Variational analysis

Configuration 131 will process 1D-retrieval (T and q profiles) from ODB most easily as a specific set of pseudo-TEMP or SATEM observations. During 1D-Var retrieval we can produce the whole profile of T and q (at all model level). Variational quality control (VarQC) can help to protect the whole NWP system to be not compromised by bad observations. The problem is that VarQC is implemented only for pseudo-TEMP observations.

Specific observation error standard deviation σ_o values are "assumed" in section 2.3.1

3. Status of implementation

Implementation of the new observation type for radar measurement started in CY28T0_T1. It is continuing with CY28T1.

3.1 Radar observation type

After consultation with ECMWF, the radar observation as new observation type has got 13th position (NRADAR = 13). The 11th and 12th positions are already set for observation types used in Reading and should be available in next cycles (from CY28_R2). One subtype was defined for the radar : "BUFR RADAR REFLECTIVITY 1". The number of CMA variables was increased to 71 (NOVARIB = 71) and CMA number for radar reflectivity was set to 192 (NVNUMB(71) = 192). This value comes from the official BUFR code table.

3.2 Cost-function (*Jo*) modifications

Due to the new observed quantity – radar reflectivity -, the number of variables in cost-function (JPXVAR) was increased and new NVAR_RFL = 26 was added to NVAR array as well as 'RFL' to CVAR_NAME. Whole data-flow for *Jo* was checked. Computation of *Jo* itself has been left general as for other observations. Missing part of *Jo* computation for radar reflectivity is now only error statistics. *Jo* values and other statistics will be stored in ODB as usual.

3.3 ODB

For radar reflectivity, two new tables are designed in ODB : *radar_hdr* and *radar_body*. *Radar_hdr* contains basic information about observation, e.g. date, time, latitude, longitude, number of elevation, etc. *Radar_body* contains data from vertical column and is composed the following fields:

- **refl** : radar reflectivity (dBZ)
- **height** : vertical position (m)
- **width** : width of radar beam at observation point (m)
- **brange** : range of observation on beam (m)

- **elev** **:** elevation which the observation comes from (degree)
- **etime** **:** starting time of elevation

as well as standard fields for departures and statistics.

3.4 Observation operator

The most important part for radar-reflectivity assimilation is the observation operator. The main part of the observation operator is a reflectivity simulator, which transforms model fields to reflectivity. This part is provided by people from Méso-NH team. Version from May 2004 is a quite complicated radar simulator, which simulates from the 3D model fields a whole volume radar measurement. There are two problems : first, we don't have the whole 3D model fields in that part where the observation operators are called from; second, the source code is in a different style than that we are using in ALADIN. It is necessary to rewrite this observation operator and extract the point reflectivity simulator only.

As it was mentioned before, reflectivity simulator should be called from two places, from HOP and from 1D-Var retrieval. Another problem is that all the necessary model fields are not available – mainly physical fields for the snow and the graupel. For this purpose we need to implement new GOM arrays. Because it is very complicated, this part is not done yet. We should decide whether to change idea of the GOM arrays - as it was done for GFL, or continue in the old way and spend lot of time first for implementation of new "GOMs" and then again in the future for new necessary arrays.

4. Conclusion

Development of radar reflectivity assimilation has already started. Lot of effort is already spent and much more work is still waiting for us. The progress in implementation brings new and new problems and we are forced to revise our first ideas. First neutral tests were performed to check if the whole system hasn't been badly affected by our modifications. Some problems were discovered, but they will be solved soon and at the end radar reflectivity assimilation will work properly and will help to improve model weather forecast.

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