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Rainfall estimation based on NAW approach using MSG-SEVIRI images: An application in north Algeria

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Abstract: In this work, we will adapt the NAW (Nagri, Adler and Wetzel), precipitation estimation approach to the north Algeria events using the Meteosat Second Generation (MSG) satellite images. The tests are carried out on seven areas of northern Algeria: Sidi Bel Abbes, Oran Port, Algiers Port, Dar El Beida, Bedjaia, Jijel-Achouat and Annaba, in winter 2006. The NAW approach is applied by thresholding to temperature from 253 K. The validation is performed by comparaison the estimated rainfall to in situ measures collected by the National Office of Meteorology in Dar El Beida (Algeria). We use the infrared data (10.8µm channel) of SEVIRI sensor in this study. The results obtained indicate that the NAW approach gives satisfactory results for the rain rates: 4mm/h assigned to the coldest 10%, 2mm/h assigned to the next 40% and 0mm/h given to the remaining 50% of the area defined as cloud. The rain rate 8mm/h assigned to the coldest 10% of the pixels in the cloud applied for the convective clouds observed for tropical regions are not valid for the Algerian climate, especially for the stratiform clouds type.

Keywords: *Precipitation, NAW approach, Stratiform cloud, Convective cloud, Meteosat Second Generation.*

1. Introduction

Precipitation is one of the most relevant meteorological and hydrological quantities. Because of floods caused by torrential rainfall accompanying with extreme weathers that can be the origin of oversize economic and human loss, the quantitative evaluation, forecast and the precision in measurement of precipitation have weighty social and economic key issue in rainfall-rich countries. However, it is not easy to estimate precipitation with height accuracy because its process is not linearly related to the cloud microphysical, thermodynamic, dynamic, and radiative processes [1].

The application of conventional measures of precipitation, which is the use of rain gauges still, is insufficient because the rainfall measurements covering land are very patchy while these over oceans are extremely few. Remote sensing, then, proves the ideal solution for rainfall estimation and monitoring. Radar meteorology has become a discipline in its own right. However, in Algeria, one of the seven ground radar sites is operational. Satellites come to correct these deficits. Thereby, making it possible to monitor the globe with more confidence using various wavelengths measured by various imagers aboard diverse types of satellite such as: GOES, METOP, NOAA, MSG…etc.

Several precipitation estimation techniques based on satellite images are proposed in the literature, where can roughly be split into two main categories: Infrared techniques and microwave techniques.

Microwave techniques sound inside the clouds and rain by using Low Earth Orbiting Satellite images [2]. Different algorithms based on such relationships are proposed [3]-[7]. However, the weak spatial and temporal resolution of the microwave data makes difficult the short-term rainfall estimates.

Contrarily to microwave observations visible and/or infrared data collected from Geosynchronous Earth Orbiting Satellite benefit from the spatio-temporal resolutions and the multi-spectral observations. Infrared techniques are based on the fact that precipitations are likely produced by the convection that is related to cold/bright clouds [2]. These approaches are widely used: [8]-[13]. However, IR techniques measure the cloud-top IR-brightness temperature and do not have a direct physical relationship with precipitations.

To take an advantage from the two approaches, combined methods were developed [14]-[19]. However, these techniques are more complex.

Because, there is no unique model with good performance for all areas in the world [20], also, rainfall is often extremely variable over time and space in the Mediterranean region [21]-[28]. So precipitation estimation is a global challenge of researchers, especially with using IR techniques that are the most adapted to this climate.

In this work, we propose to adapt the NAW (Nagri, Adler and Wetzel) approach [10] to the Algerian climate using Meteosat Second Generation (MSG) images [29]. Thereby is an infrared threshold technique. Recall that, it is originally used for the daily estimation of convective rainfall applied to GOES infrared satellite images and tested in Florida region [10]. However, satellite images delivered from the Spinning Enhanced Visible and Infrared Instrument (SEVIRI) on board MSG allow better characterizing clouds by the means of multi-spectral and multi-temporal images with high spatial resolution [29].

