Assessment and quantification of meteorological data for implementation of weather radar in mountainous regions

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सार – इस पत्र के दायरे अवलोकन और ग्रेनोबल क्षेत्र में जल-मौसम वैज्ञानिक खतरा जो ऊंचाई और भू-आकृति विज्ञान में इलाके की महत्वपूर्ण परिवर्तन की विशेषता है का पता लगाने में सुधार है। Grenobleis के सिटी, 500 मीटर अप करने के लिए 200 के बीच ऊंचाई पर स्थित ऊंचाई की इस श्रृंखला में मौसम रडार स्थापित करने के लिए बेहतर गुणवत्ता माप की ओर जाता है, लेकिन दृश्यता और अच्छी तरह से कवरेज क्षमता के रूप में रुचि इस क्षेत्र के अन्य स्थलों पर कम हो जाएगा। दो साइटों ग्रेनोबल में भविष्य के मौसम रडार के कार्यान्वयन के लिए चुना जाता है; (I) Moucherotte (1920 m a.s.l.) और (ii) सेंट Eynard (1365 m a.s.l.)। कई सिमुलेशन और डेटा विश्लेषण के क्रम में कुछ जमीन स्टेशनों और रेडियो लग डेटा के रूप में अच्छी तरह से मौसम संबंधी आंकड़ों पर विचार करके वर्षा परिवर्तनशीलता के बारे में स्पष्ट चित्र प्राप्त करने में प्रदर्शन कर रहे हैं। पिछले काम की तुलना में, इस अध्ययन में वर्षा के ऊर्ध्वाधर संरचना के जलवायुविज्ञानशास्त्र माना जाता है। इस संदर्भ में, कई सांख्यिकीय गणनाओं 0 डिग्री सेल्सियस इज़ोटेर्म ऊंचाई के मामले में किया जाता है। वर्षा त्रुटि का आकलन, जमीन अव्यवस्था और स्क्रीनिंग प्रभाव के संदर्भ में, VISHYDRO कोड का उपयोग करके सांख्यिकीय गणनाओं, द्वारा विभिन्न quintiles के लिए कई ऊंचाई कोण के लिए दोनों छांटे साइटों में प्रदर्शन कर रहे हैं। दोनों साइटों पर प्रदर्शन संगणना से प्राप्त परिणामों के लगभग similar.In इसके अलावा, महत्वपूर्ण तहत और अधिक अनुमान वर्षा त्रुटि के स्क्रीनिंग और जमीन अव्यवस्था प्रभाव के कारण का पता चला रहे हैं। आदेश में और अधिक सटीक परिणाम अन्य साइटों, आगे अनुकरण के लिए परीक्षण किया जा करने के लिए दूसरी ओर की जरूरत है, क्योंकि जमीन अव्यवस्था और Moucherotte पर स्क्रीनिंग प्रभाव सेंट Eynard के साथ बहुत अधिक तुलना नहीं है को प्राप्त करने के लिए, इस साइट भविष्य मौसम रडार को लागू करने के लिए विचार किया जा सकता है ग्रेनोबल क्षेत्र पर मौसम संबंधी प्रक्रियाओं के अवलोकन के लिए।

ABSTRACT. The scope of this paper is to improve observation and detection of hydro-meteorological hazard over the Grenoble region which is characterised by significant changes of terrain in altitude and geomorphology. The city of Grenoble is located at a height between 200 up to 500 m, installing the weather radar in this range of elevation leads to better quality measurements, but visibility and as well coverage capability will be reduced at the other sites of the affected region. Two locations are shortlisted for the implementation of the future weather radar in Grenoble; (*i*) Moucherotte (1920 m a.s.l.) and (*ii*) Saint Eynard (1365 m a.s.l.). Several simulation and data analysis are performed to get the clear picture about precipitation variability by considering meteorological data from individual ground stations and radio sounding data as well. Compared to previous work, in this study is considered climatology of the vertical structure of the rainfall. In this context, several statistical computations are done regarding 0°C isotherm altitude. Concerning rainfall error estimation, ground clutter and screening effect, statistical calculations by using VISHYDRO code, are performed by for different quintiles for several elevation angles in both shortlisted sites. The results obtained from calculations carried out on two locations are almost similar. Also, significant under and over-estimation of rainfall error due to screening and ground clutter effect are detected. To achieve more accurate results, other sites need to be tested for further simulation. On the other hand since ground clutter, and screening effect at the Moucherotte is not too high compare with Saint Eynard, this site may be considered for implementing the future weather radar for observation of the meteorological processes over the Grenoble region.

Key words – Floods, Grenoble, Ground clutter, Convective rainfall, Stratiform Rainfall, Screening effect, Rainfall, Weather radar.

1. Introduction

Measurement of hydro-meteorological parameters is a crucial task. Origin of hydro-meteorological measurements is found since early civilisation. Analysis of precipitation is an essential work for different purposes, for instance, estimation of horizontal precipitation has an importance on evapotranspiration process from earth

surface which indicates a global atmospheric cycle, (Hannesen, 2001; Herron *et al*., 2014; Kalma *et al*., 2008). Different stakeholders need information about precipitation. Farmers needs information about precipitation to control agriculture device or to optimize farm usage, on the other hand, hydrologists need that data to consider as input for rivers stage forecasts, flood warnings or waste water flow regulation (Dile and Srinivasan, 2014; Ochoa *et al*., 2014; Samui *et al*., 2004). Moreover, we can state that precipitation amount; rainfall variability has a major role and significant impact on properties and human life. From the past events it is known that origin of a different kind of natural hazard, especially floods are due to heavy rainfalls, (Cifelli *et al*., 2012; Selenica *et al*., 2011). So accurate observation, prediction and estimation of hydro-meteorological parameters is the most important step to prevent human life from significant damages that may be caused by natural hazards.

Measuring of the precipitation as we mentioned above, has begun earliest starting from 1441 when King Sejong and his son. Prince Munjong has been the first that invented and standardised rain gauge stations and next are Sir Christopher Wren, who developed the mechanical self-emptying tipping bucket rain gauge (Chun and Jeon, 2005; Biswas, 1967). This type of rain gauge is still continued to be used for rain measurements at most home weather stations. Measurements done by using these type of instruments provides useful information about precipitation amount, quality of precipitation and so on, but still the information is restricted. The information about precipitation obtained by these primary rain gauge stations cannot be valid for the vast area since there is 2 type of precipitation : (a) convective and (b) stratiform. According to (Gianfranco *et al*., 2012; Wagener and Gupta, 2005) estimation of rainfall from the radar is not an easy process, since there are several sources of errors where most of them are due to the environmental context. In the presence of complex terrain, characterised by hills and mountains, rain rates estimation is a complicated process, (Singh *et al*., 2014; Hunink *et al*., 2014; Biju *et al*., 2008). In such circumstances, the primary sources of error in radar rainfall estimation are mostly due to the ground clutter contamination, partial or total beam shielding, and vertical variability of reflectivity (VPR). While according to (Zhang *et al*., 2012) the VPR profiles in relation with errors occurred during data acquisition from the radar, depend on mostly from vertical gradients of reflectivity and also from a height of the lowest and unblocked radar beams. So it is stated that, if the beams are near the ground or, if the vertical variation of reflectivity within and below the lowest beams is zero, then the radar error associated with the VPR profiles would not be taken into account. So reflectivity

observations are adjusted based on the parameterized VPR. Also, calibration error does not impact the VPR. Related to the type of rainfall (*i.e*., convective or stratiform), the convective rainfall can be identified when the bright band is not clearly detected, and the VPR reveals apparent features of stratiform precipitation when the bright band is clearly detected (Cao *et al*., 2013).

