The EUMETSAT Network of Satellite Application Facilities

NWC SAF
Support to Nowcasting and Very Short Range Forecasting

Algorithm Theoretical Basis Document for "Convective Rainfall Rate" (CRR-PGE05 v4.0)

SAF/NWC/CDOP2/INM/SCI/ATBD/05, Issue 4, Rev. 0

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Prepared by AEMET

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DOCUMENT CHANGE RECORD

Version	Date	Pages	CHANGE(S)
Document code SAF/NWC/CDOP/INM/SCI/ATBD/05		
3.0	2 March 2009	33	Initial version (content derived from Software User Manual for PGE05 (Convective Rainfall Rate) of the SAFNWC/MSG: scientific part) Indications and recommendations given by the DRI MSG 2009 have been included.
3.1	11 May 2010	36	Document updated for the SAFNWC/MSG PGE05 v3.1. CRR rain rate algorithm retrieval updated to work using lightning data information (SPR 374 / SMR 352).
3.1.1	1 April 2011	37	Minor changes done according to action MSG-DRI2010-10. No scientific updates, adapted date, issue and rev. to v2011.
3.1.2	15 February 2012	37	Minor changes done according to SPR 485/SMR 457. No scientific updates, adapted date, issue and rev. to v2012.
4.0	15 July 2013	36	Modifications for PGE05 v4.0: • Calibration matrices have been substituted by analytical functions. • A tuning of the calibration analytical functions has been done. • The CRR classes output includes a new class and colour palette. • The CRR hourly accumulations output provides precipitation accumulations from 0.0 to 51.0 mm with a step of 0.2 mm and includes a new colour palette. • The CRR intensity output provides rain rates from 0.0 to 51.0 mm/h with a step of 0.2 mm/h and includes a new colour palette. • Modification of ComputeAccum.c related to SPR 505/SMR 480. • Indications and recommendations given by the NWC SAF SW Package MSG 2013 PCR and DRR have been included.

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1. INTRODUCTION

1.1 SCOPE OF THE DOCUMENT

The Eumetsat "Satellite Application Facilities" (SAF) are dedicated centres of excellence for processing satellite data, and form an integral part of the distributed EUMETSAT Application Ground Segment (http://www.eumetsat.int). This documentation is provided by the SAF on Support to Nowcasting and Very Short Range Forecasting, NWC SAF. The main objective of NWC SAF is to provide, further develop and maintain software packages to be used for Nowcasting applications of operational meteorological satellite data by National Meteorological Services. More information can be found at the NWC SAF webpage, http://www.nwcsaf.org. This document is applicable to the NWC SAF processing package for Meteosat satellites meteorological satellites, SAFNWC/MSG.

This document is the Algorithm Theoretical Basis Document (ATBD) for the MSG product PGE05 (CRR) of the SAFNWC/MSG software package.

The Algorithm Theoretical Basis Document describes the physics of the problem together with the mathematical description of the algorithm. It also provides information on the product objectives, the needed input data and the output product.

1.2 SCOPE OF OTHER DOCUMENTS

The Product User Manual [AD 1] contains practical information on the characteristics of the product, including the input data and the output product. It also gives information about the algorithm's implementation.

The Interface Control Document ICD/1 [AD 3] describes the External and Internal Interfaces of the SAFNWC/MSG software.

The Interface Control Document ICD/3 [AD 4] defines the format of the output products generated by the SAFNWC/MSG software.

The Architectural Design Document [AD 5] presents the general architecture of the SAFNWC software, and gives details on each AEMET– related PGE.

1.3 SOFTWARE VERSION IDENTIFICATION

This document describes the algorithm implemented in the PGE05 version v4.0 of SAFNWC software package delivery.

1.4 IMPROVEMENTS FROM PREVIOUS VERSION

A change has been applied in the algorithm retrieval of rain rates without changing the physical base. Calibration matrices have been substituted by analytical functions. Also, a tuning of the calibration analytical functions has been done against radar data. For this purpose radar data from BALTRAD, Spanish and Hungarian radar networks have been used.
Modification in the outputs:
- o A new class has been included in the CRR Classes output. The interval of this new class is from 0.2 to 1 mm/h. The colour palette has been modified accordingly.

o The CRR hourly accumulations output provides precipitation accumulations from 0.0 to 51.0 mm with a step of 0.2 mm. The colour palette of this output has been modified to include values from 0.2 mm.

o The CRR intensities output provides rainfall rates from 0.0 to 51.0 mm/h with a step of 0.2 mm/h and includes a colour palette.

Validation results are reported in the Validation Report for "Convective Rainfall Rate" [AD 2].

1.5 ACRONYMS

AEMET	Agencia Estatal de Meteorología
ATBD	Algorithm Theoretical Basis Document
BALTRAD	Baltic Radar Network
CAPPI	Constant Altitude Plan Position Indicator
CRR	Convective Rainfall Rate
CSI	Critical Success Index
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAR	False Alarm Ratio
HRIT	High Rate Information Transmission
ICD	Interface Control Document
IR	Infrared
MAE	Mean Absolute Error
MCTP	Microphysical Cloud Top Properties
ME	Mean Error
MRV	Maximum Reflectivity in the Vertical
MSG	Meteosat Second Generation
NWCLIB	Nowcasting SAF Library
PC	Percentage of Corrects
PGE	Product Generation Element
POD	Probability of Detection
PUM	Product User Manual
PWRH	Moisture Correction Factor
RAINSAT	Rainfall Satellite Technique
RLR	Rainfall-Lightning Ratio
RMS	Root Mean Square error
RR	Rain Rate
SAF	Satellite Application Facility
SAF NWC	Satellite Application Facility for Nowcasting

SEVIRI	Spinning Enhanced Visible and Infrared Imager
SW	Software
2-V	2-Variable
3-V	3-Variable
VIS	Visible
VIS-N	Normalized Visible
WV	Water Vapour

1.6 REFERENCES

1.6.1 Applicable Documents

For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the current edition of the document referred applies.

Reference	Title	Code	Vers	Date
[AD 1]	Product User Manual for "Convective Rainfall Rate" (CRR - PGE05 v4.0)	SAF/NWC/CDOP2/INM/SCI /PUM/05	4.0	15/07/13
[AD 2]	Validation Report for "Convective Rainfall Rate" (CRR-PGE05 v4.0)	SAF/NWC/CDOP2/INM/SCI /VR/12	1.0	15/07/13
[AD 3]	Interface Control Document for the External and Internal Interfaces of the SAFNWC/MSG	SAF/NWC/CDOP2/INM/SW /ICD/1	7.0	15/07/13
[AD 4]	SAFNWC/MSG Output Products Format Definition	SAF/NWC/CDOP2/INM/SW /ICD/3	7.0	15/07/13
[AD 5]	Architectural Design Document for the AEMET- related PGEs of the SAFNWC/MSG	SAF/NWC/CDOP2/INM/SW /AD/4	7.0	15/07/13
[AD 6]	User Manual for the SAFNWC/MSG Parallax Correction Tool	GMV/SAFCDOP/VSAREP/0 2	1.0	02/06/08
[AD 7]	NWC SAF Product Requirements Document	NWC/CDOP2/SAF/AEMET/ /MGT/PRD	1.2	15/07/13

Table 1. List of Applicable Documents

	Algorithm Theoretical Basis Document for "Convective Rainfall Rate" (CRR-PGE05 v4.0)	**Code:** SAF/NWC/CDOP2/INM/SCI/ATBD/05
		Issue: 4.0 **Date**: *15 July 2013*
		File: SAF-NWC-CDOP2-INM-SCI-ATBD-05_v4.0
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1.6.2 Reference Documents