This paper is structured as following: a brief description of the satellites data and the rain gauges sites used in this work are provided in the next section. NAW approach is discussed next. Section IV presents the applications of NAW algorithm to the north Algeria. Section V is dedicated to the analysis and interpretation of NAW technique results involved in this exercise. Conclusions and further works are summarized in the final section.

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2. Study Area and Dataset

2.1. SEVIRI dataset

We constituted a database consisting of 1920 images collected by the SEVIRI sensor in 10.8µm Infrared channel (C9 channel) during winter 2006. For each 12 spectral channel and every 15 minutes, the High Rate SEVIRI images are acquired, each pixel being encoded on 10 bits. To reduce the computation time and to present better the study area, we take 1100x1100 pixels from the original size image (3712x3712 pixels). These satellite data are coupled to ground measurement covering the national territory.

2.2. Study Area

To validate the NAW approach, we use collected and archived data from the Algerian National Office of Meteorology (Dar El Beida). These data are recorded at ground sites that make daily measurements in 76 operational rain gauges covering the territory. The rain gauge sites chosen in this study are (Figure.1): Sidi Bel Abbes (35 ° 18 N, 2° 61 W), Oran Port (35 ° 7 N, 0° 65 W), Algiers Port (36 ° 76 N, 3° 1 E), Dar El Beida (36 ° 71 N, 3 ° 25 E), Bedjaia (36 ° 71 N, 5 ° 06 E), Jijel-Achouat (36 ° 88 N, 5 ° 81 E), and Annaba (36 ° 83 N, 7 ° 81 E).

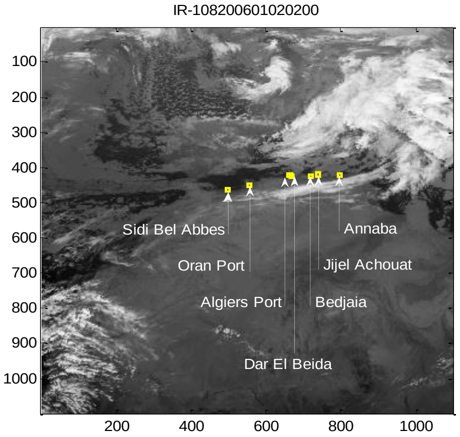

Figure 1. Representation of the seven study areas on the MSG satellite image, IR-10.8 of 02/01/2006 at 0200 h UT

3. NAW Approach

The Nagri, Adler and Wetzel approach (NAW) is an IR precipitation estimation technique based on the threshold temperature. It first delimits clouds of a given image that are colder than 253 K isotherm. Then, for each area which is considered as cloud, it assigns a rain-rate R_1 to the coldest 10%, a lower rain-rate R_2 to the next warmest 40%, and a rain-rate R_3, equal to zero in the first setting of the method, to the remaining 50% of the pixels in the cloud. This means that the threshold attributed for high and low precipitation may not be the same for all types of cloud. The technique was originally calibrated for convective rainfall over Florida, where, the nominal rain-rates assigned are [10]: $R_1 = 8$, $R_2 = 2$ and $R_3 = 0$ mm/h. This distribution of rainfall within a cloud is defined as below:

$$\text{If} \quad T < T_{10}, R_1 = 8mm/h \qquad (1)$$

$$\text{If} \quad T_{10} < T < T_{50}, R_2 = 2mm/h \qquad (2)$$

$$\text{If} \quad T > T_{50}, R_3 = 0mm/h \qquad (3)$$

Where,
R_1, R_2, R_3 are the rain rates assigned to the cloud pixels.
T_{10} and T_{50} are the warmest temperatures of the coldest 10% and 50% of the pixels respectively.
Attempts are made to adjust rain rates for mid-latitude [30]-[32]. It is found that the rain rates recalibration allows a better description of non-tropical events. Therefore, according to the authors, NAW approach must, be validated and adapted for the new areas.

4. Results

In this section, we present the intensities of rainfall measured on the ground and estimated by NAW method at seven sites of ONM considered. As an illustration, we are going to limit the study period of 02/01/2006 to 21/01/2006.