Terrain effect is mostly evident during the spring since the melting layer is still not too high in altitude from the terrain surface while during the summer period because of the distance of melting layer is several kilometres above the surface, the ground effect will be decreased with increasing the altitude of melting layer. If we have a look at the experience of other country concerning to the weather radar implementation, it is concluded that for instance, in the United States of America there is done significant improvement on weather radars by achieving accurate information on precipitation and storm monitoring, (Robert *et al*., 2002). The primary purpose of the study performed by authors above is to estimate the radar coverage on the mountain region or in generally on the area characterised by the significant diversity of terrain, like in our case. The study that we are talking about is done on a particular part of the United States of America, which as we mentioned above is characterised by diverse terrain, the weather radar is tested for different elevation angle. So during the trial for various elevation angles is deduced that data received from radar in low elevation angle are not clear enough because of a mask (*i.e*., screening effect) of the terrain (*i.e*., mountains). So after several tilts of radar elevation angle is concluded that optimised elevation angle of the radar is between [1.45° - 2°]. In this range, an excellent coverage of particular region from the radars is achieved, but also this depends on from the positioning and altitude of the weather radar. So from here it is concluded that by using this range of tilting elevation angle, we have to play with altitude location of the radar to improve the quality of measurements retrieved from the weather radar. Another research done by (Jonathan *et al*., 2009) in complex terrain is in relation with evaluation hourly radar rainfall estimation due to optimising the parameters in the reflectivity to rainfall (*Z-R*) relationship. Correcting for the range dependence, in estimating rainfall (*R*) due to the vertical variability of (*Z*) in snow and melting-layer. In this case, author's effort to improve low-altitude radar coverage by merging rainfall estimated from two research radars, operating at different frequencies and polarisation states. After several computation authors of this study state that, the effectiveness of the radar calibration depends on the optimisation of relation reflectivity to rainfall (*Z-R*). Also, it is noted that results obtained from radars in low or middle altitude are better to compare the performance in higher altitude. Hydrological prediction

and forecasting can be considered as the one of the most important task in weather radars operation (Newman *et al*., 2014).

As mentioned above the primary source of a potential flood are extreme events as the result of rain. About this issue, different studies are performed to demonstrate the effect of rain on stream flow rate. In this context, a study done by (Borga, 2002; Isotta *et al*., 2013; Saad *et al*., 2015; Glaser and Stang, 2004; Josephine *et al*., 2014), indicate that weather radar improves apparently the results, by increasing the simulation efficiency up to 30%. In other words, the aim of these studies performed by the authors above is to assess the impact of errors in the weather radar in relation with rainfall-runoff modelling due to the vertical profile of reflectivity. The author has performed several simulations, by considering data received from rain gauge network and weather radars. After comparison, results indicate that lower radar scans reveal a simulation efficiency of 0.75 while for higher radar scans efficiencies are lower. According to the results obtained, authors suggest the radar as close as possible to the ground. So implementing the radar closer to the ground (*i.e*., lower or middle altitude) can provide us better information about meteorological data for given area but on the other hand effect of ground clutter is high. Scatter from ground clutter targets, reduce the quality of information received by the radar, ground clutter is categorised as either normal propagation (NP) clutter or anomalous propagation clutter (AP) (Hubbert *et al*., 2009). There are different ways to categorised clutter mitigation, actually for operational radar are three reduction levels: (*i*) radar design and physical placement, (*ii*) clutter filtering and (*iii*) post processing of the integrated radar moments and products for clutter censoring.

Water is used for multipurpose such as water supply, hydrological risk, hydropower, irrigation, and tourism, so in this context is crucial also to have a good understanding of the long-term hydrological process (Delrieu *et al*., 2009; Smarty and Moore, 1991). The need for better understanding of hydrological models leads to a more difficult prediction of water balance component. So in these circumstances weather radar provides the unique solution to characterised rainfall variability in given space and time (Tang *et al*., 2014). Weather radars are very necessary due to significant information that we are retrieving from them concerning to different hydro-meteorological parameters. Therefore, we should be aware of some issue like; the bright band effect that radar is facing during operation. Better understanding of processes that happening in melting layer is essential to many remote sensing applications (Heyraud *et al*., 2007; Alexakis *et al*., 2014; Raghavan, 2013;
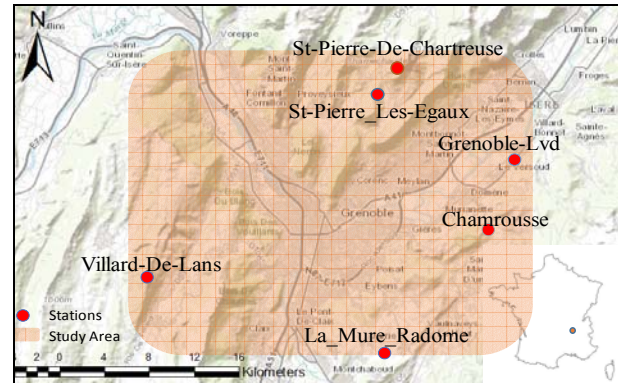

Fig. 1. Representation of study area and ground stations location

Amudha and Raj, 2013). Detailed images of the reflectivity provide us necessary information about variables that characterised precipitation. Another study was done by (Kirstetter *et al*., 2013) concerning the vertical profile of reflectivity, state that is imperative to identify the (VPR's) to correct rainfall estimation. In this study authors has a model the vertical variations of the equivalent reflectivity factor. Vertical model required detailed information about the meteorological process, size distribution, ice density, and morphology and melting layer structure at each height level to accurately simulate radar reflectivity. To describe the atmosphere in different altitude, three different vertical layers are considered: upper layer (ice, solids particles), middle layer (melting zone), and the lower layer (*i.e*., raindrop particles). To have information about melting layer altitude authors in this study have computed the mean 0 °C isotherm altitude; in the zone where most stratiform rains occur. The method performed by the authors of this work (VPR-s identification) is based on simple VPR models, and it is applied on similar type's rain data.