Reference	Title
[RD.1]	Kidder, S.Q., and T.H. Vonder Haar, 1995: Satellite Meteorology: An Introduction. Academic Press
[RD.2]	Scofield, R.A., 1987: The NESDIS operational convective precipitation estimation technique, Mon. Wea. Rev., Vol.115, pp.1773-1792.
[RD.3]	Vicente, G.A. and R.A. Scofield, 1996: Experimental GOES-8/9 derived rainfall estimates for flash flood and hydrological applications, Proc. 1996 Meteorological Scientific User's Conference, Vienna, Austria, EUM P19, pp.89-96.
[RD.4]	Kurino, T., 1996: A Rainfall Estimation with the GMS-5 Infrared Split-Window and Water Vapour Measurements, Tech. Rep., Meteorological Satellite Centre, Japan Meteorological Agency.
[RD.5]	Schmetz J., S. S. Tjemkes, M. Gube and L. van de Berg, 1997: Monitoring deep convection and convective overshooting with METEOSAT. Adv. Space Res., Vol. 19, pp433-441.
[RD.6]	Vicente, G.A., Scofield, R.A. and Menzel W.P. 1998: The Operational GOES Infrared Rainfall Estimation Technique, Bull. American Meteorological Society, Vol. 79, No. 9, pp. 1883-1898.
[RD.7]	Vicente, G.A., Davenport, J.C. and Scofield, R.A., 1999: The role of orographic and parallax corrections on real time high resolution satellite rainfall estimation, Proc. 1999 Eumetsat Meteorological Satellite Data User's Conferences, EUM P26, pp. 161-168.
[RD.8]	Jorge Sánchez-Sesma and Marco Antonio Sosa: EPPrePMex, A Real-time Rainfall Estimation System Based on GOES-IR Satellite Imagery. IPWG, October 2004, Monterey, California, USA.
[RD.9]	Algorithm Theoretical Basis Document for "Convective Rainfall Rate" (CRR-PGE05 v3.1.1). SAF/NWC/CDOP/INM/SCI/ATBD/05.
[RD.10]	Gutierrez, J. M. and Aguado, F.: Quality image for the Spanish Radar National Composite, Proceedings of ERAD 2006, 318-320.
[RD.11]	Tapia, A., Smith, J. A., Dixon, M., 1998: Estimation of Convective Rainfall from Lightning Observations, Bull. American Meteorological Society, Vol. 37, pp. 1497-1509.

Table 2. List of Referenced Documents

2. ALGORITHM OVERVIEW OF CONVECTIVE RAINFALL RATE (CRR) PRODUCT

Convective Rainfall Rate (CRR) product is a Nowcasting tool that provides information on convective, and stratiform associated to convection, instantaneous rain rates and hourly accumulations.

In the processing of the product, CRR uses some calibration analytical functions that have been calibrated taking as "truth" the radar data. There are two types of functions:

- 2-Variable (2-V) function that depends on 10.8IR and (10.8IR - 6.2WV) SEVIRI channels

- 3-Variable (3-V) function that depends on 10.8IR, (10.8IR - 6.2WV) and 0.6VIS-N SEVIRI channels

The 3-V calibration analytical function gives better results but there are some situations in which it can't be used, for instance, during the night time. The type of calibration to be used can be chosen by the user through the CRR model configuration file.

The analytical functions have been calibrated using radar data from:

- Baltic radar network

- Hungarian radar network

- Spanish radar network

To take into account the influence of environmental and orographic effects on the precipitation distribution, some corrections can be applied to the basic CRR value. The possible corrections are the moisture correction, the cloud top growth/decaying rates or evolution correction, the cloud top temperature gradient correction and the orographic correction.

At this stage, the CRR precipitation pattern computed in the previous step is combined with a precipitation pattern derived through a lightning algorithm.

At the end of the process CRR product produces five different outputs.

In one of them, the CRR value in mm/h is converted into classes. There are 12 classes that divide the rain rates in some different ranges and each pixel of the output image has a rain class assigned.

There exists an output that contains the information on the instantaneous rain rate in mm/h in each pixel of the image. The hourly accumulation output gives information about the precipitation occurred during the last hour.

The classes, the instantaneous rain rate in mm/h and the hourly accumulation outputs have the same colour palette.

Information on the corrections applied and the processing status is available on the CRR_QUALITY and CRR_DATAFLAG outputs respectively.

3. ALGORITHM DESCRIPTION OF CONVECTIVE RAINFALL RATE (CRR) PRODUCT

3.1 CONVECTIVE RAINFALL RATE (CRR) THEORETICAL DESCRIPTION

In this section the theoretical basis and practical implementation of the algorithm are described.

3.1.1 Goal of the Convective Rainfall Rate (CRR) product

Convective Rainfall Rate (CRR) product, developed in the NWC SAF context, provides information on convective, and stratiform associated to convection, rain rates coming from MSG-SEVIRI channels. This product provides forecasters with some complement to other NWC SAF products aiming at rain and convection monitoring as PGE04 (Precipitating clouds), PGE11 (Rapid development thunderstorms) and PGE02 (Cloud type).

3.1.2 Physics of the problem

All visible and infrared precipitation estimation schemes are necessary indirect because the radiation does not penetrate through the cloud. The cloud's brightness temperature and visible reflectance may be related to the rain falling from it, but the raindrops themselves are not directly sensed [RD.1].

The empirical relationship that the higher and thicker are the clouds the higher is the probability of occurrence and the intensity of precipitation is used in the CRR algorithm. Information about cloud top height and about cloud thickness can be obtained, respectively, from the infrared brightness temperature (IR) and from the visible reflectances (VIS) [RD.2][RD.3].

IR-WV brightness temperature difference is a useful parameter for extracting deep convective cloud with heavy rainfall [RD.4]. Negatives values of the IR-WV brightness temperature difference have been shown to correspond with convective cloud tops that are at or above the tropopause [RD.5].

Some observable features (like environmental moisture, cloud growth, cloud top structure, topography underneath, etc.) affect to convective precipitation rates more than the stratiform rain cases [RD.6][RD.7].

It is stated that convective phenomena are related to the electrical activity in the clouds. The lightning algorithm is based on the assumption that the higher is the spatial and temporal density of lightning occurrence, the stronger is the convective phenomenon and the higher is the probability of occurrence and the intensity of convective precipitation.

3.1.3 Mathematical Description of the Convective Rainfall Rate (CRR) algorithm

3.1.3.1 Convective Rainfall Rate (CRR) algorithm outline

The CRR algorithm developed within the NWC SAF context estimates rainfall rates from convective systems, using IR, WV and VIS-N MSG SEVIRI channels and calibration analytical functions generated from both SEVIRI and Radar data.

The calibration functions, which have been calibrated through a statistical process, try to connect satellite multi-band imagery with rain rates. In the calibration process composite radar data are compared pixel by pixel with geographically matched MSG data with the same resolution. Rainfall rate RR is obtained, as a function of two or three variables (IR brightness temperature, IR-WV brightness temperature differences and normalised VIS reflectances):

RR = f (IR, IR-WV, VIS-N), for 3-V calibration

RR = f (IR, IR-WV), for 2-V calibration

The basic CRR mm/h value for each pixel is obtained from the calibration functions. If in a pixel the sun zenith angle is lower than a threshold and the solar channel is used, the basic CRR data is obtained from a 3-V analytical function which uses 10.8IR, 6.2WV and 0.6VIS-N imagery. If in a pixel the sun zenith angle is higher than the threshold or lower, but the solar channel is not going to be used, the basic rain rate values are obtained from 2-V analytical function which only uses 10.8IR and 6.2WV imagery. The threshold that decides, depending on the sun zenith angle, whether the solar channel can be used or not, is chosen by the user through the CRR model configuration file. The name of this threshold in the configuration file is DAY_NIGHT_ZEN_THRESHOLD and its default value is 80º.

When the solar channel is used, the normalised visible reflectances are obtained dividing by the cosine of the solar zenith angle. The option of using the solar channel in the computation of the CRR values can be chosen by the user through the CRR model configuration file.

In the retrieval of basic CRR values from 3-V calibration function, some pixels could occasionally present normalised visible reflectances greater than 100. In those cases the CRR values will be retrieved using the 2-V calibration function. This occurs in few instances and has been observed mainly under very low sun illumination conditions. Those pixels can be easily identified as they will have assigned a value as a missing data in some channel in the CRR_DATAFLAG output.

A filtering process is performed in order to eliminate stratiform rain data which are not associated to convective clouds: the obtained basic CRR data are set to zero if all the pixels in a grid of a selected semisize (def. value: 3pix) centred on the pixel have a value lower than a selected threshold (def. value: 3mm/h). The threshold and the size of the grid can be modified by the user by means of the model configuration file.

To take into account the temporal and spatial variability of cloud tops, the amount of moisture available to produce rain and the influence of orographic effects on the precipitation distribution, several correction factors can be applied to the basic CRR value. Therefore, the possible correction factors are the moisture correction, the cloud top growth/decaying rates or evolution correction, the cloud top temperature gradient correction and the orographic correction.

Lightning activity can provide valuable information about convection. A lightning algorithm can be applied to derive a precipitation pattern that will be combined with the CRR one computed in the previous step in order to complement it.

At the end of the process the final values of the CRR rainfall rates in mm/h are used in order to obtain three different outputs:

- CRR rainfall rates in mm/h

- CRR classes: rainfall rate in mm/h is divided into twelve classes as it is showed in Table 5.

