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IMPLEMENTATION OF THE EHIMI SOFTWARE PACKAGE IN THE WEATHER RADAR OPERATIONAL CHAIN OF THE CATALAN METEOROLOGICAL SERVICE

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1. INTRODUCTION

This paper gives an overview of the performance in an operational environment of the EHIMI system (Hydrometeorological Integrated Forecasting Tool), a software package designed to correct radar observations in real time for its use in hydro-meteorological applications.

The EHIMI system has been developed during the last years by the Applied Research Group in Hydrometeorology (GRAHI) of the Polytechnic University of Catalonia and implemented operationally in collaboration with the Catalan Meteorological Service (SMC, Meteocat) through a collaborative project funded by the Catalan Water Agency and the SMC. Processing and corrections of the EHIMI tool deal with ground clutter echoes, topographic beam sheltering, bright band, convective identification and attenuation by rainfall.

In this paper several precipitation events are used to illustrate the corrections and details of the operational experience and performance of the EHIMI tool.

A discussion about the benefits of the EHIMI corrected observations, current applications, and future developments related to the improvement of radar Quantitative Precipitation Estimates (QPE) are also provided. Moreover, a description is given of the reingestion of corrected radar products in the Sigmet IRIS software operational at SMC and the updated modular structure of the EHIMI system.

In particular, topics covered include a new warning module which details the geographical areas where previously defined precipitation thresholds are reached and a hydrological module fed by radar and rainguage observations.

2. THE EHIMI MODULAR STRUCTURE

The EHIMI system has evolved in the last years from earlier versions (Sanchez-Diezma *et al.,* 2002) to a modular structure. EHIMI aims to cover the full chain of processes involved in the hydrometeorological exploitation of weather radar systems. To fulfill all these aspects the EHIMI package has been modular divided in four basic types of applications:

- XRad, GenRad: devoted to all aspects related with the weather radar processing and correction algorithms for the Quantitative Precipitation Estimates (QPE), and the generation of rainfall and meteorological radar based products.
- MoViRad and AniPRad: tools designed for the visualization and animation of radar products.
- GenHi: main module devoted to integrate radar rainfall estimates into an hydrological distributed model to produce forecasted water levels and other distributed hydrological products.
- MoVHi: tool designed for the visualization and animation of hydrological products.

The modular design has been a key point for the success of the current implementation of EHIMI in the Catalan Meteorological Service (SMC) and the Catalan Water Agency (ACA). Figure 1 shows the current running scheme of EHIMI at both SMC and ACA. The essential aspects are as follows:

- An XRad module monitors a set of GenRads modules that apply the chain of radar correction-products for each of the radars of the network (an specific GenRad is applied

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for a virtual radar in order to generate the composite products).

- A GenHi module produces the hydrological products for a series of basins (currently the model has been adjusted to two intermediate size basing surround the Barcelona area of approximately 1000 km^2).
- Visualization Modules (MoViRad, AniPRad, MoVHi) are installed in Pc-sites to support the different activities of the SMC and ACA offices (forecasting and warning, routinely check of hydrometeorological product, visualization and analysis of historic events, etc.). Institutional clients also use the visualization modules to consult specific products.

A more detailed description of the characteristics of these modules is provided en the next sections.

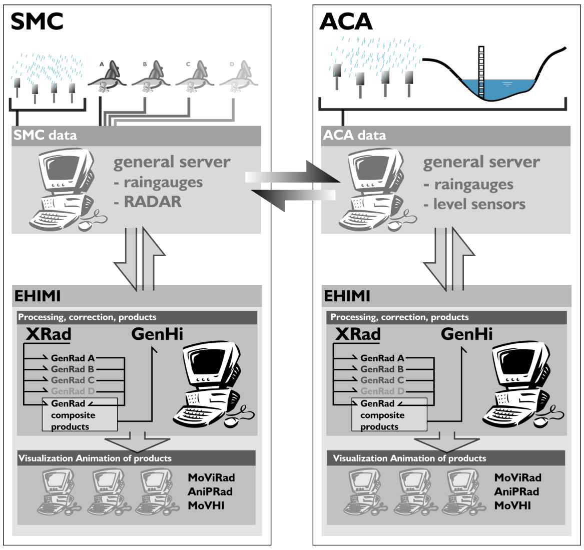

Figure 1. Schematic illustration of the current implementation of EHIMI modules at ACA and SMC.