2. Data and methodology

2.1. *Problem statement and data*

The issue discussed in this paper is addressed to the need of weather radar installation in the Grenoble region to forecast precipitation events. The primary duty of this radar will be especial to predict extreme events, which are origin and source of the potential flood, (Alexakis *et al*., 2014; Wheater *et al*., 2005; Singh *et al*., 2011). About flood events, from the past, it is known that there is a significant threat to the social and economic point of view, so installation of the weather radar in the Grenoble region is essential. While, on the other hand, the implementation of the radar is another challenge. The Grenoble area is characterised by the significant diversity of the terrain as shown in (Fig. 2).

Installing the radar on the mountains can be an economical solution because the area covered by the radar is larger than installing more than one radar on the hills, or down part of the region. Therefore installing the weather radar on the mountain failed to provide better information because the altitude of the 0 °C isotherm during the most of the precipitation events is below mountain height. While installing the radar in the down part of the region could provide better information, but the result is somehow restricted only to small areas. So the objective of this study is to solve these challenges and to optimise the implementation of the weather radar in that way, which can provide accurate results and considerable coverage area to avoid installation of several radars on down part of the Grenoble region. It is evident that type of precipitations indicates the vertical profile of the atmosphere. So in this context, it is also performed a study related to the variability of perception within 24 hr for indeed given ground stations, where 76 rainy days with threshold 10 mm are considered to deduce when and in which station stratiform or convective precipitation are more evident. Regarding radio sounding, as we mentioned above, there is considered radio sounding from Lyon. Meteorological data receive from radio sounding are crucial to have an idea about 0 °C isotherm and in generally to investigate the variation of vertical profile reflectivity (VPR). Also, we should be aware of wind direction, so regarding radio sounding, it is drawn wind rose tin order to investigate the direction of wind if it is directed towards our region or not. It is deduced that most of the time wind direction is towards our area that means the same wind at significant percentage effect also our study area, so confidently we can consider meteorological data received from radio sounding Lyon.

2.2. *Methodology*

Implementing the weather radar on a terrain with high diversity is not easy work, in our case we are in the same situation. The Grenoble region as we have mentioned above is characterised by a diverse terrain, so is difficult to define the exact position for implementing weather radar, to have better information about meteorological data for the particular time in given space scale. So our task is to optimise a quality of data received from radar for given time and space. In this context to find out an optimised solution, different strategy and methodology are followed. First of all, it is started with data analysis, which is based on the particular statistical computation of meteorological data received by ground stations in Grenoble and radio sounding Lyon. Concerning to meteorological data received by ground stations in Grenoble as shown in (Fig. 1), the stations that are considered in this study are as following : La_Mure_Radome, St-Pierre-De-Chartreuse,
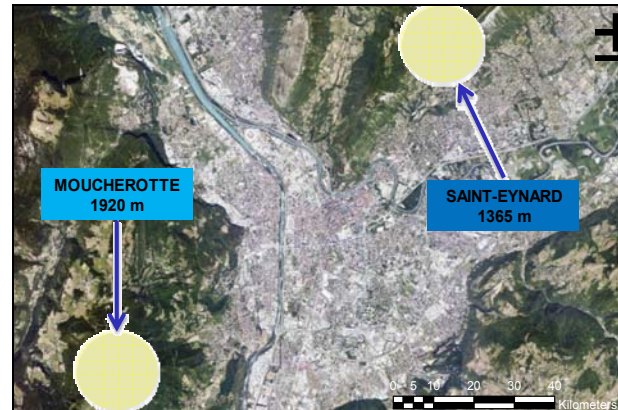

Fig. 2. Location of two shortlisted sites for implementation of future weather radar

St-Pierre_Les-Egaux, Grenoble-Lvd, Villard-De-Lans and Chamrousse. We consider these stations because they are somehow closer to the location proposed for implementing the future weather radar. Also since they are placed in different altitude, we can have significant information about precipitation variability. Except for statistical analysis, we have also performed some other computation regarding vertical profiles (VPRs) modelling. Also by modelling vertical profiles (VPRs) we can have an idea about reflectivity (Wattrelot *et al.*, 2013). Performing the physical simulation; implementing the radar on different location and to wait months or maybe years to judge the quality of data received from radar for these various areas it cost time, money and is not beneficial at all. So in this context researcher from "LTHE" laboratory has developed tools called VISHYDRO to perform the certain simulation. So two sites (Fig. 2) are shortlisted for the future weather radar Grenoble; Moucherotte (1920 m a.s.l.) and Fort Saint Eynard (1365 m a.s.l.).

In our study by using VISHYDRO tools are performed several and different simulations regarding ground clutter, screening effects, and rainfall error estimation. After this computation with data received from considered stations, the results are compared to two locations proposed for implementing future weather radar in Grenoble.

2.2.1. *VISHYDRO principle*

As we have mentioned in the beginning, to estimate the interaction between weather radar and terrain (ground clutter and screening effect), the vertical profile of reflectivity (VPR) and rainfall error, VISHYDRO code is used. For simulating interaction between radar and terrain and rainfall error, we have used meteorological data provide from the hydro-meteorological ground station
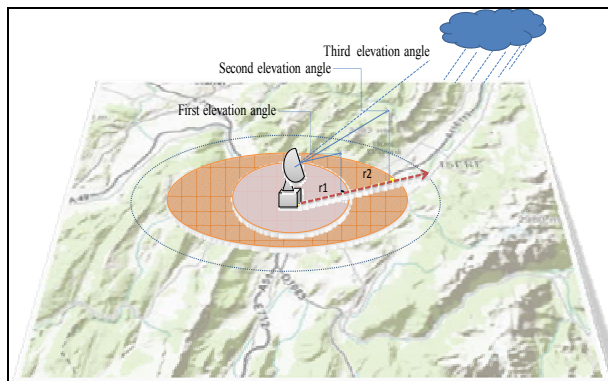
Fig. 3. Working principle of VISHYDRO

Figs. 4(a-d).   Representation of vertical profile of reflectivity (VPR).
(a) Stratiform precipitation (b) Convective precipitation
(c) Bright band achieved at around 1 km altitude
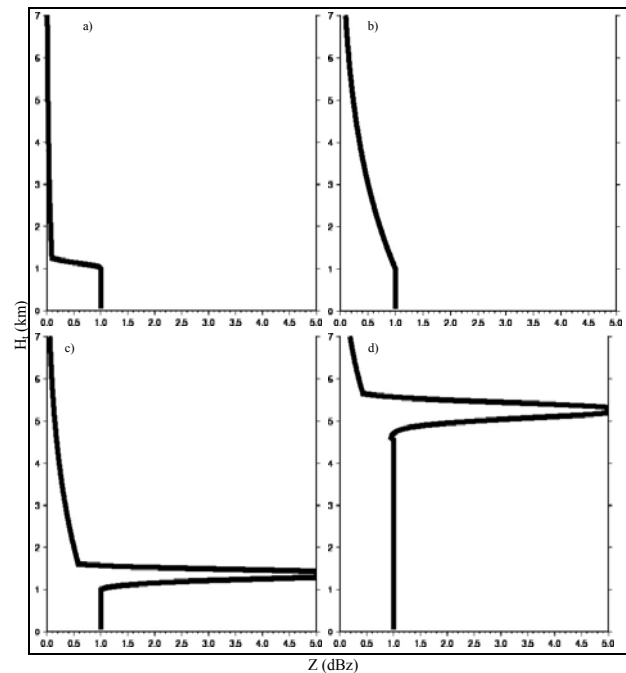(d) Bright band performed at around 5 km altitude