- CRR hourly accumulations: A trapezoidal integration [RD.8RD.8RD.8] is performed in order to compute the hourly accumulations.

  ❖ Normal mode:

Six scenes are used in this process: the instantaneous scene corresponding to the time of the hourly accumulation and the five previous instantaneous scenes. The CRR rate in mm/h output is the one used to make the computing.
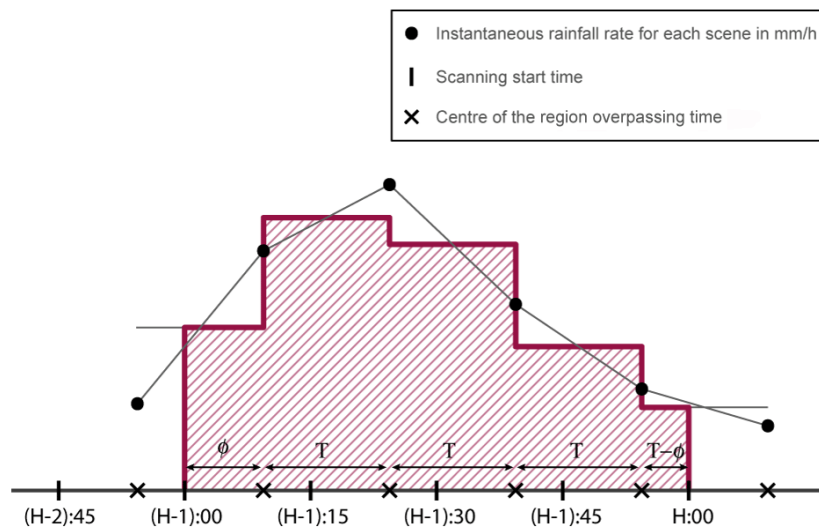
Figure 1. Trapezoidal integration

The nominal time of a scene corresponds to the moment when the satellite starts the scanning. Some minutes are needed to overpass the centre of the region where the product is being running. In order to avoid the time window effect, the following equation has been used to compute the hourly accumulations:

$$A_6 = \frac{I_1 + I_2}{2}\phi + \frac{I_2}{2}T + I_3 T + I_4 T + \frac{I_5}{2}T + \frac{I_5 + I_6}{2}(T - \phi)$$

Where:

- A_i: hourly accumulation, in mm, corresponding to the time i.

- T: time interval between scenes in hours (T= 0.25)

- Φ: part of T that corresponds to the time that takes the satellite to reach the centre of the region.

- I_i: Instantaneous rainfall rate for each scene in mm/h

The hourly accumulation won't be computed when there is a lack of more than two scenes or two consecutive ones in the complete interval.

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❖   Rapid Scan mode:

Fourteen scenes are used in this case: the instantaneous scene corresponding to the time of the hourly accumulation and the thirteen previous instantaneous scenes.

The equation that is used in the trapezoidal integration for the Rapid Scan mode is:

$$A_{14} = \frac{I_1 + I_2}{2}\phi + \frac{I_2}{2}T + \left(\sum_{i=3}^{12} I_i\right)T + \frac{I_{13}}{2}T + \frac{I_{13} + I_{14}}{2}(T - \phi)$$

Where:

- A_i: hourly accumulation, in mm, corresponding to the time i.

- T: time interval between scenes in hours (T= 1/12)

- Φ: part of T that corresponds to the time that takes the satellite to reach the centre of the region.

- I_i: Instantaneous rainfall rate for each scene in mm/h

The hourly accumulation won't be computed when there is a lack of more than six scenes or four consecutive ones in the complete interval.

3.1.3.2 Convective Rainfall Rate (CRR) calibration analytical functions procedure

The analytical functions have been built taking the previous calibration matrices as starting point. The calibration matrices obtaining method can be read in ATBD for CRRv3.1.1 [RD.9]

The calibration matrices were modelled and described by the analytical functions that best fitted them. An example of this modelling can be seen in Figure 2.
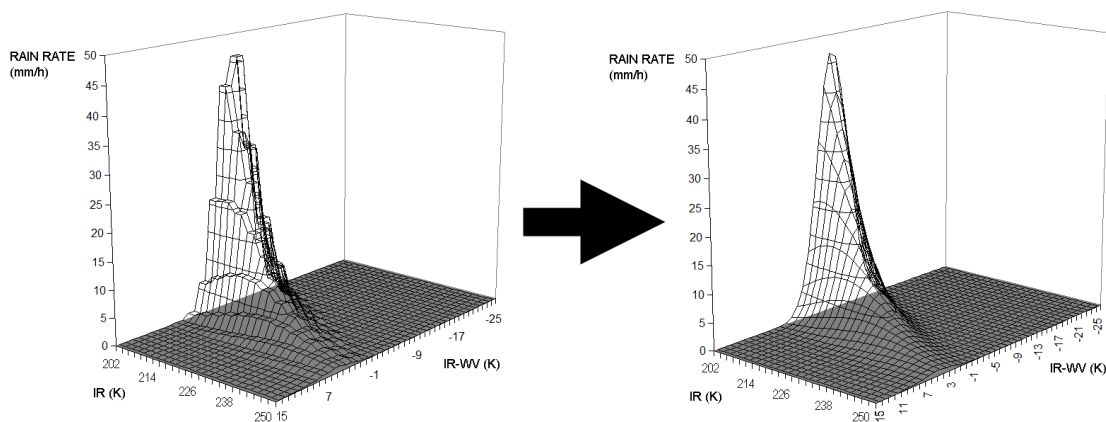

Figure 2: From calibration matrices to analytical functions

The perfect matching between matrices and functions is impossible to reach; also, the calibration process over a function is easier than over a matrix. For these reasons a new calibration process was done over the functions.

3.1.3.2.1 Analytical functions calibration process

The calibration process was done using the following radar data:

Radar network	Type of radar	Frequency Scanning Radar	Dataset used	Type of product used	MSG scans over the radar area	Matching time
Baltrad network	C- Band	15 minutes	21 rainy days June-August 2004	Pseudo-CAPPI at 2Km	About 11 min later than the MSG time slot	MSG time slot 15 min later than the radar one.
Hungarian radar network	C- Band	15 minutes	18 rainy days May-September 2009	Maximum reflectivity in the vertical (MRV) and Echotop	About 11 min later than the MSG time slot	MSG time slot 15 min later than the radar one.
Spanish radar network	C- Band	10 minutes	111 rainy days throughout 2009	PPI and Echotop	About 10 min later than the MSG time slot	0 and 30 min MSG slots have been matched to 10 and 40 min radar images respectively.

Table 3. Description of the radar calibration data

For a better matching of radar – satellite images, the radar products were converted into MSG projection using a bi-linear interpolation scheme.

A quality control has been used for the Spanish radar dataset taking advantage of the quality image generated for the radar national composite products [RD.10]. No quality control methods have been used for Baltrad and Hungarian radar datasets.

Ground echoes, like anomalous propagation echoes, were removed in Pseudo-CAPPI, MRV and PPI scenes. To that end 10.8IR SEVIRI imagery were used together with the basic AUTOESTIMATOR algorithm [RD.6].

Considering that CRR is a specific product for convective situations, only images with convective echoes, as far as possible, were used during the calibration process. To that end, Echotop product was used when available. Only scenes where the ratio between the number of echoes greater than 6 Km and the ones greater than 0 Km was lower than 15% in the Echotop image were selected.

Since images with convective situations can also include non convective echoes, a calibration area was selected. This selection included the area corresponding to 15x15 pixels boxes centred on that ones that reached a top of 6 km and a rain rate of 3 mm/h simultaneously.

Since the perfect matching is not possible a smoothing process in 3x3 pixels boxes was done for a better radar-satellite matching.

Once the radar calibration dataset was prepared, CRR was run using the analytical functions applying small shifts to the coefficients. Also a smoothing process in 3x3 pixels boxes was done over CRR imagery. Then several comparisons between CRR rain rates and radar rain rates were done computing accuracy and categorical scores. Special attention was paid to RMSE,

POD and FAR. The coefficients of the functions were adjusted and the ones which got the best scores were chosen.

3.1.3.2.2 Analytical functions description

An analytical function is easier to handle and to analyze than a big matrix. Two calibration functions were obtained:

2-V calibration function: RR (IR, IR-WV)

The function independent variable is (10.8IR-6.2WV) SEVIRI data and its coefficients have a dependence on 10.8IR SEVIRI data. The mathematical formulation of this function is the following:

$$RR(mm/h) = H(IR) * \exp\left[-0.5 * \left(\frac{(IR-WV)-C(IR)}{W(IR)}\right)^2\right]$$

Where RR is the rain rate in mm/h, and H(IR), C(IR) and W(IR) are coefficient functions depending on 10.8IR SEVIRI data.