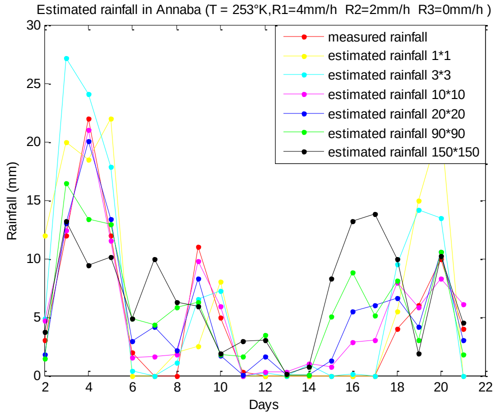

Figure 2. Measured and estimated precipitations accumulation for various windows over Annaba station

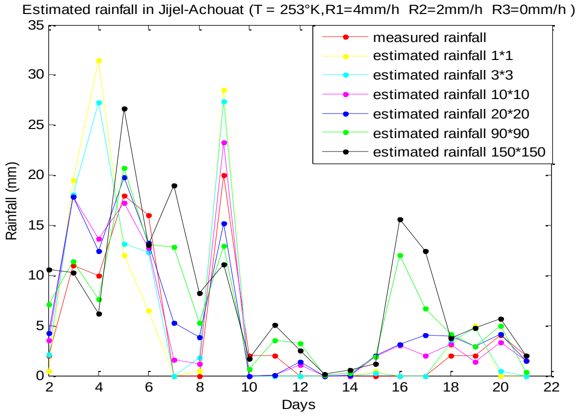

Figure 3. Measured and estimated precipitations accumulation for various windows over Jijel-Achouat station

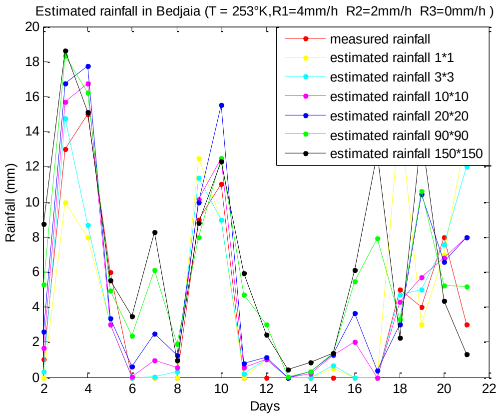

Figure 4. Measured and estimated precipitations accumulation for various windows over Bedjaia station

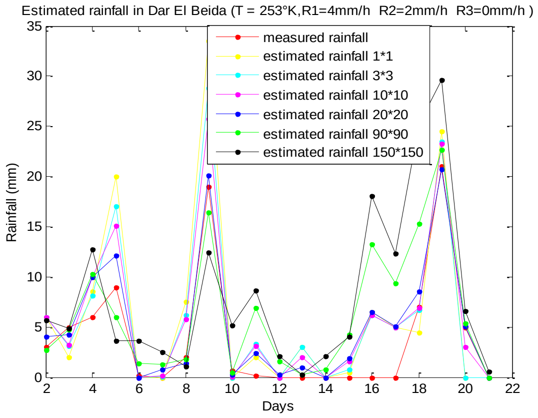

Figure 5. Measured and estimated precipitations accumulation for various windows over Dar El Beida station

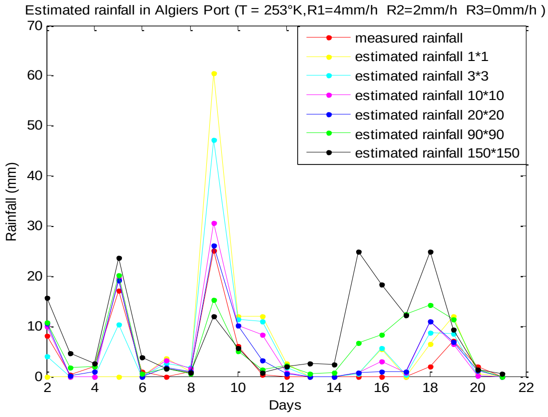

Figure 6. Measured and estimated precipitations accumulation for various windows over Algiers Port station