in Grenoble region, which are considered in this study. In this context, are considered 76 rainy days with threshold 10 mm. As we have mentioned above two possible sites are deemed to perform the simulation (Moucherotte, Saint-Eynard). So basically in VISHYDRO code, we have introduced digital terrain (DTM) with 5 km grid resolution (Borga, 2002) and rain amount for 76 rainy days. To optimise the best position, several simulations are performed by changing the elevation angle of the radar as shown schematically in (Fig. 3). While regarding the vertical profile of reflectivity (VPR) meteorological data provide from radio sounding Lyon are considered. Also in this step of our study, several simulations are performed to notice how VPRs changes in altitude (bright band effect formation). Author express the acknowledgment to the Pierre-Emmanuel Kirstetter who has completed the simulation of VPRs.

2.2.2. *VPR modeling*

Having information about the vertical profile of atmosphere (VPR) is crucial because in this way we can have information about the type of precipitation, bright band and so on. In our case since we do not have any weather radar that is implemented already in the affected region, we did not make any computation about VPRs. Below in [Figs. 4(a-d)] are presented some models of VPRs. From the VPR shown in [Fig. 4(a)] we deduce that we have stratiform type precipitation while [Fig. 4(b)] represents the convective type of precipitation. In [Figs. 4(c&d)] is presented VPRs which represents bright band effect achieved in different altitudes.

2.2.3. *Statistical computation of meteorological data from ground stations*

To perform the respective computations, three years measurements   are   considered. With   three   years Measurements, we deduce that there are several events

with different rain intensity, but we are going to consider rain events with a threshold of rain intensity 10 mm, which can provide us significant information about variation of meteorological parameters. Because of geo-location characteristic one of the stations which are given more priority is Grenoble-Lvd (VSD). So regarding this station from certain of data that are presented it is deduced that rainy days with threshold 10 mm is [76 days]. In (Fig. 5) are shown rainfall distribution with different frequencies. Also, determination coefficient concerning to mean daily temperature and variation of temperatures within the altitude is investigated.

From histogram shown in (Fig. 5-I), we deduce that range of daily rain amount is [10.2-55.2 mm]. Also, we see that rain events with the volume of rain between 10-20 mm are more frequently, and rainfall event with the amount of rain higher than 20 mm are less commonly. While in (Fig. 5-II), is presented hourly rain rate, where it is noticed that more often hourly rain rate is range between [1-4 mm]. Another important analysis is to predict 0 °C altitude in connection with daily mean temperature by using regression analysis as shown in (Fig. 5-III). From the (Fig. 5-IV), we see that altitudes up to 2000 m correspond to the temperature less than 10 °C, even that better results of determination coefficient as Shown in (Fig. 5-III), are achieved in a range [10-20 °C].
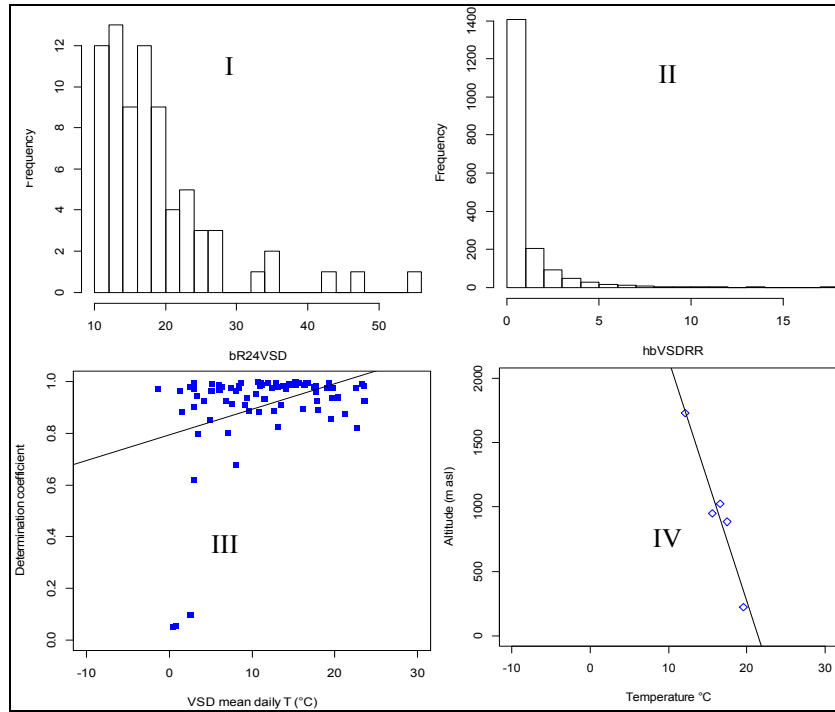
Figs. 5(I-IV). Representation of: (I) Rainfall distribution at VSD (II) Hourly rain rate at VSD (III) Regression quality versus mean T at VSD and (IV) 0 °C isotherm altitude estimation at the daily time step using a regression analysis of the mean daily T as function of altitude
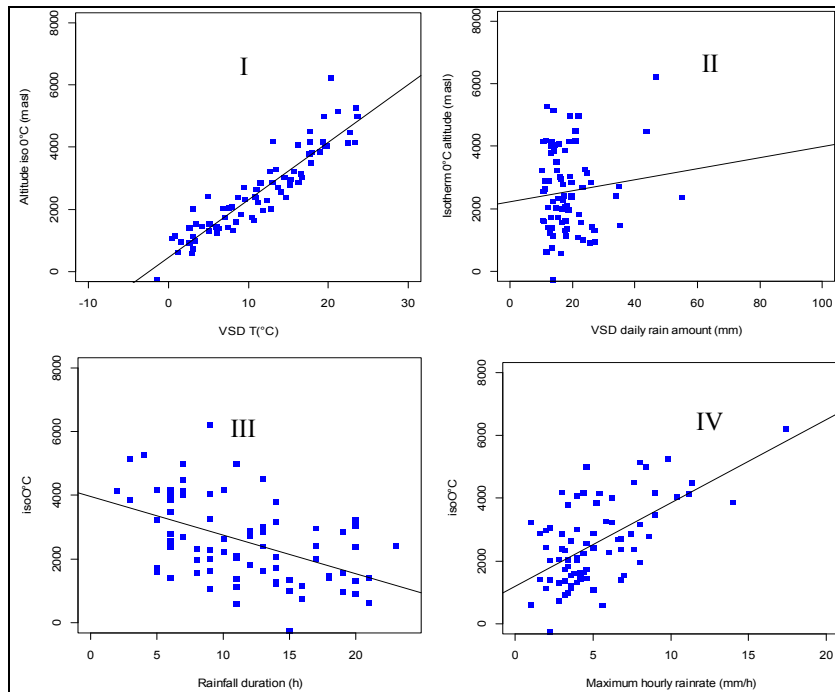
Figs. 6(I-IV). Representation of correlation: (I) iso 0 °C altitude versus T at VSD (II) iso 0 °C altitude versus daily rain amount at VSD (III) iso 0 °C altitude versus rainfall duration and (IV) iso 0 °C altitude versus maximum hourly precipitation rate
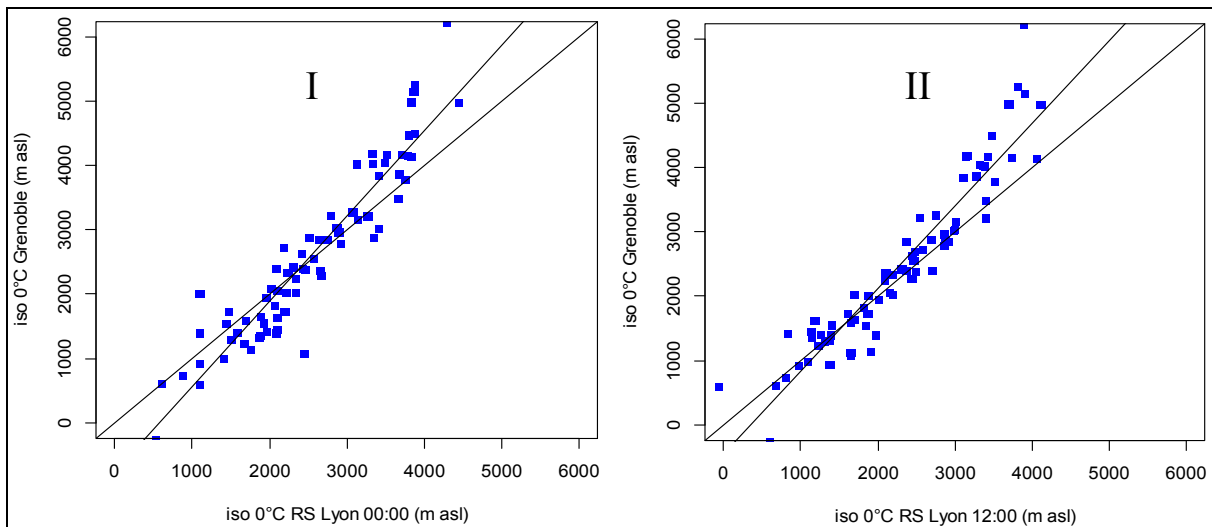
Figs. 7(I-II).   Representation of (I) Correlation means iso 0 °C altitude Grenoble versus iso 0 °C altitude Lyon 00 h TU and (II) iso 0 °C Grenoble versus iso 0 °C Lyon 12 h TU