Looking at the formula of this function it can be observed that it is a symmetric bell-shaped curve where H(IR) is the height, C(IR) is the position of the symmetry axis and W(IR) is related to the width of the curve. All these parameters, depending on 10.8IR data, have a meaning.

The mathematical formula of the coefficient function related to the height of the 2-V calibration function, H(IR), is the following:

$$H(IR) = a * \exp[b * IR]$$

Where the coefficients are: $a = 8*10^8$ and b = - 0.082

According to these coefficients the graph of this curve is shown in Figure 3.
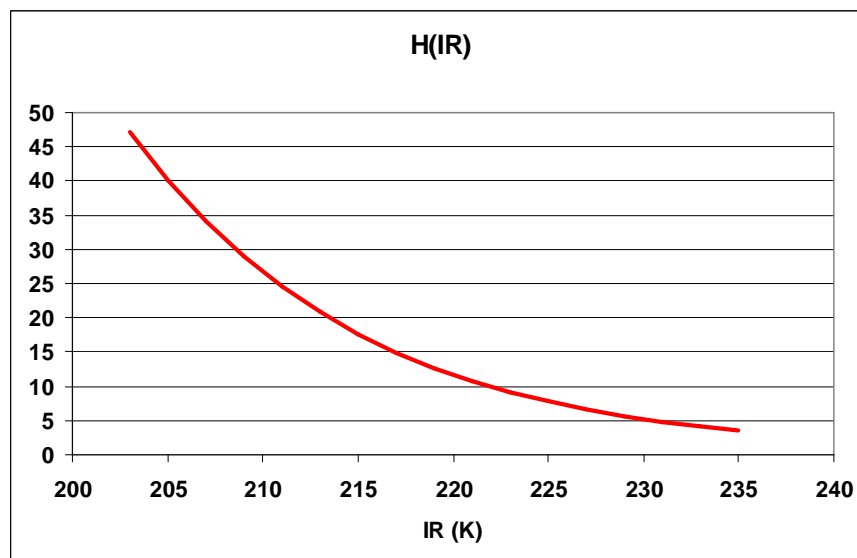

Figure 3: Height of the 2-V function plotted between 205K and 235K.

It is clear from the curve that the lower the IR brightness temperature the higher H(IR), so the higher are the estimated rain rates.

Regarding the position of the symmetry axis C(IR), the formula is:

$$C(IR) = c * IR + d$$

Where the coefficients are: c = 0.2 and d = - 45.0

This function is plotted in Figure 4.
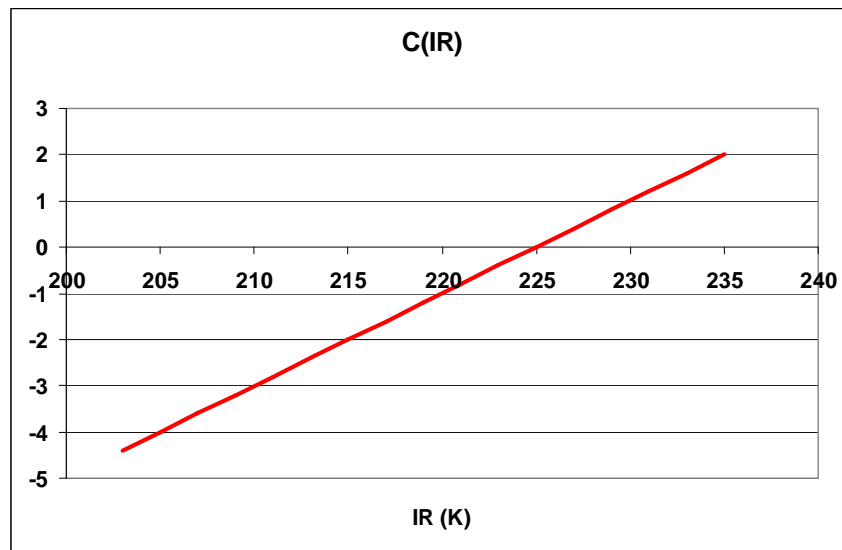
Figure 4: Coefficient related to the position of the symmetry axis of the 2-V function.

As it has been seen, the 2-V calibration function is a symmetric bell-shaped curve whose independent variable is (IR-WV) and whose coefficients depend on IR. The symmetry axis of the "bell curve" is given by C(IR). Looking at Figure 4 it can be deduced that the highest rain rates are estimated for IR-WV values close to zero; and the lower are the IR brightness temperatures, the lower the value of IR-WV that provides the highest rain rates estimations.

Finally, the equation that provides information on the width of the bell-shaped curve is:

$$W(IR) = f * \exp\left[-0.5\left(\frac{IR+g}{h}\right)^2\right] + j$$

Where f = 1.5; g = - 215.0; h = 3.0 and j = 2.0

The graph of the W(IR) is plotted in Figure 5.

Figure 5: Coefficient that provides information on the width of the 2-V function

W(IR) is also a symmetric bell-shaped curve whose symmetry axis is centred in 215K. This means that for this brightness temperature the curve gets 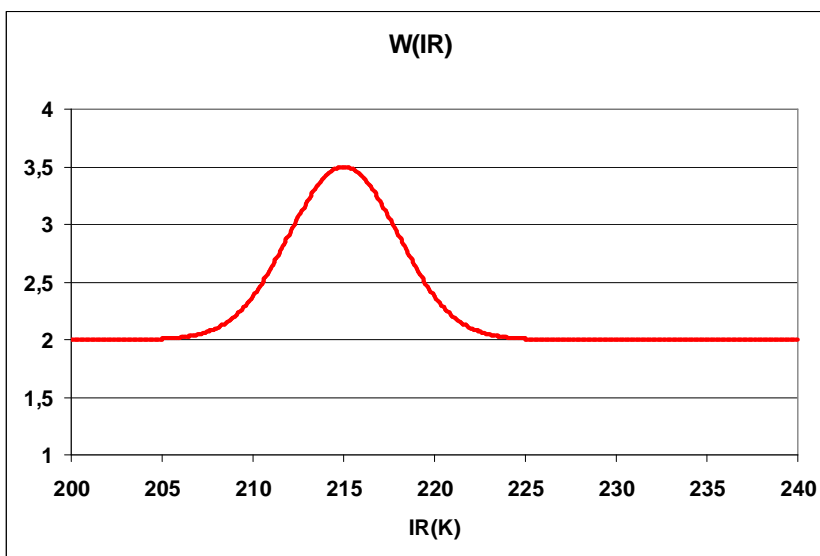wider so it could be deduced that for IR=215K, there is a higher likelihood of precipitation occurrence although the rain rates are not the highest.

3-V calibration function: RR(IR, IR-WV, VIS)

The 3-V function independent variables are 10.8IR-6.2WV and 0.6VIS-N SEVIRI data and its coefficients have a dependence on 10.8IR SEVIRI data and on latitude. Its mathematical formulation is the following:

$$RR(mm/h) = \exp\left[-0.5 * \left(\frac{VIS\_N - C\_Vis(Lat)}{8.5}\right)^2\right] * H(IR) * \exp\left[-0.5 * \left(\frac{(IR-WV) - C(IR)}{W(IR)}\right)^2\right]$$

$$\underbrace{\qquad\qquad\qquad\qquad}_{(Factor\_VIS-N)} \quad \underbrace{\qquad\qquad\qquad\qquad\qquad\qquad}_{(Factor\_IRWV)}$$

The 3-V calibration function is the product of two symmetric bell-shaped curves, Factor_VIS-N and Factor_IRWV. The Factor_IRWV one is similar to the 2-V function and Factor_VIS-N depends on the VIS-N imagery.

