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TOWARDS THE ASSIMILATION OF RADAR REFLECTIVITIES: IMPROVING THE OBSERVATION OPERATOR BY APPLYING BEAM BLOCKAGE INFORMATION

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1. INTRODUCTION

Weather radars play an important role in the remote sensing of precipitation and can provide a very detailed description of its three-dimensional structure and temporal evolution. Quantitative precipitation estimation (QPE) and quantitative precipitation forecast (QPF) are typical application areas of radar measurements. QPE is for instance required by hydrological models while QPF comprises the assimilation of radar data into numerical weather prediction (NWP) models and nowcasting systems.

To perform short-range forecasts over Western Europe, Météo-France is running operationally the limited-area model ALADIN (Aire Limitée Adaptation dynamique Développement International) with four daily updates towards observations using a three-dimensional variational (3Dvar) data assimilation scheme. Currently, Météo-France is developing an NWP system for the convective scale that will run operationally in 2008. This system, called AROME (Application de la Recherche à l'Opérationel à Méso-Echelle), covers the French territory with a 2.5 km horizontal resolution. It uses a complete data assimilation system derived from the ALADIN 3Dvar but the microphysics parameterizations are different in ALADIN and AROME.

In order to assimilate radar reflectivities, the NWP model must have the capability to simulate realistic reflectivities. So, as a first step an observation operator, derived from the operator developed for the MESO-NH model (Caumont et al., 2006), has been implemented in the ALADIN 3Dvar assimilation scheme in order to simulate reflectivities from the model hydrometeors. As the AROME model uses ALADIN 3DVar software, AROME uses the same observation operator. The AROME model has an advanced representation of the water cycle with five hydrometeor classes (cloud water, rainwater, primary ice, snow and graupel) governed by a bulk microphysics parameterization (the same as in the MESO-NH model). The observation operator can be evaluated in ALADIN through using rain and snow prognostic variables but without graupel which is not available and can't be modeled. The assimilation scheme for radar reflectivities consists of two steps: the first step is a retrieval of columns of pseudo-observations of humidity and other model prognostic variables from a reflectivity column, and the second step consists of assimilating the pseudo-observations through the 3DVar assimilation system.

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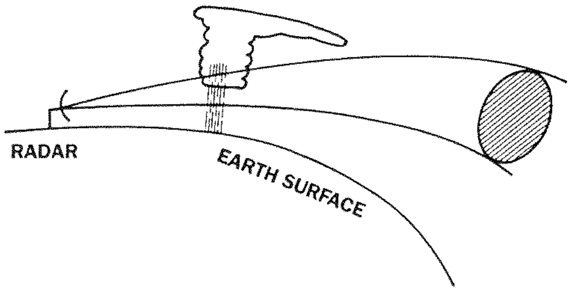
2. BEAM PROPAGATION

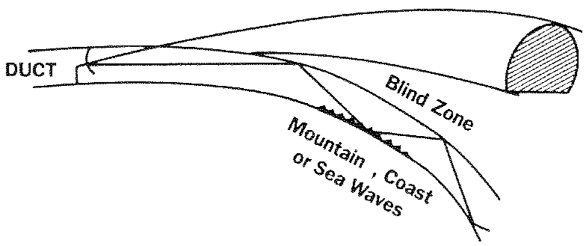
A well-known factor that affects radar observations in complex terrain is beam blockage (see e.g. Germann and Joss, 2003). The screening effect of topography is likely to occur at low elevation angles, the most useful for radar precipitation estimation and also for data assimilation. Anomalous beam propagation (AP) is another factor that may affect the quality of radar observations. It occurs when the radar beam is refracted less (subrefraction) or more (superrefraction) than in the so-called normal or standard propagation conditions (Turton et al., 1988) (Fig. 1(a)). Superrefraction may increase substantially the number and intensity of ground or sea clutter echoes. This applies in particular to ducting (Figs 1(b) and 1(c)) which is an extreme case of superrefraction. It occurs when the radar beam is bent towards the ground with a curvature greater than that of the Earth's surface.

At the Norwegian Meteorological Institute (met.no) Gjertsen and Dahl (2002) developed a beam propagation model (BPM) to correct errors in CAPPI products related to topographical beam blockage. They simulate the radar's field of view using information on the scan geometry, a digital elevation model (DEM) and vertical profiles of humidity, temperature and pressure. The beam paths are computed by a geometrical-optics approach taking into account the atmospheric conditions. It is assumed that a single profile of humidity, temperature and pressure describes the atmosphere in the entire radar volume. If no atmospheric profiles are specified beam propagation is simulated according to a vertical refractivity gradient based on the US standard atmosphere. To simulate anomalous propagation it is possible to use atmospheric profiles from radiosondes or NWP model forecasts which are representative for the radar site. Operational NWP models can provide information with high temporal and spatial resolution but they still suffer from an inadequate description of the atmospheric boundary layer.