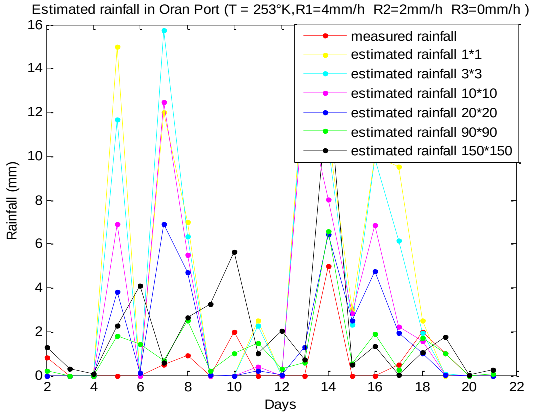

Figure 7. Measured and estimated precipitations accumulation for various windows over Oran Port station

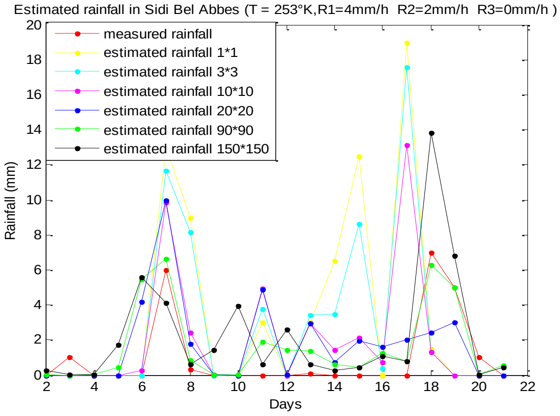

Figure 8. Measured and estimated precipitations accumulation for various windows over Sidi Bel Abbes station

Evaluation of the precipitation estimation approach is carried out by using the Bias (Figure.9), the Root Mean Square Error (RMSE) and the Correlation Coefficient (R) illustrated in (Figure.10) for various windows. The RMSE and the Bias are defined as below:

$$BIAS = \frac{1}{N}\sum_{i=1}^{N}(X'_i - X_i) \tag{4}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X'_i - X_i)^2} \tag{5}$$

Where, X_i and X'_i are the ground measured and estimated values for day i respectively and N is the number of days.

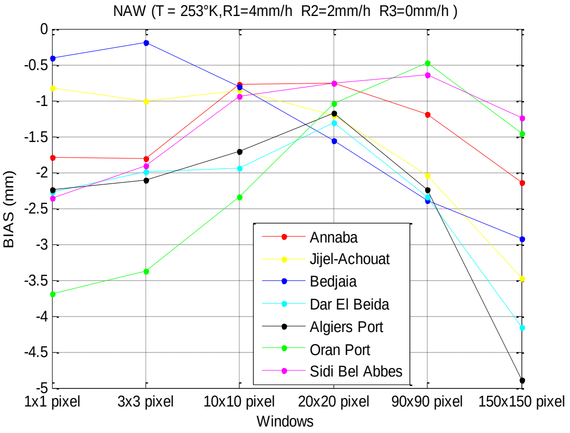

Figure 9. BIAS of different study area, day-by-day comparison, using different windows

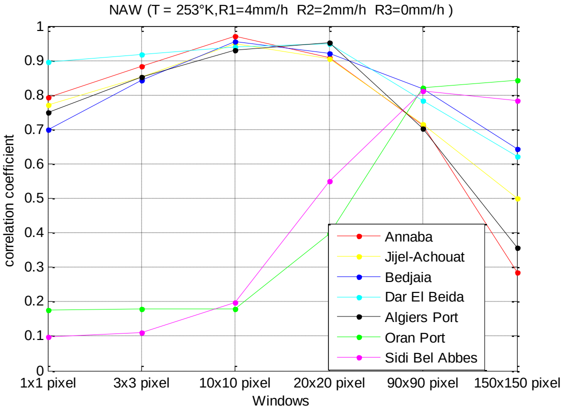

Figure 10. Correlation coefficient of different study area, day-by-day comparison, using different windows

The validation statistics obtained for R, BIAS and RMSE are presented in Table 1. Note that, for each site, only the best window's parameters are presented.

5. Analysis and Interpretation

The Figure.2-Figure.8 present the estimation results and ground measurements for the seven test stations applied to the first two decades of January 2006. They show that the estimate of rain on a daily scale is satisfactory.