3. THE XRAD-GENRAD MODULES

Figure 2 summarizes the main corrections and products included in the GenRad module (the XRad module is basically devoted to launch and check the performance of each GenRad module).

The correction algorithms currently implemented are related with the following aspects:

- Correction of radar rainfall measurements stability using mountain returns (Sempere-Torres *et al.*, 2003). This procedure provides a general factor of correction (in dBZ) by comparing the distribution of average and current ground clutter echo maps.
- Interpolation of lost azimuths: it enables to fill small sectors not scanned by the radar.
- Orographic corrections: which involves radar orientation errors and screening effects (an algorithm based in the simulation of the radar beam interception by the terrain using a DEM is used, Delrieu and Creutin, 1995, Sánchez-Diezma, 2001), ground clutter substitution (Doppler information and a precipitation type based substitution technique are used, Sánchez-Diezma *et al.*, 2001) and removal of contamination due to radar secondary lobes (an algorithm based in the analysis of the vertical reflectivity gradients is used, Bellon and Kilambi, 1999)
- Removal of residual speckles not related with the precipitation (a technique that combines thresholds and the size of the speckles is applied).

Once the corrections are applied the basic chain of products provided are:

- Corrected polar data in IRIS format to re-ingest in the SMC product chain, and Cartesian PPIs for the visualization tools.
- Warning of attenuated areas: the Hitschfeld and Bordan equation (1954) is used to provide a product that warns about areas where a certain path integrated attenuation is exceeded.
- Identification of precipitation types: convective areas (Steiner *et al.*, 1995) and bright band areas (Sánchez-Diezma *et al.*, 2000). Currently a product that presents each type of precipitation is generated.
- Accumulated products (Austin and Bellon, 1974), half an hour moving window, 1h and 24 h accumulations are currently generated.
- Composite products from reflectivity and accumulated products.
- Radar-raingauge combination for 24 h accumulation, based on an average radar-raingauge adjustment factor.
- Warnings: geographical information is used to determine areas where a warning is necessary. A threshold and size of the precipitation inside the area is fixed to

activate the alert. This warning is applied to reflectivity and accumulated products and over different types of regions of interest (political department, cities, airports, etc.).

4. RADAR VISUALIZATION MODULES

Visualization modules (MoviRad and AniPrad) are designed to provide access to different levels of information. Thus several types of users and tasks can take advantage of the tools.

The main characteristics spans from basic radar products (PPIs, precipitation types, composites, accumulations, etc.) to the inspection of 3d radar volumes (reflectivity and Doppler data) and combination of topographic and geographical information and warnings products. Also warnings about quality of some products is graphically provided (radar fail full on composite products or temporal gaps on accumulated products).

5. THE HYDROLOGICAL TOOLS

The hydrological model implemented in GenHi module is DiCHiTop (Corral *et al.*, 2002, Corral, 2004), a semi-distributed model based on Topmodel. In this model, the catchment is split into hydrological square cells where a lumped model is applied.

The runoff generated by each cell is routed to the outlet following a single unit hydrograph process, which is obtained from the definition of a simplified drainage network. Finally, the sum of all cell runoffs provides the total discharges at the outlet.

Two models are selected to reproduce the rainfall-runoff transformation at cell scale, depending on the degree of urbanization. In rural cells, an adaptation to Mediterranean basins of Topmodel is used and the Soil Conservation Service loss function is applied in highly urbanized cells.

The model is currently implemented in two basins providing distributed runoffs in cells of 1 km^2. Both basins are under the view of three C-band radars of the SMC network at distances below 100 km.

The basins are covered by several raingauge networks (an average of one tipping bucket type raingauge each 150 km^2) operated by ACA, and SMC. Several stage sensors managed by the ACA also cover both basins.

Hydrological products resulting from the GenHi module together with the raingauge and stage sensors information are visualized by the MovHi module.