The interpretation of the bell-shaped curve Factor_IRWV is the same as in the case of the 2-V function. For the 3-V function the H(IR), C(IR) and W(IR) coefficients are the following:

$$H(IR) = a * \exp[b * IR]$$

Where: a = $1.25*10^8$ and b = - 0.073

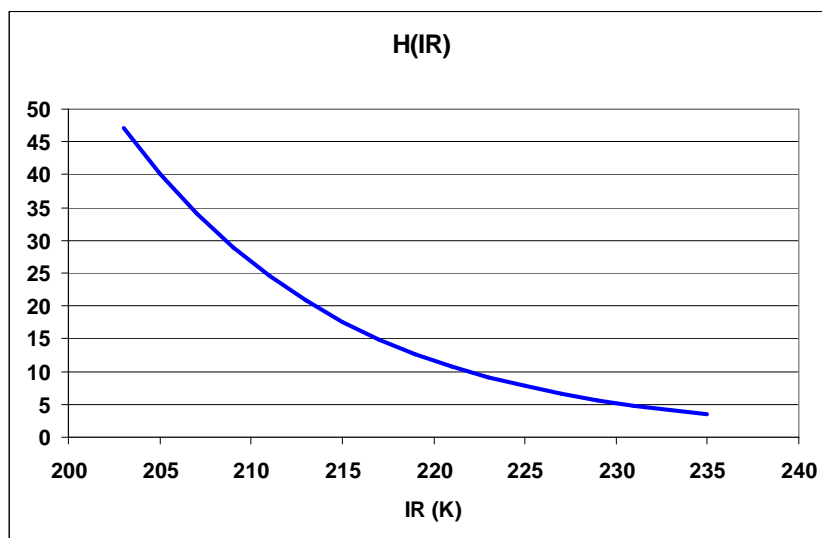|	Algorithm Theoretical Basis Document for "Convective Rainfall Rate" (CRR-PGE05 v4.0)	**Code:** SAF/NWC/CDOP2/INM/SCI/ATBD/05
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Figure 6: Height of the 3-V function plotted between 205K and 235K.

$$C(IR) = c * IR + d$$

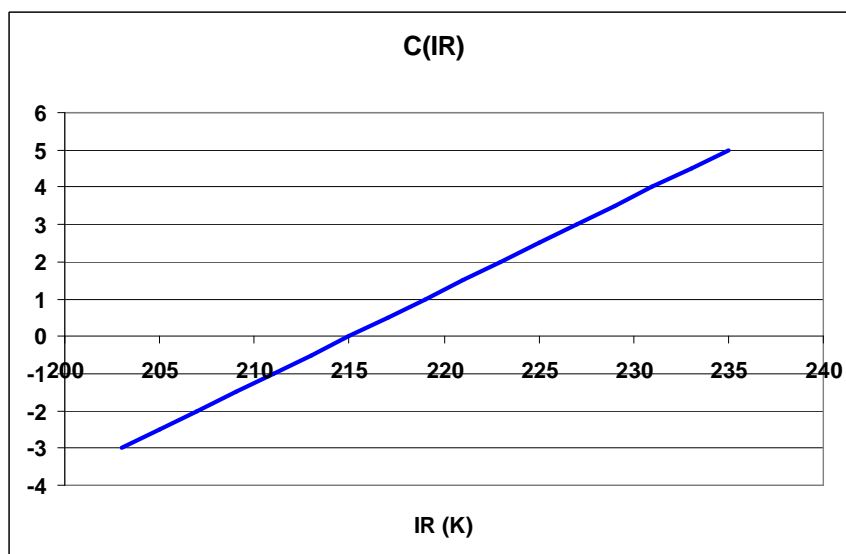Where: c = 0.25 and d = - 53.75

Figure 7: Coefficient related to the position of the symmetry axis of the 3-V function.

$$W(IR) = f * \exp\left[-0.5\left(\frac{IR + g}{h} \right)^2 \right] + j$$
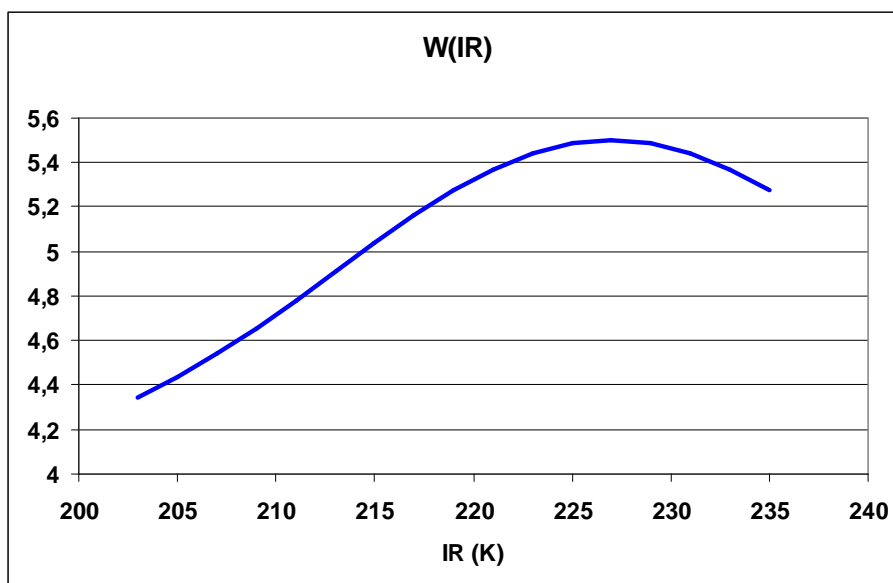
Where: f = 1.5; g = - 227.0; h = 14.0 and j = 4.0

Figure 8: Coefficient that provides information on the width of the 3-V function

Regarding the H(IR) coefficients for 2-V and 3-V functions, both the shape and the maximum rain rates estimated are very similar.

As for the position of the symmetry axis, the lower the IR brightness temperatures, the lower the value of IR-WV that provides the highest rain rates estimations for both 2-V and 3-V functions. The difference is that in 3-V case, the (IR-WV) values that provide the highest rain rates are a bit higher than in the case of 2-V function.

In the case of the coefficient that provides information on the width of the 2-V and 3-V functions, the difference is higher. It can be observed that the 3-V function is always much wider and the IR brightness temperature for which there is a higher likelihood of precipitation occurrence is warmer (227K) than in the case of the 2-V function. This means that 3-V function rain rates estimations are higher for the same range of IR brightness temperatures and (IR-WV) differences than 2-V function rain rates estimations. 2-V function limits the rain rate estimations to lower IR brightness temperatures.

It must be taken into account that 3-V function is also composed of other symmetric bell-shaped curve Factor_VIS-N that depends on the VIS-N imagery. It can be interpreted that Factor_IRWV is the height of Factor_VIS-N, so the highest estimations given by 3-V function will be given by Factor_IRWV, and Factor_VIS-N filters these estimations depending on the normalized visible reflectances.

The higher is the VIS-N reflectance, the higher is the optical thickness of the cloud so the higher should be the rain rate assigned. This can be seen in Figure 9.

It has been seen that for Spanish latitudes the highest rain rates are obtained for VIS reflectances of about 82%, for different years. According to the other radar-satellite datasets (Hungary and Baltrad) reflectances that provide the highest rain rates decrease with latitude. The quantity of solar energy that reaches higher latitudes is lower than the ones that reach latitudes closer to the equator and normalization process is not good enough to fix this problem. This dependence on the latitude could be a corrective effect additional to the normalization.

To take account of this fact a latitude dependency has been included in the 3-V function. As can be observed in Figure 9, the lower is the latitude the higher is the reflectance for which 3-V function assigns higher rain rates. This latitude dependence can be observed in Figure 10.
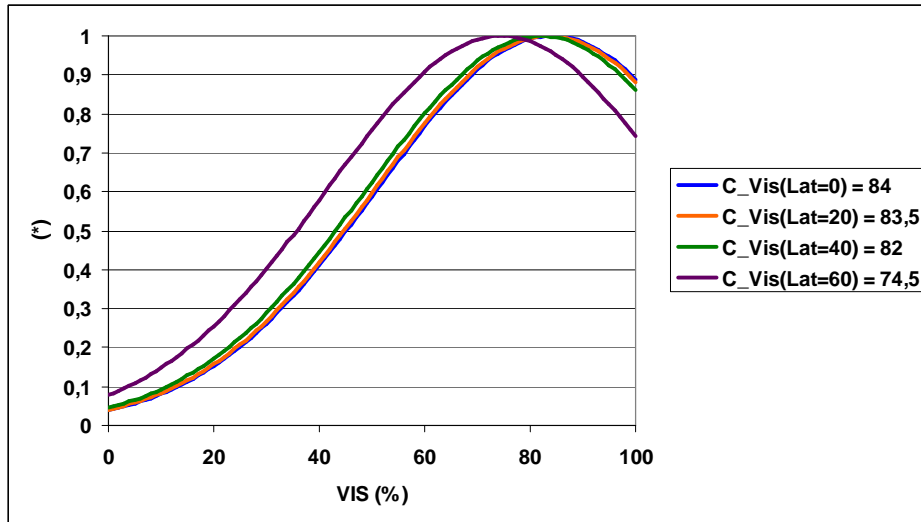
Figure 9: Dependence of the 3-V function on the Normalized Visible reflectances.