Also, there is goodness fit between temperature and altitude, which means 0 °C will be reached in proportional with increasing altitude. Several correlation studies are performed to investigate the relation between 0 °C isotherm altitude and meteorological parameters (*i.e.*, temperature, rains). In (Fig. 6-I) is presented a correlation of 0 °C isotherm with temperature and daily precipitation amount at the Grenoble-Lvd station (VSD). Whereas there observed a good correlation between 0 °C isotherm altitude and temperatures, in particular for a range [5-20 °C], there is the real trend. In generally for given value of temperature, there is not high variation regarding 0 °C isotherm altitude, in this context, we can have an idea about the range of temperature for certain different height. On the other hand in (Fig. 6-II) we deduce that correlation between daily rain amount and 0 °C isotherm is not so good, in the range [15-30 mm] there is a significant variation that means given the value of daily precipitation amount is achieved in several different altitudes.

As we see from (Fig. 6-III), there is a significant trend between 0 °C isotherm and rainfall duration, but still, there is not a good correlation. In this case, there is a negative correlation, so it is concluded that when rainfall duration increase, 0 °C isotherm decrease. Also for given period of rainfall there is different of 0 °C isotherm in the range [100-6500 m], probably this change is linked to the type of precipitation. Regarding the correlation between 0 °C isotherm and maximum hourly rain rate, as shown in (Fig. 6-IV) in this case, we have a better correlation. Here we have a positive correlation, both variables are increasing. Also, it is concluded that maximum hourly rain rate is achieved in higher 0 °C isotherm altitude, for instance, 18 mm/h is reached in around 6500 m altitude. While in the range [3-10 mm/h], there is different of maximum rain rate for given height.