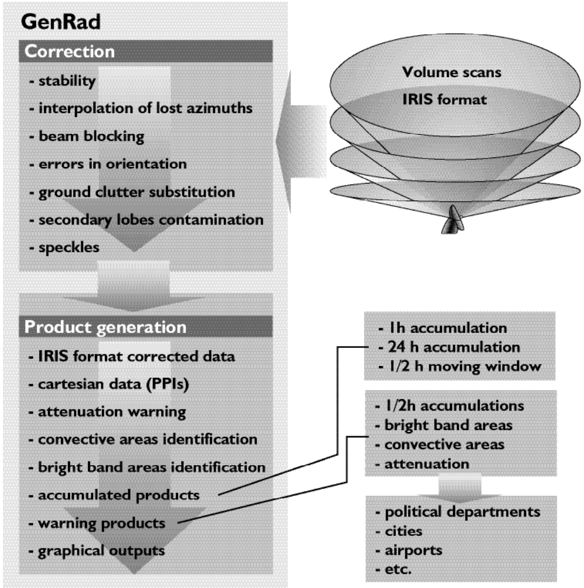

Figure 2. Chain of corrections and radar products currently produced by EHIMI system.

6. TWO CASE STUDIES

In order to illustrate the use of the EHIMI system two precipitation events are briefly commented in this section.

Case 1: 17th August 2003

The first case study is illustrated using observations of the Puig d'Arques radar (PDA). The event took place during the summer season, the 17th of August 2003. It may be appreciated that convective cells showed important vertical development, with altitudes often exceeding 8 km (Figure 3).

Moreover, convection was also organized linearly in a squall line structure that crossed the region from the SW to the NE over the coastal and pre-coastal area of Catalonia (NE Spain).

In Figure 4 the performance of the EHIMI clutter corrections are demonstrated. Both ground and sea clutter are eliminated producing a rainfall pattern with a much more consistent appearance. In particular, low intensity spurious echoes near the radar are correctly eliminated.

However, another low intensity echo band (NW of the radar) apparently related to the anvil of the squall line, might be overcorrected.

Case 2: 27th September 2003

The second event used to illustrate the EHIMI capabilities took place in the autumn season (27th September 2003), when most heavy rainfall episodes occur in the Western Mediterranean. The event was characterized by non-organized and shallow convection (Figure 5).

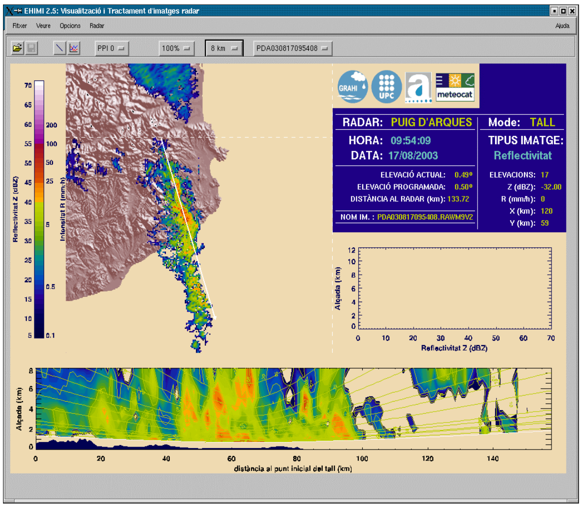

Figure 3. General view of the EHIMI screen. It includes three parts: PPI view (top left); image details (top right) and cross section above topography (bottom). Observations were collected the 17th of August 2003 9:54Z with the PDA radar.

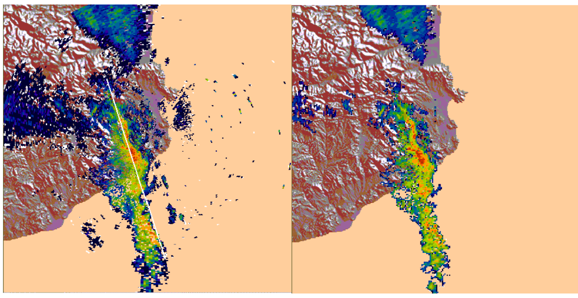

Figure 4. Uncorrected (left) and corrected (right) PPI collected the 17th of August 2003 9:54Z with the PDA radar. Corrections include clutter cancellation and substitution and orographic beam blockage.