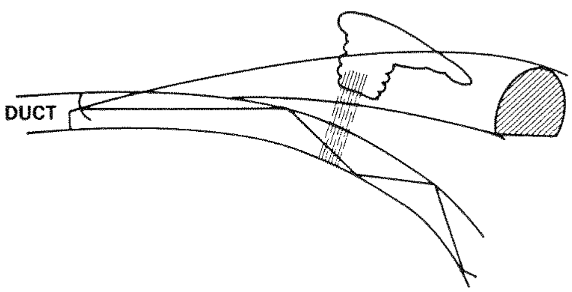
BPM output fields are (i) the degree of beam block-



(a) Normal propagation conditions with precipitation.



(b) Anomalous propagation (superrefraction) conditions.



(c) Anomalous propagation conditions with precipitation.

FIG. 1: Normal propagation conditions with precipitation and anomalous propagation (superrefraction) conditions with and without precipitation. From Alberoni et al. (2001) and Koistinen et al. (2003)

age, (ii) the corresponding correction factor which can be applied to operational radar products, and (iii) the visibility for a given elevation angle and half-power beam width. BPM's beam blockage correction is well documented in Bech et al. (2007). The visibility is defined as the height of the lower beam boundary taking into account topographical blockage.

Within the framework of the NORDMET Activity on Radar Applications (NORA) a study for radars of the BALTEX Radar Network (BALTRAD) has been performed. It reveals that beam blockage correction for standard propagation reduces the gauge-radar scatter and bias in average (Bech et al., 2007). An operational implementation of the correction matrices for BALTRAD is planned for this year. Recently, the BPM has been extended to correct polar volume data as well.

3. BEAM BLOCKAGE IN THE OBSERVATION OPERATOR

3.1 *Radar data*

Currently, the French radar network (also called ARAMIS) consists of 24 radars (Fig. 2) whereof 16 radars are equipped with Doppler technology and three with dual polarization technology. At the end of this year, the entire network is dopplerized and seven radars can measure dual polarization. A detailed description of the operational single radar and composite QPE products at Météo-France is given by Parent du Châtelet et al. (2006).

Data assimilation applies radar reflectivities within the operational measurement radius of 250 km. The distance to the radar is used as quality measure through the observation error covariances: the larger the distance the lower is the weight of the observation in comparison to the model background.

The polar volume data is averaged to a conical cartesian grid of 1×1 km^2. When we introduce the data in the model, we compute the horizontal coordinates of these pixels and put pixels from different elevations in the same column with the geo-location of the lowest pixel. Advection is applied in order to synchronize the PPI-images from the different elevations carried out within 15 minutes.

Specific BUFR files of data for the NWP models have been generated: they contain the reflectivity data (which will be corrected for attenuation by rain concerning polarimetric data) and a quality flag allowing to distinguish precipitation from spurious echoes (e.g. ground clutter). Additional files contain maps of partial masks (these maps are produced from long-term averaged reflectivity maps and the Surfilum Software (Delrieu et al., 1995) which uses a high-resolution DEM) making it possible to balance the impact of the data in the assimilation.

Although beam blockage correction maps exist for each elevation angle, reflectivities are not corrected insofar as the strong rates of masking are difficult to correct. It is indeed more judicious to consider beam blockage in the simulation of reflectivities from model fields (sect. 3.2).