2.2.4. *Statistical computation of meteorological data from radio sounding Lyon*

To have information and to investigate what happen in a vertical profile of the atmosphere as we have mentioned above, there are consider also meteorological data received from radio sounding. In the absence of radio sounding in Grenoble, there are considered radio sounding from Lyon. As shown below in [Figs. 7(I-II)] there are performed some other correlation study. In (Fig. 7-I) is presented a correlation between mean iso 0 °C Grenoble versus iso 0 °C Lyon 00 h TU. As we see, there is a real trend but only in the range [2000-3000 m], is deduced a good correlation. While in (Fig. 7-II) is presented a correlation between iso 0 °C Grenoble versus iso 0 °C Lyon 12 hTU. As it is submitted there is the better trend than the first case and also high correlation especially for the range [1000-3000 m]. So from here is concluded that meteorological parameters measured from meteorological station, located in Grenoble are well fitted with meteorological parameters measured from radio sounding Lyon, this is more evident generally during the events that occurred in a first part of the day. On the other hand, during the second part of the day, we do not have the same results, since air mass occasionally moving closer to earth surface, diversity of terrain effect meteorological parameters that characterise both regions.
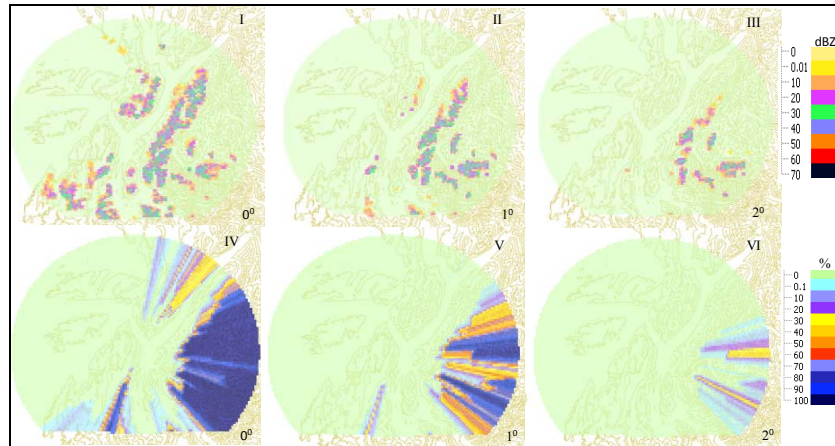
Figs. 8(I-VI).   Representation of (I) Ground clutter for elevation 0° (II) Ground clutter for altitude 0° (III) Ground clutter for altitude 1° (IV) Screening effect for elevation 1° (V) Screening effect for altitude 2° and (VI) Screening effect for altitude 2°
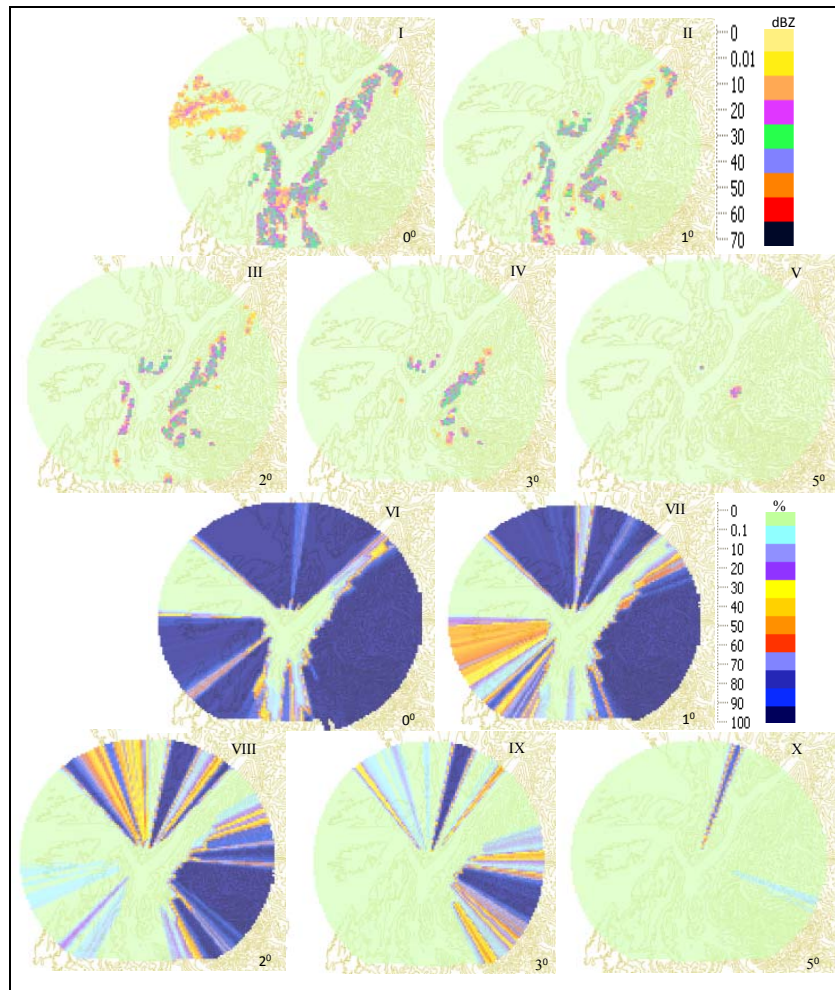
Figs. 9(I-X).   Representation of (I) Ground clutter for elevation 0 °C (II) Ground clutter for elevation 0° (III) Ground clutter for elevation 1° (IV) Ground clutter for elevation 1° (V) Ground clutter for elevation 2° (VI) Screening effect for elevation 2° (VII) Screening effect for altitude 3° (VIII) Screening effect for altitude 3° (IX) Screening effect for altitude 5° and (X) Screening effect at altitude 5°
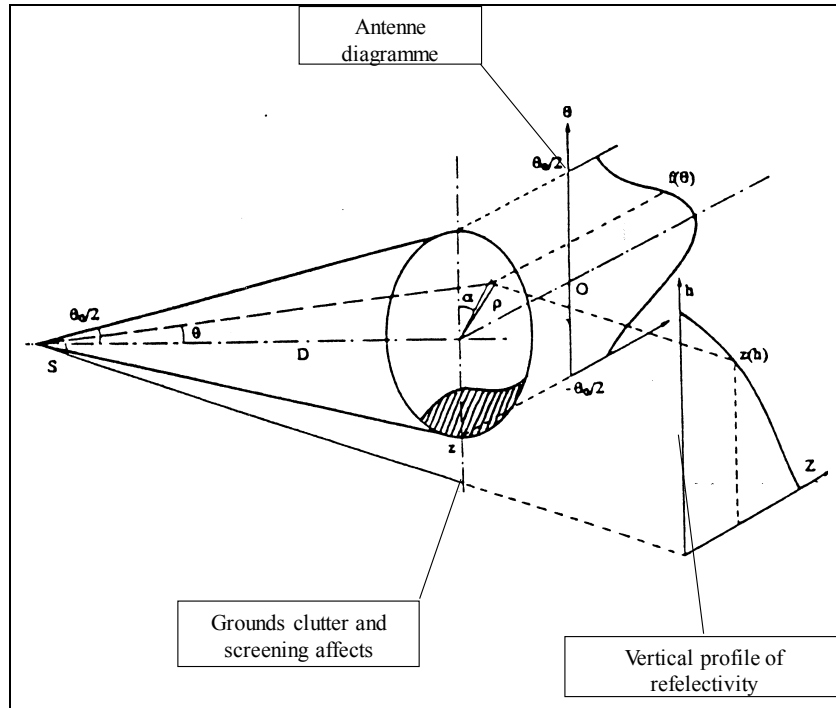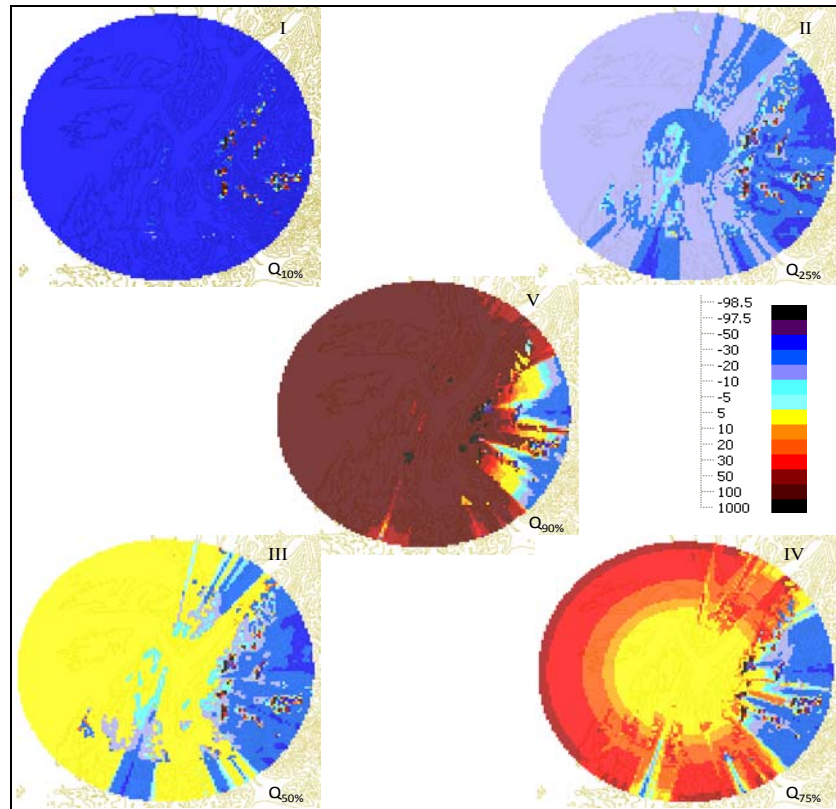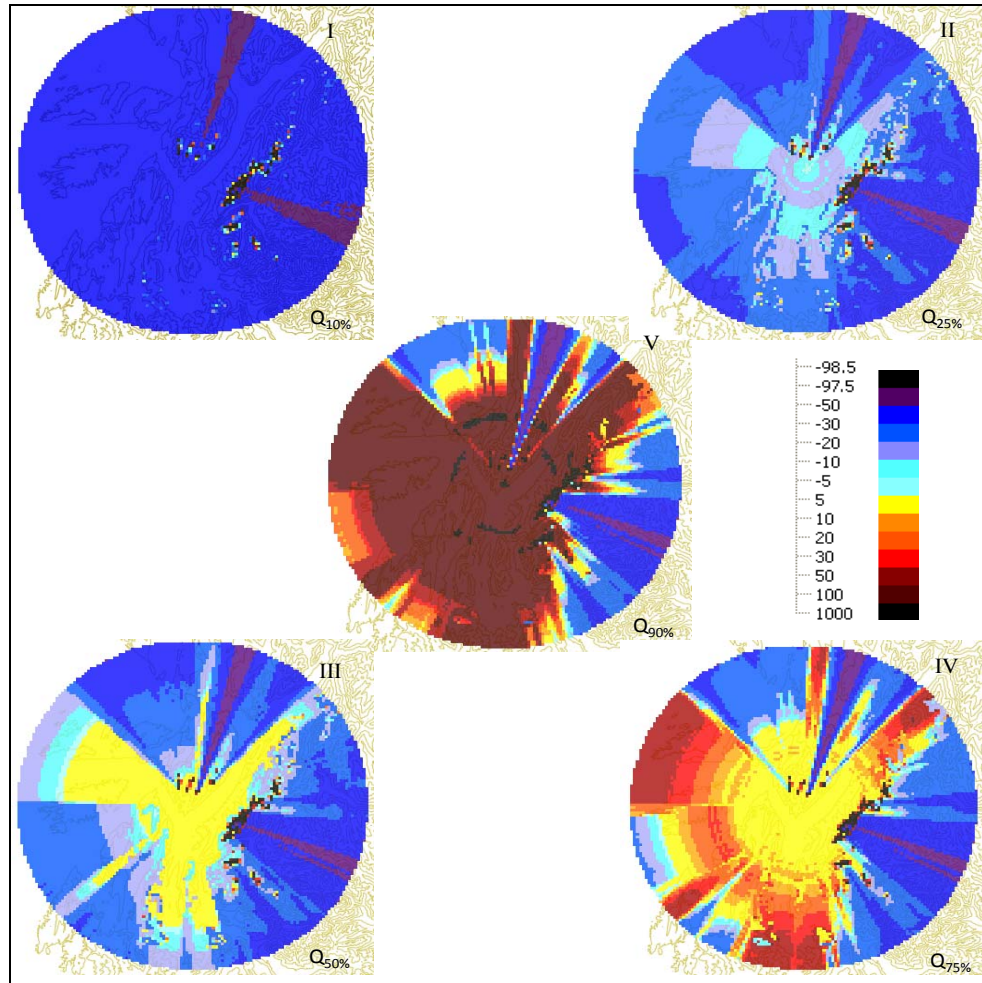
Fig. 10. Quantification of radar rain rate error (Pellarin *et al.*, 2002)