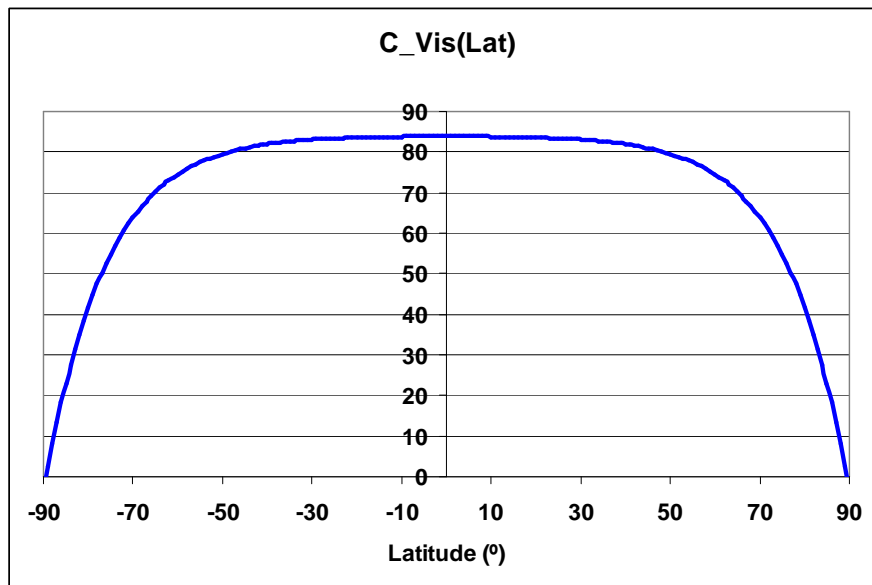*Figure 10: Dependence of the Normalized Visible reflectances on Latitude*

3.1.3.3 Convective Rainfall Rate (CRR) correction factors description

3.1.3.3.1 Moisture Correction Factor

When thunderstorms take place in quite moist environments the computed rainfall rate should be greater than when they occur in dry air masses. To take into account this effect a

moisture correction factor has been developed. It adjusts the estimates when the air is dry or quite moist. This factor has been defined as the product of the total precipitable water, PW, in the layer from surface to 500 hPa. by the relative humidity, RH, (mean value between surface and 500 hPa. level), obtained from a numerical model.

In order to compute the PWRH factor, the precipitable water is expressed in inches of water and the relative humidity in percentage. This factor takes values between 0.0 and 2.0. An environment is considered to be dry if PWRH is significantly below 1.0 and quite moist if PWRH is greater than 1.0.

The PWRH factor decreases rainfall rates in very dry environments and increases them in very moist ones. However, for high latitudes where convective systems can contain hail (so that radar rainfall is unrealistically high), if IR cloud top temperature is lower than 215K , there is no need to increase the rainfall rates, but instead, it is necessary to decrease them whenever the environment is dry (PWRH<1.0). Based on this justification, the following criterion is applied:

If latitude >55°N, T10.8 < 215 K and PWRH >1.0 the computed rainfall rate should not be multiplied by the PWRH correction factor.

Otherwise, the computed rainfall rate is multiplied by the PWRH correction factor.

3.1.3.3.2 Cloud Growth Rate Correction Factor

Convective rain is assumed to be associated with growing clouds exhibiting overshooting tops. Consecutive satellite IR images are used to indicate vertically growing and decaying cloud systems.

A convective system is more active and produces greater rainfall rates when the tops are becoming colder and expanding. Based on the conclusion that decaying clouds with cold tops that are becoming warmer produce little or no rainfall, the output is modified according to the following:

· If a IR pixel in the second scene is colder than in the first one, convection is intensifying, so rainfall rate computed in that pixel with the information from the second scene remains the same.

· If a IR pixel in the second scene is warmer than in the first one, convection is weakening. In this case, rainfall rate computed with the information from the second scene is multiplied by a coefficient. The coefficient value can be modified by the user through the Keyword COEFF_EVOL_GRAD_CORR_00 in the model configuration file (Default value for Normal Mode (0.35) is set in the configuration file. Recommended value for Rapid Scan mode is 0.55).

· If there is no change in the cloud-top temperature in the two consecutive scenes (no growth or decay), rainfall rate computed from the second scene stays the same.

Therefore, the cloud growth correction factor, also designated as evolution correction factor, is only applied if the analysed pixel becomes warmer in the second image.

3.1.3.3.3 Cloud-top Temperature Gradient Correction Factor

When consecutive IR scenes are not available, cloud growth rate correction factor can not be applied. Then cloud-top temperature gradient correction is used instead.

This alternative correction method is based on the fact that much information can be extracted from cloud-top structure on a single IR image.

Cloud-top temperature gradient correction factor, also designated as gradient correction factor, is based on a search of the highest (coldest) and lowest (less cold) cloud tops. The concept of finite difference is used to locate the maximum and minimum local temperature within grids of 3x3 or 5x5 pixels centred on the point $P_0=(x_0,y_0)$. The idea is to search for the pixels that are below the average cloud top surface temperature (local temperature minima) and assume that these pixels indicate active convection connected to precipitation beneath.

Cloud-top temperature can be named as $T=T(x,y)$, where T is the cloud-top temperature as a function of the x and y co-ordinates. For those pixels whose T is lower than 250K, the following analysis is done:

Maxima and minima can be found studying the first and second derivative of T. The process is the following:

Second derivative of T in the point $P_0=(x_0, y_0)$:

$$T''_x (x = x_0) = \left.\frac{\partial^2 T}{\partial x^2}\right|_{x=x_0}$$

$$T''_y (y = y_0) = \left.\frac{\partial^2 T}{\partial y^2}\right|_{y=y_0}$$

$$T''_{xy} (x = x_0, y = y_0) = \left.\frac{\partial^2 T}{\partial x \partial y}\right|_{x=x_0, y=y_0}$$

Hessian in $P_0=(x_0, y_0)$:

$$H = (T''_x (x = x_0)) \cdot (T''_y (y = y_0)) - (T''_{xy} (x = x_0, y = y_0))^2$$

P_0 is characterized in the following way:

- $H > 0$ and $T''_x(x=x_0) < 0 \Rightarrow maximum$

- $H > 0$ and $T''_x(x=x_0) > 0 \Rightarrow minimum$

- $H < 0 \Rightarrow no\ maximum,\ no\ minimum$

- $H = 0 \Rightarrow not\ known$

Once this analysis has been done in a grid of 3x3 pixels, the previous derived rainfall rate is adjusted in the following way:

- If the pixel P_0 has a temperature maximum, indicating a relatively low cloud top with P_0 warmer than its surrounding, the previous rainfall rate is multiplied by a coefficient whose value can be modified by the user through the keyword COEFF_EVOL_GRAD_CORR_01 in the model configuration file (Default value: 0.25).

- If the pixel P_0 has a temperature minimum, which means that P_0 is colder than the surrounding indicating a high cloud top, the previous rainfall rate stays the same.

- If P_0 has not a temperature maximum or minimum, which means that P_0 is at the same height and temperature as the surrounding pixels, the previous rainfall rate is multiplied by a coefficient whose value can be modified by the user through the keyword COEFF_EVOL_GRAD_CORR_02 in the model configuration file (Default value: 0.50).

- If P_0 temperature can not be defined as a maximum or a minimum, the whole process is repeated using pixels within a 5x5 pixel's grid.

- Finally, if P_0 temperature remains undefined as a maximum or a minimum within the 5x5 pixel's grid, the original rainfall rate value is not modified.

3.1.3.3.4 Parallax Correction Factor

Two important factors for accurate precipitation estimations from satellite imagery are the position of the cloud tops and the influence of orographic effects on the distribution of precipitation.