Rainfall fell over the whole Catalan region, but affected mostly the central coastal area. It caused some local floods around Barcelona city and increased significantly flows in some nearby catchments.

These effects did not correspond to specially appealing radar echo structures, causing some problems in the early detection of the event during the surveillance tasks. In this event the EHIMI convective and bright band detection products performed mostly correct. However, in some isolated cases results were slightly confusing.

For example, in Figure 6, some tiny areas were identified as convective, though it is unclear from their pattern. Moreover, a bright band was apparently detected but again its strange pattern seems to indicate a false alarm and, therefore, a wrong detection. These effects might be caused by problems in the data acquisition, in particular, in the elevation angles of some observed radar rays, which differ slightly from their nominal value. The attenuation product of the EHIMI system (Berenguer *et al.*, 2002) depicted clearly some interesting features of the event, as observed by the PBE radar (Figure 7). Though during this rainfall episode echoes were not very intense, C-band attenuation had significant effects along some radials (for example in the N-NW directions).

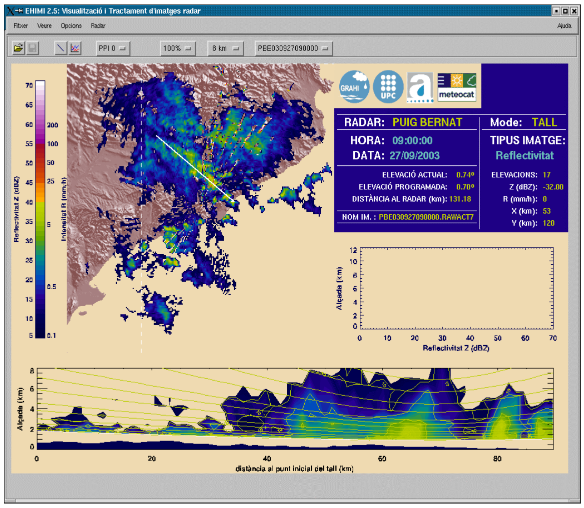

Figure 5. General view of the EHIMI screen. Observations were collected the 29th of September 2003 9:00Z with the PBE radar.

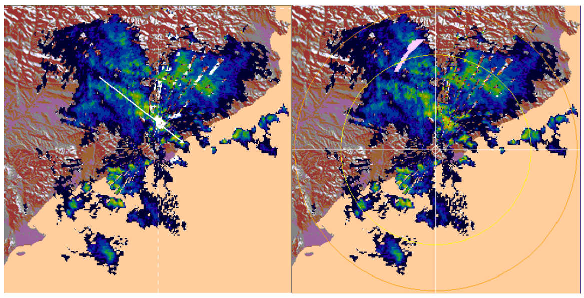

Figure 6. Convective areas detection (left) and bright band detection (right). White echoes indicate detected areas. Observations collected with the PBE radar at 9:00Z 29th of September 2003.

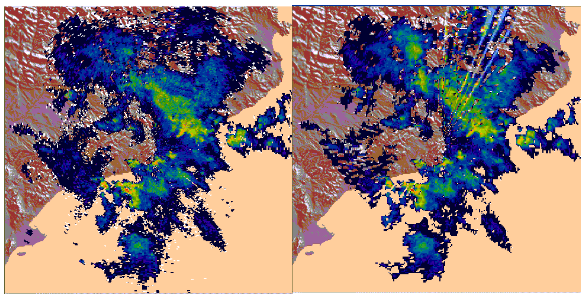

Figure 7. Original PPI radar image (left) and attenuation detection and correction product (right). White echoes indicate heavily attenuated areas. Observations collected the 29th of September 2003 9:00Z with the PBE radar.

7. THE PRECIPITATION WARNING SYSTEM

The Catalan Meteorological Service has among its responsibilities issuing severe weather warnings to Civil Defense administrative authorities of Catalonia.

Several heavy rainfall thresholds are considered in the current warning system, consisting of high rainfall rates potentially associated to flash floods. In particular a threshold of 20 mm is set for temporal periods of thirty minutes. A specific module of the EHIMI tool has been programmed to highlight the counties of Catalonia where this threshold of cumulated rainfall was overpassed (Figure 8).