Figs. 11(I-V). Representation of average rainfall error in Moucherotte for different quintiles: (I) $Q_{10\%}$ (II) $Q_{25\%}$ (III) $Q_{50\%}$ (IV) $Q_{75\%}$ and (V) $Q_{90\%}$

Figs. 12(I-V).   Representation of average rainfall error in Saint-Eynard for different quintiles: (I) $Q_{10\%}$ (II) $Q_{25\%}$ (III) $Q_{50\%}$ (IV) $Q_{75\%}$ and (V) $Q_{90\%}$

3.   Results and discussion

3.1. *Ground clutter and screening effects in Moucherotte*

Weather radars during the operation are also facing with some phenomenon like ground clutter, screening effect and so on. So in the first simulation performed in Moucherotte the site which is located at 1920 m altitude, there is computed ground clutter and screening effect for different elevation angle as shown in [Figs. 8(I-VI)]. From the results obtained after respective computations, it is deduced that with progressive increasing the elevation angle of radar, ground clutter, and screening effects are decreasing. That means visibility of radar is growing proportionally with increasing of elevation angle. Therefore to have a significant coverage on the radar, we cannot increase the elevation angle indefinitely. So, an

equilibrium should be defined between elevation angle and coverage.

3.2. *Ground clutter and screening effects in Saint-Eynard*

As we did for the first site, the same procedure of computations is performed for the second site (Saint-Eynard) which is located on altitude about 1365 m. So in this context, since this site is located on height lower than the first place, particular attention is given to ground clutter and screening effects. That is why for this site we have performed computations by considering more elevation angles than the first site. Results of calculations are shown in [Figs. 9(I-X)], it is concluded that by increasing progressively elevation angle ground clutter and screening effect are decreasing, but as we mentioned above we should be aware of radar coverage.
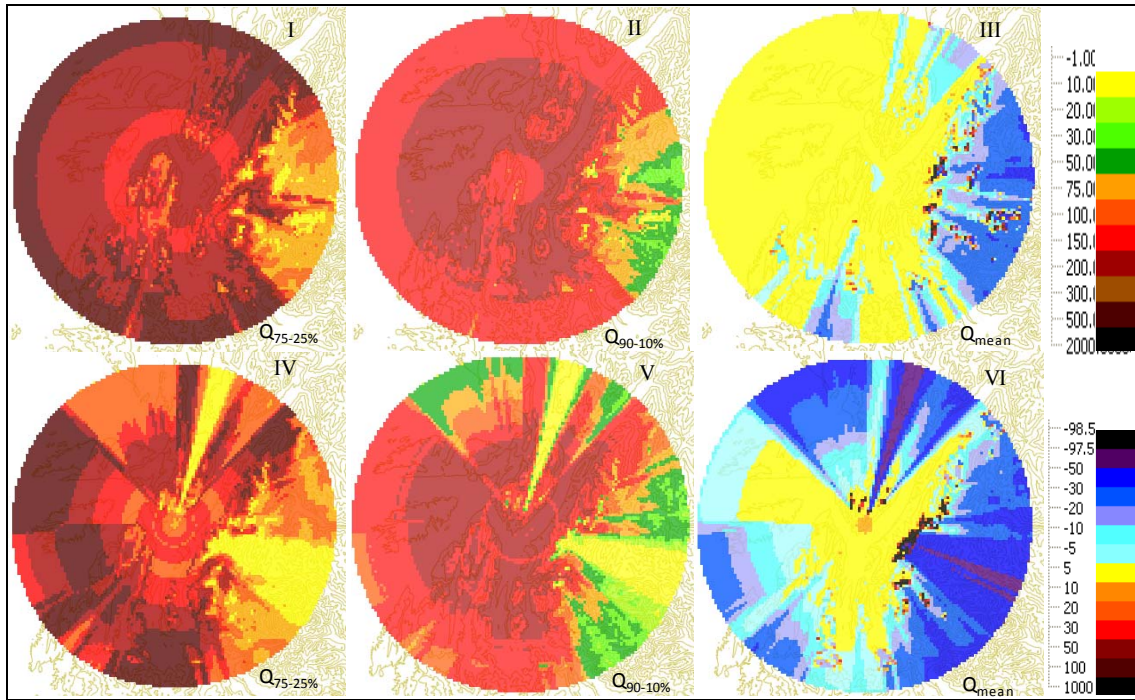
Figs. 13(I-VI). Representation of rainfall error regarding quintiles differences for both sites: (I) $Q_{75-25\%}$ Moucherotte (II) $Q_{90-10\%}$ Moucherotte (III) Q_{mean} Moucherotte (IV) $Q_{75-25\%}$ Saint-Eynard (V) $Q_{90-10\%}$ Saint-Eynard and (VI) Q_{mean}Saint-Eynard

3.3. *Estimation of rainfall error*

In the computations presented in the previous section are shown the results of ground clutter and screening effect for both sites. As it is mentioned VISHYDRO tools is used to obtain these results, so the same tools are used to compute rainfall error by introducing rains events and digital terrain (DTM). A schematic representation of radar rain rate error quantification is shown in (Fig. 10). This is also linked with working principle of VISHYDRO. In more details, to compute rainfall error for both sites particular procedure is followed.

For each elevation angle computation of rainfall error for different quintiles are performed ($Q_{10\%}$, $Q_{25\%}$, $Q_{50\%}$, $Q_{75\%}$, $Q_{90\%}$, $Q_{75-25\%}$, $Q_{90-10\%}$, Q mean). Then after computations for each elevation angle the average (optimised) value of rainfall error is estimated regarding quintiles mentioned above, the same computations are performed for both sites. Below are shown the equations used to compute rainfall error.

$$\frac{R^*}{R} = \left(z_a(r,\theta,\varphi) + \frac{Z_{sol}(r,\theta,\varphi)}{Z_0(x,y)} \right)^{1/b} \qquad (1)$$

Radar estimation:

$$R^*(A,T) = \frac{1}{M}\sum_{i=1}^{M} R^*(m_i,T) \qquad (2)$$

Unknown real precipitation:

$$R(A,T) = \frac{1}{A}\int_A R(\underline{x},T)\,d\underline{x} \qquad (3)$$

Z_a: Function of screening and VPR

Z_{solt}: Apparent reflectivity of ground clutter

Z_0: Parameter (rain at ground)

B: Z-R relationship exponent

3.3.1. *Estimation of rainfall errors in Moucherotte*

Below in [Figs. 11(I-V)] are presented the average results of rainfall error for given quintiles; ($Q_{10\%}$, $Q_{25\%}$, $Q_{50\%}$, $Q_{75\%}$, $Q_{90\%}$). As we see from the [Figs. 11(I-V)], results are significantly different for each quintile. It is

deduced that there are some under-estimation due to screening effect and over-estimation due to ground clutter effect. Also, it is noticed that for ($Q_{10\%}$, $Q_{90\%}$) there is considerable over and under-estimation. While the best case where rainfall error is not too high correspond to quintiles $Q_{50\%}$.

3.3.2. *Estimation of rainfall errors in Saint-Eynard*

The results of average (*i.e*., optimised) rainfall error regarding different quintiles; ($Q_{10\%}$, $Q_{25\%}$, $Q_{50\%}$, $Q_{75\%}$, and $Q_{90\%}$) are presented below in (Fig. 12). As we see from the (Fig. 12) it is significant under and over estimation especially for ($Q_{10\%}$, $Q_{90\%}$). While the best cases which are characterised from no to high rainfall error are cases for quintiles ($Q_{50\%}$, $Q_{75\%}$), which almost have some similar results.

3.3.3. *Comparisons of 2 Series (Moucherotteand Saint-Eynard)*

As is shown in the previous section there are some significant differences of rainfall error regarding quintiles for both sites. So to compare the results of rainfall error for two locations, differences between quintiles; ($Q_{75-25\%}$, $Q_{90-10\%}$ and Q_{mean}) are computed; the results are shown in [Figs. 13(I-VI)].

From the figure above we deduce that for difference $Q_{75-25\%}$ involving both sites, there are significant under-estimation while for $Q_{90-10\%}$ there is a decrease of rainfall error. About average estimation of precipitation, error results are not so bad for both sites. From this comparison, we conclude that for both simulated sites, almost same results are obtained. Therefore ground clutter and screening effect at the Moucherotte is less than in Saint-Eynard, so Moucherotte could be considered for implementing the future weather radar in Grenoble.

4.   Conclusions

The aim of this study is to optimise the best solution for implementing future weather radar in the Grenoble region. As we have mentioned this case was a little bit complicated because of the significant diversity of geomorphology at given region. So in this context, there are performed detail climatology study based on data received from ground stations and radio sounding Lyon as well. After several statistical computations carried out with the data's collected from both mentioned sources we conclude that: regarding iso 0 °C altitude most of the time, it varies at the range [1000-2500 m] which has a significant effect on VPRs errors. Regarding the type of precipitation, the affected region is characterised by stratiform rain, but also convective precipitation is evident

in some cases. By using the VISHYDRO tools, there are done several computations regarding ground clutter, screening effect and also rainfall error estimation for both sites, shortlisted as favourite locations, for implementing future weather radar. After these calculations performed with VISHYDRO, we conclude that results obtained from Moucherotte regarding ground clutter, screening effects and also rainfall error estimation are a little bit much better than Saint-Eynard but still there is no big difference between them. So in this context, we may give more priority to the Moucherotte but we should be aware of iso0^0C altitude which is not so high [1000-2500 m] since the altitude of Moucherotte is 1920 m. In these circumstances, it could be better to simulate other sites, located in height a bit lower than Moucherotte to look for better results.

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