The exact cloud position with respect to the ground below is needed to apply the orographic correction. This is not a problem when a cloud is located directly below the satellite; however, as one looks away from the sub-satellite point, the cloud top appears to be farther away from the satellite than the cloud base. This effect increases as you get closer to the limb and as clouds get higher.
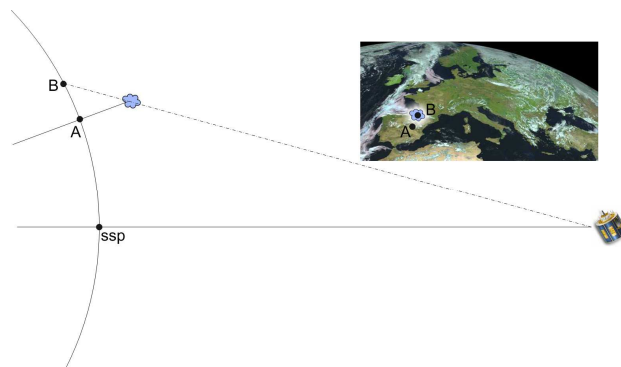

Figure 11. Parallax geometry

The parallax correction depends on three factors: a) the cloud height, b) the apparent position on the earth of that cloud and c) the position of the satellite.

The last two factors are known, but the first one has to be estimated. Two height estimation methods have been studied: numerical model and climatological profile obtained from the 1962 standard atmosphere model. Both of them are based on the conversion of each 10.8IR brightness temperature to height.

By default, height is estimated using NWP data. Parallax correction needs the NWP geopotential and temperature data at some levels (1000, 925, 850, 700, 500, 400, 300, 250 and 200). If NWP previous and next (according to the forecast time) models are available for the current slot time, a linear interpolation between these two models is performed.

Using 10.8IR temperature, a linear interpolation is done among NWP temperatures and geopotential giving as a result the cloud height for each pixel. This height is then converted to meters.

In case of lack of NWP data or different number of pressure levels found (between temperature and geopotential) the NWP method for height calculation won't be used, and the climatological profile will be applied instead.

The used climatological data contain geopotential and temperature information related to five zones: 0º-15º, 15º-30º, 30º-45º, 45º-60º and 60º-75º. Two seasons are considered, summer and

winter. A linear interpolation is used for latitude position and a cosine interpolation is used for Julian date.

Cloud height (in meters) is obtained using a bi-lineal interpolation according to the pixel temperature and considering the nearest four climatological temperature and geopotential measurements.

Parallax correction begins by converting the point and satellite locations into cartesian coordinates using the Earth centre as the origin. The Earth's surface is considered as an ellipsoid with an equatorial radius of 6378.077 Km. and a polar radius of 6356.577 Km. A virtual ellipsoid (as the earth's one) is performed using the distance from the cloud top to the earth centre. The cross point between the line joining the satellite and the apparent cloud surface position and this ellipsoid is found. The surface point connecting it with the Earth centre is then obtained, providing as result the new co-ordinate of the pixel. Finally, cartesian coordinates are converted into geographical ones.

When Parallax Correction is working, a spatial shift is applied to every pixel with precipitation according to the basic CRR value. In this re-mapping process, and only for a very small percentage of pixels, it could happen that (1) two pixels of the original image are assigned to the same pixel of the final image or (2) a pixel of the final image is not associated to any pixel of the original image (a "hole" appears in the final image). To solve these special cases, the next solutions have been implemented in the software:

- Case (1): the algorithm takes the maximum value of the rainfall rate

- Case (2): the software identifies the pixels with "hole". A 3x3 median filter centred on that hole pixel is applied in order to assign a rainfall rate value (to compute the median, the pixels within the 3x3 box identified as holes are excluded)

The theoretical basis used in the computing of the Parallax correction in both the PGE05 product and the SAFNWC/MSG Parallax Correction Tool [AD 6] is the same.

3.1.3.3.5 Orographic Correction Factor

Local topography has long been recognised to have an effect on the distribution and intensity of precipitation. However, the rain induced by orographic forcing is a complex process associated with complicated flows. Rainfall amounts are dependent on the atmospheric flow over the mountains and on the characteristics of the flow disturbances created by the mountains themselves.

This correction factor uses the interaction between the wind vector (corresponding to 850 hPa level from the NWP) and the local terrain height gradient in the wind direction to create a multiplier that enhances or diminishes the previous rainfall estimate, as appropriate.

The wind direction for the 48-km grid cell containing the location being tested is assumed to be constant in magnitude and direction. A one-dimensional cross-section of the terrain, determined by the wind direction, is extracted from the elevation map. The wind path length, D pixels, is variable from 3 km (pixel resolution) to 24 km (8 pixels), depending upon wind speed. Accordingly, D is determined by a 15-minute fetch (converted into units of pixels) of the wind speed U:

$$D = U * \frac{900s}{3000m / pixel}$$

The extracted terrain cross-section extends D pixels upwind and downwind from the reference site, giving a total length of 2D+ 1 pixel. The height of the test location can be denoted as Z_{D+1}; the location farthest upwind is Z_1, the location farthest downwind is Z_{2D+1}. The slope between a point A and a downwind point B can be defined as

$$S_{AB} = \frac{(Z_B - Z_A)}{(B - A)}$$

For each pixel, A, upwind of the site and the site itself (i.e., from 1 to D+1), the slope between it and each point B within D pixels downwind is calculated (i.e., from A+1 to A+D). The maximum slope found for each point A is retained as the slope S_A. The net slope S, used for the correction, is equal to the mean of the S_A values.

Finally, we can define a rainfall rate enhancement parameter, M, as the result of the vertical velocity induced by a wind with horizontal speed U blowing over a surface with slope of S. Since M should not have effect on the rainfall amounts on a flat terrain, it can be written as:

$$M = 1 + S * U$$

M is limited to be between 0.2 and 3.5. Every CRR rain point is multiplied by the co-located M values. The eight pixels all around the image edge can not be corrected.

3.1.3.4 Lightning algorithm

As lightning activity is related with convection, this information has been added to the product.

An algorithm for rainfall estimation using lightning information has been developed. This algorithm is based on the assumption than the higher is the spatial and temporal density of lightning occurrence, the stronger is the convective phenomenon and the higher is the probability of occurrence and the intensity of convective precipitation.

Only Cloud-to-Ground lightning flashes are used by this algorithm. To incorporate this information into the product a rain rate has been assigned to every lightning depending on:

- the time distance ($\Delta\tau$) between the lightning event and scanning time of the processing region centre.

- the location of the lightning

- the spatial density of lightning in a time interval.

In order to know the rain rate to be assigned to each lightning the process proposed in Tapia et all. [RD.11] has been followed in this way:

A representative set of convective storms occurred over Spain have been selected. For each of them a Rainfall-Lightning Ratio (RLR) has been computed. This RLR takes into account the quantity of precipitation measured as well as the number of lightning occurred during each event. The mean of the RLR obtained for the selected storms is 10.08 mm/lightning.

The procedure followed is the following:

First of all, the number of lightning occurred within an interval Δt before the scanning time of the processing region centre, are assigned to each pixel according to its latitude and longitude. The interval Δt is selected by the user (default value: 15 minutes).

Afterwards a rain amount is assigned to every pixel according to the number of lightning allocated to it. The variability of the spatial correlation between lightning and rainfall within the storm area suggest the use of a uniform distribution of rainfall about lightning flashes [RD.11].

For this reason, instead of assigning the RLR just to one pixel, this quantity of precipitation is spread around the pixel in order to obtain a more homogeneous pattern of precipitation in this way:

Figure 12. Spreading of the RLR value in a 5 by 5 pixels box

Being Z1, Z2, Z3 and Z4 the rain rate assignments according to the RLR obtained in the calibration process. The spreading of the RLR value has been done in the following way:

Z1= 0.228 * RLR (default value: 2.30 mm)

Z2= 0.074 * RLR (default value: 0.75 mm)

Z3= 0.025 * RLR (default value: 0.25 mm)

Z4= 0.010 * RLR (default value: 0.10 mm)

Simultaneously, the time of occurrence of each lightning event is taken into account. Since the point of view of instantaneous precipitation rates, lightning closer in time to the instant of rainfall measurement are better spatially correlated to the convective nuclei at that moment. So a higher weight is given to those lightning that occurred closer in time to the scanning time of the processing region centre (CRR time). To do that, all rain rates already assigned are multiplied by the factor COEFF_τ being:

$$COEF\_\tau = -1*10^{-7}(\Delta\tau)^4 - 3*10^{-3}(\Delta\tau)^2 + 1$$

Where Δτ is the interval of time between the time of occurrence of the lightning and the CRR time:

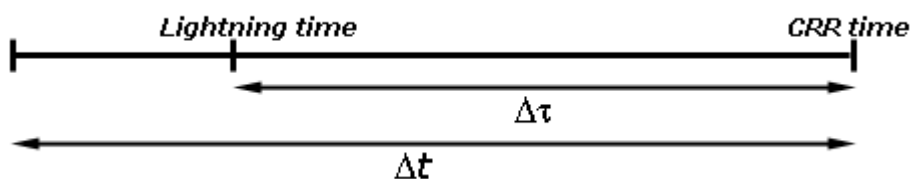*Figure 13. Diagram that shows the relationship between Δτ and Δt*

Based on the fact than the higher is the spatial density of lightning occurrence the higher is the probability of the occurrence of greater intensities of precipitations, the density of lightning around each pixel is taken into account in the last step. To do that, rain rate corresponding to each pixel is multiplied by COEFF_N with:

$$COEFF\_N = a * \left(1 - b^N\right)$$

Where N is the number of lightning occurred in a 11x11 pixels box centred on every pixel within the Δt interval. a and b are the parameters of the equation (default values: a=0,45; b=0,7).