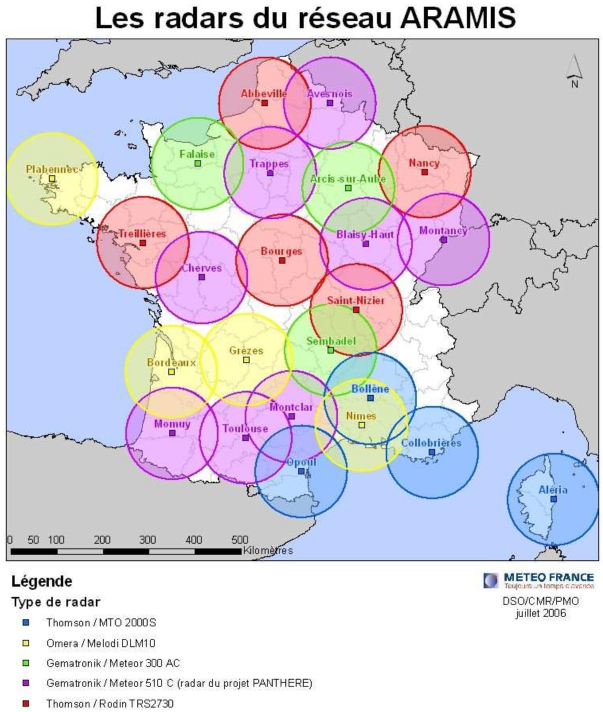


FIG. 2: French radar network. The radius of the circles is 100 km and the color code corresponds to the different radar types.

3.2 *Concept*

In the ALADIN data assimilation scheme, interpolation of variables from model space (model levels) to radar space (beam center) is part of the observation operator. The interpolation is performed for each elevation angle separately. Currently, a Gaussian-shaped radar beam is assumed when it comes to vertical interpolation of model variables. Furthermore, it is assumed that the radar beam propagates according to standard conditions (no AP). Figure 3 illustrates the vertical interpolation with and without beam blockage. Gauss-weights are computed for all model levels within the beam width (dotted lines). Currently, topographical shielding is not considered, i.e. the vertical interpolation (dashed lines) is always performed within the theoretical beam width (black circles). This is justified for flat regions (in Fig. 3 at 60 km), but in mountainous regions the interpolation might consider model levels which are not visible by the radar (in Fig. 3 at 80 km). By using BPM's visibility maps for standard propagation the vertical interpolation becomes more realistic where the radar beam is partly blocked (red solid line; beam blockage is 19.55%). In this case the lower integration limit is lifted to the lowest visible height at that azimuth and range (red circles) while the weights remain untouched.

To simulate the visibility at a specified elevation angle BPM needs the topography in observation space, namely the radar grid. It can be derived from the NWP model

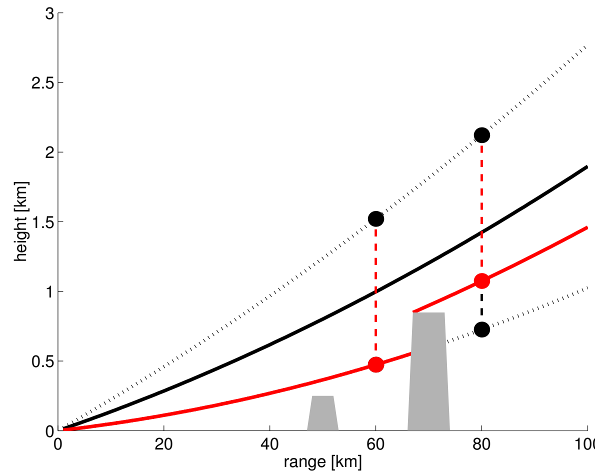


FIG. 3: Vertical interpolation from model to radar space (along dashed lines). The black solid line corresponds to the beam center while the dotted lines mark the beam width of the unblocked beam. The red solid line defines the actual visibility at this elevation angle assuming atmospheric standard conditions. The circles indicate the integration limits used in the vertical interpolation for the blocked (red) and unblocked beam (black), respectively.

(AROME) itself or from an external data base (like the US Geological Service DEM GTOPO30 or the French DEM used for creating maps of partial masks). We started with the first alternative and simulated visibility maps for Sembadel radar (sect. 3.3). These are static and rigidly coupled with the radar product to be assimilated, i.e. any changes in the product definition or the radar position will have an impact on the visibility maps.

3.3 *Case study*

The C-band radar in Sembadel has been manufactured by Gematronik and is in operation since 1996. Its antenna is located at 45.29°N latitude, 3.71°E longitude and 1141 m asl altitude (Fig. 4). The half power beam width is 0.9°.

Figure 5 depicts BPM's simulated visibility (as defined in sect. 2) for Sembadel radar at 0.4° elevation angle assuming atmospheric standard conditions. AROME's topography has been interpolated to the radar grid using a semi-Lagrangian approach. Note that the topography covers only partly the radar measurement domain due to NWP model set-up. At this time AROME has been run only on small domains for computational cost reasons, but currently it is running on a domain covering France. The visibility heights simulated by the BPM will be applied to adjust the integration limits used for the Gaussian-weighted vertical interpolation of the AROME model levels to the height of the beam center (sect. 3.2).