The rainfall observed over the north Algeria has some typical distinctive features. Its spatial distribution from west to east has some preferred window's variations of convective rainfall and stratiform rainfall. Standard metrics used for inter comparisons between estimated and ground measurements rainfall: Bias, RMSE and R.

Bias results are generally consistent from -0.4749 through -1.3110. For all sites, it shows negative values. This means that the ground measurements rainfalls are lower than the estimated ones. This is explained by the presence of high clouds (such as the cirrus) that are certainly cold but not precipitants.

Also, it has good statistics results for MRSE and R that are varied from 2.5093 mm to 0.9539 mm and from 0.8106 to 0.971 respectively for the selected windows.

For all tested area, the best estimation is obtained for the rain rates: 4mm/h assigned to the coldest 10%, 2mm/h applied to the next 40% and 0mm/h given to the warmest 50% of the area defined as cloud. However, Nagri, Adler and Wetzel propose 8mm/h, 2mm/h, and 0mm/h assigned to the coldest 10%, the next 40% and the warmest 50% respectively [10], applied to the convective clouds. Therefore, we deduce that the precipitation during this period is also caused by stratiform clouds such as stratocumulus that are relatively warm.

The difference in spatial location between satellite measurements and ground measurements is not negligible. Indeed, the spatial scale of a point of the satellite image at sub-satellite point is 9 km^2 (for all SEVIRI channels except HRV channel), while the reception area of a rain gauge is reduced to just a few square decimetres. This difference can lead to significant errors between the estimated rainfall and in situ measurements.

Similarly, we found that the estimation error can be also related to the analysis window. This error is not due to the method itself, but having assumed that the study area is square, when in reality, it has a definite shape. As the clouds have very high spatial and temporal variability, not taking into account some pixels may lead to a significant error in the estimation of precipitation. To improve the results, we suggest having a mask or a map of the study area to consider only the threshold as a single variable analysis.

We have shown for the NAW approach that the size of analysis windows decrease from the north east to the north west of Algeria .As it was represented in (Figure.2 to Figure.4) corresponding to the east regions (Annaba, Jijel-Achouat and Bedjaia), the more adaptable analysis window is10x10 pixels. Contrarily to the east regions, the most suitable window in west areas: Oran port (Figure.7) and Sidi Bel Abbes (Figure.8) is 90x90 pixels. For the central regions: Dar el Beida (Figure.5) and Algiers port (Figure.6), the low error is measured for the window of 20x20 pixels. These results are logic because the precipitation in Algeria increases from the east to the west and decrease from the north to the south. Also, the convective clouds are more presented in the east contrarily to the stratiform clouds that are more present in the west regions. Similarly, Mesoscale cyclones are more observed in the east areas.

Table 1. The best window's parameters for each station

Regions	RMSE (mm/day)	BIAS (mm/day)	R
Annaba	1.6554	-0.7747	0.9713
Jijel-Achouat	2.4100	-0.8660	0.9472
Bedjaia	1.7535	-0.8107	0.9560
Dar El Beida	2.3473	-1.3110	0.9487
Algiers Port	2.5093	-1.1671	0.9503
Oran Port	0.9539	-0.4749	0.8208
Sidi Bel Abbes	1.4739	-0.6373	0.8106

6. Conclusion

The NAW satellite rainfall estimation method, based on thresholding clouds top temperature is presented and adjusted for the north Algeria. This method is applies to infrared images provided from SEVIRI imager. It has been tested over seven different regions: Three regions in the east of Algeria (Annaba, Jijel-Achouat and Bedjaia), two regions in the west (Sidi Bel Abbes and Oran port) and two regions from the centre (Dar El Beida and Algiers port).

The NAW approach has the merit of being simple and independent of the ground observations. However, its application to the single infrared 10.8μm channel has conceptual limitation. Indeed, the analysis based on single channel of SEVIRI has the inability to exclude the cirrus.

On the other hand, analysis windows show variability from east to west of the northern part of Algeria. The increase in the dataset certainly improves results.

Other applications of the method NAW still need to be conducted to test this method on other climatic regions on south Algeria, where the convective clouds are present in summer.

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