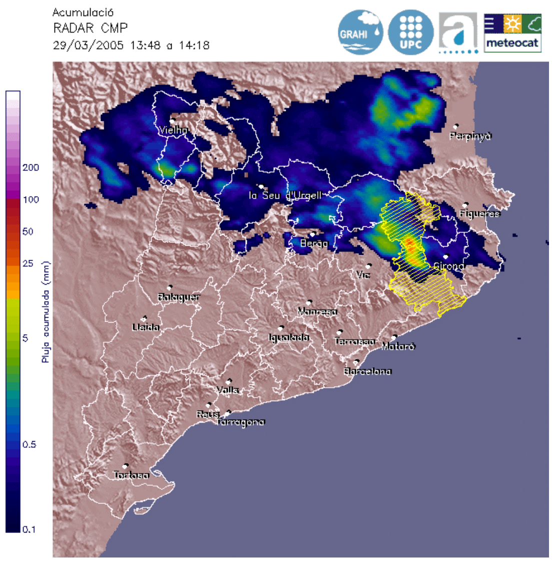

Figure 8. SMC radar composite showing thirty-minute radar QPE and highlighted areas indicating zones with rainfall rates above 20 mm in thirty minutes.

In this section a comparison between composite observations obtained with the SMC radar network (Bech *et al*., 2004) and rain gauge records of events overpassing 20 mm in 30 minutes is given. Nineteen events that took place between April 2004 and May 2005 were considered in this analysis.

A preliminary result of the events showed a general tendency of the radar QPE to underestimation: 42% of the cases were not detected in the radar composites. This was an expected result taking into account that several corrections such as VPR or attenuation correction (which may increase radar QPE values) are not still applied operationally. On the other hand, it should be noted that a static ground clutter mask was applied in the areas not covered by Doppler measurements and, due to frequent anomalous propagation events (Bech *et al*., 2003), this might also contribute to increased radar QPEs in some areas. This effect is most noticeable over the sea and though does not affect particularly this analysis (focused on gauges located over ground) it is particularly challenging for verifying Numerical Weather Prediction precipitation forecasts over the Mediterranean Sea.

It was also noted that in cases where all three radars of the network were available the radar could issue correctly the warnings while the composites made up only with one radar caused 66% of the non-detected warnings, which were observed by the gauges.

Besides, some of the cases examined –as the second example presented in the previous section– were associated to relatively low and moderate convection but highly efficient precipitation mechanisms, which usually are underestimated by radar observations (Martín *et al.* 2001). Moreover, a single standard Z-R relationship has been considered in the radar images, a fact which also may contribute negatively as shown by previous studies performed in the region (Rigo and Llasat, 2002).

Another factor to be considered is the orographic enhancement of precipitation. This effect is not modeled in the radar QPE and 50% of the raingauge-based warnings were observed in stations located at more than 500 m asl.

8. SUMMARY AND CONCLUSIONS

An overview of the EHIMI system, a software system to correct radar data in real time to provide hydrometeorological quantitative applications capabilities, has been given in this paper.

Processing of the EHIMI system includes clutter and orographic beam blockage corrections, convective, bright band, and attenuation identification and correction, addressing the major problems, which limit radar data quantitative applications. The system, deployed by the GRAHI-UPC group and implemented operationally in collaboration with the Catalan Meteorological Service and the Catalan Water Agency is currently under development.

Future improvements of the EHIMI system will involve better ground clutter identification and substitution (Berenguer *et al.* 2005b), improvement of the precipitation types identification (Franco *et* al. 2005), and radar-raingauge merging (Velasco-Forero, *et* al. 2005). Also new products as Vertical Reflectivity

Profile correction (Franco *et* al., 2004) and short-term radar based rainfall forecast (Seed, 2003, Berenguer *et al*. 2005a) are foreseen in order to enhance not only current radar QPE capabilities but also to support operational nowcasting tasks.

This is particularly important to complement other surveillance and very short term forecasting techniques and studies carried out in the Catalan Meteorological Service, such as those based in satellite images (Veciana et al. 2003) or combining radar and lightning observations (Pineda et al. 2004).

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