Figure 6 shows the simulated degree of beam blockage for Sembadel radar at 0.4° elevation angle assuming atmospheric standard conditions. There are basically two

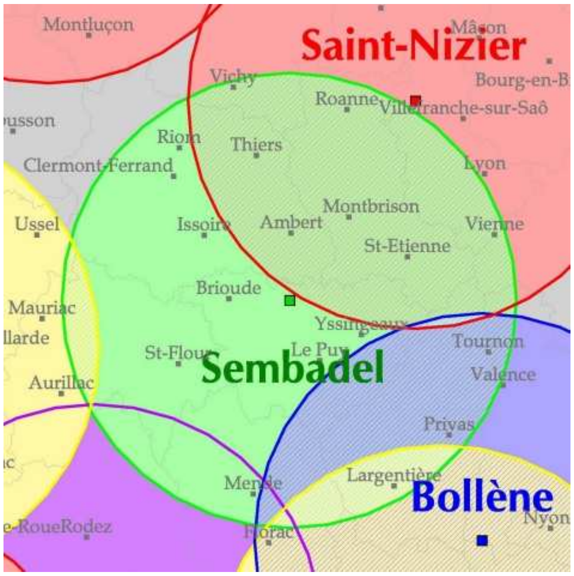


FIG. 4: Measurement range of Sembadel radar. The circles correspond to a radius of 100 km.

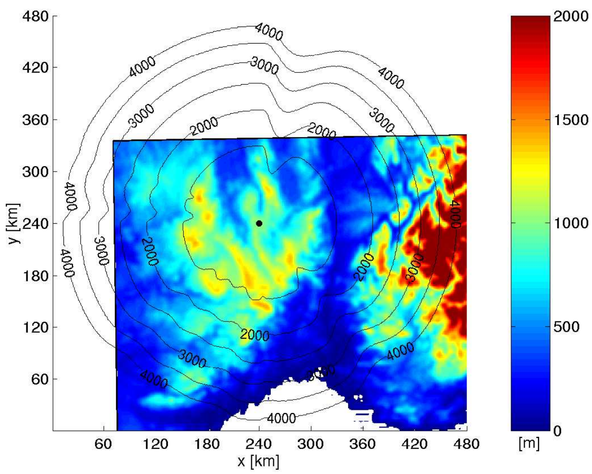


FIG. 5: Sembadel radar (black circle): contour lines of simulated visibility (as defined in sect. 2) at 0.4° elevation angle assuming atmospheric standard conditions. AROME's topography in observation space (colored) covers only partly the radar measurement domain.

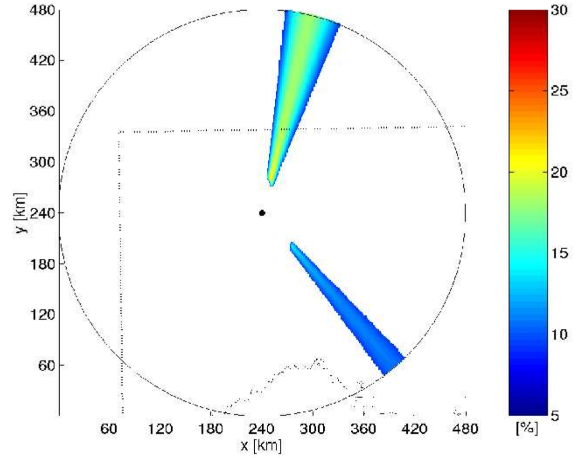


FIG. 6: Sembadel radar: simulated degree of beam blockage at 0.4° elevation angle assuming atmospheric standard conditions (white color indicates blockages below 5%). AROME's topography in observation space covers only partly the radar measurement domain (dotted line; see also Fig. 5).

blocked sectors which correspond to the reduced visibility in Fig. 5. The one in NNW direction has a maximum blockage of approximately 20%.

It is expected that the suggested modification of the observation operator will have a positive impact on the ALADIN 3DVar data assimilation system and furthermore will improve short range weather forecast at mesoscale. Currently, the visibility maps are static. To consider AP in a consistent way BPM has to be run with atmospheric profiles from AROME.

4. SUMMARY

The assimilation of weather radar measurements into NWP models benefits from advanced quality information. A beam propagation model (BPM) has been used to simulate the visibility of the French radar Sembadel assuming atmospheric standard conditions. This information will be applied to adjust the integration limits used for the Gaussian-weighted vertical interpolation from the AROME model levels to the height of the beam center. The impact of the suggested modification of the observation operator on the AROME forecasts will be evaluated this summer.

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