Once the precipitation pattern has been computed, it is compared to the CRR precipitation pattern in order to obtain the final product. This final product contains the highest rain rate of the two.

3.2 LIST OF INPUTS FOR CONVECTIVE RAINFALL RATE (CRR)

3.2.1 Dynamic inputs for Convective Rainfall Rate (CRR)

➢ Satellite imagery:

The following SEVIRI brightness temperatures and normalized visible reflectances are needed at full IR spatial resolution:

T10.8μm	TPrev10.8μm	T6.2μm	VIS0.6μm
Mandatory	Optional*	Mandatory	Optional

Table 4. CRR SEVIRI inputs

The SEVIRI channels are input by the user in HRIT format and extracted on the desired region by SAFNWC software package.

* If TPrev10.8μm is not available, the Cloud Growth Rate Correction Factor can not be computed but the Cloud-top Temperature Gradient Correction Factor is computed instead as an alternative.

➢ Numerical model:

This information is mandatory for moisture and orographic corrections. When this information is not available, CRR is computed without applying these two corrections.

Parallax correction can run without the NWP parameters using the climatological profile.

For moisture correction:

Relative Humidity at 1000, 925, 850, 700 and 500 hPa

Dew Point temperature at 2 m

Temperature at 2 m

Temperature at 1000, 925, 850, 700, 500 hPa

Surface Pressure

For parallax correction:

Temperature at 1000, 925, 850, 700, 500, 400, 300, 250 and 200 hPa

Geopotential at 1000, 925, 850, 700, 500, 400, 300, 250 and 200 hPa

For orographic correction:

U and V wind components in 850 hPa

➢ Lightning information file for PGE05:

A file with information on every lightning stroke occurred in a time interval is mandatory to choose the option of adjusting the CRPh precipitation pattern with the lightning information provided by ground based lightning detection networks. Information about the "Lightning information file for CRPh product" structure can be found in the Interface Control Document [AD 3].

The CRR lightning algorithm and the coefficients applied have been derived for Spain using the lightning information from the AEMET lightning detection network.

Ground based lightning detection networks provide information with different performances in detection efficiency and location accuracy. For this reason, the keyword APPLY_LIGHTNING in the model configuration file is set to 0 and by default the lightning information is not used.

Before to use the lightning algorithm it is highly recommended to the user to adapt the lightning coefficients to the specific performances of the used lightning detection network through the appropriate keywords in the model configuration file.

3.2.2 Static inputs for Convective Rainfall Rate (CRR)

The following information is included or computed by the software package:

➢ Sun angles associated to SEVIRI imagery

This information is mandatory in order to normalize the VIS image when the solar channel is used. It is computed by the CRR software itself using the definition of the region and the satellite characteristics.

➢ Ancillary data sets:

Saturation Vapour table is mandatory for Humidity correction.

Saturation Vapour Polynomial Coefficients table is mandatory for Humidity correction.

Elevation mask is mandatory for orographic correction

Climatological profile is necessary as a back up for Parallax correction in case NWP is not available.

➢ Model configuration file for PGE05:

The CRR model configuration file contains configurable system parameters in the product generation process related to algorithm thresholds, ancillary datasets, numerical model data, corrections to be applied, etc. The complete list of these parameters and the explanation of the most useful ones are available in the Product User Manual [AD 1] and in the Interface Control Document [AD 3].

3.3 DESCRIPTION OF THE CONVECTIVE RAINFALL RATE (CRR) OUTPUTS

CRR product is coded in HDF5 format. The available outputs are the following:

CRR classes:

The rainfall rates obtained by the CRR algorithm expressed in mm/h are converted into eleven classes as it is shown below:

CLASSES	RAINFALL RATE (mm/h)
0	rate < 0.2
1	0.2 = rate < 1
2	1 = rate < 2
3	2 = rate < 3
4	3 = rate < 5
5	5 = rate < 7
6	7 = rate < 10
7	10 = rate < 15
8	15 = rate < 20
9	20 = rate < 30
10	30 = rate < 50
11	rate ≥ 50

Table 5. CRR classes

This output includes its own colour palette.

CRR hourly accumulations:

Rainfall rates from the images in the last hour are used in order to compute the hourly accumulation. This output provides precipitation accumulations from 0.0 to 51.0 mm with a step of 0.2 mm and includes a palette that uses the same colours as the classes and the instantaneous rain rates in mm/h outputs palettes.

CRR intensity in mm/h:

This output provides rainfall rates from 0.0 to 51.0 mm/h with a step of 0.2 mm/h and includes a palette that uses the same colours as the classes and the hourly accumulation outputs palettes.

CRR_QUALITY:

8 bits mask indicating which corrections have been applied for each pixel. Moreover, it indicates whether the product is latitude dependant or not, and if the SEVIRI solar channel and the lightning information have been used during the computation of the CRR:

1 bit for moisture correction:

    0: No correction

    1: Corrected by PWHR factor

1 bit for cloud growth rate correction:

    0: No correction

    1: Corrected by IR data from previous slot

1 bit for cloud top temperature correction:

    0: No correction

    1: Corrected by IR temperature gradient

1 bit for parallax correction:

    0: No correction

    1: Corrected by parallax

1 bit for orographic effect correction:

    0: No correction

    1: Corrected by orographic effects

1 bit for latitude dependant: set always to 1 since dependency on latitude is always taken into account

1 bit for solar channel used:

    0: No solar channel used

    1: Solar channel used

1 bit for lightning information used:

    0: No lightning information used

    1: Lightning information used

CRR_DATAFLAG:

    8 bits mask indicating the processing status of each pixel:

1 bit for 10.8IR, 6.2WV or 0.6VIS-N data missing

    0: All the channel data required are available

    1: There is a missing data in some channel

1 bit to indicate if the set of SEVIRI data is out of the calibration matrices range: set always to 0 since calibration matrices are not used.

1 bit to identify mathematical errors

    0: No mathematical error

    1: A mathematical error has occurred

	Algorithm Theoretical Basis Document for "Convective Rainfall Rate" (CRR-PGE05 v4.0)	**Code:** SAF/NWC/CDOP2/INM/SCI/ATBD/05
		Issue: 4. 0 **Date**: *15 July 2013*
		File: SAF-NWC-CDOP2-INM-SCI-ATBD-05_v4.0
		Page: 32/36

1 bit for the convective filter

> 0: The CRR value remains the same

> 1: The CRR value has been set to zero because of the filtering process

1 bit for the filled holes after parallax correction

> 0: No hole due to the parallax correction

> 1: Hole due to the parallax correction filled by a median filter

2 bits the hourly accumulation CRR band status

> 0: All required bands were available

> 1: One previous CRR band is missing

> 2: At least two previous CRR bands are missing (no consecutive)

> 3: At least two previous CRR bands are missing (some are consecutive)

1 bit for the status of the CRR pixels used to compute the hourly accumulation

> 0: All the pixels used in the computing of the hourly accumulation have their CRR_DATAFLAG bits set to 0

> 1: At least one of the pixels used in the computing of the hourly accumulation has at least one of its CRR_DATAFLAG bits set to 1

4. PRACTICAL CONSIDERATIONS

4.1 VALIDATION OF CONVECTIVE RAINFALL RATE (CRR)

The following tables summarize the validation results of this CRRv4.0. More details can be obtained from the Validation Report for "Convective Rainfall Rate" (CRR-PGE05 v4.0) [AD 2].

Green colour values in tables mean that FAR or POD values obtained in that validation fulfill the FAR and POD target values defined in the NW CSAF Product Requirements document [AD 7].

4.1.1 Instantaneous rates

4.1.1.1 Accuracy statistics

Algorithm	N	Mean (mm/h)	ME (mm/h)	MAE (mm/h)	RMSE (mm/h)
3-V function	846153	0,60	0,47	1,18	2,81
2-V function	868860	0,63	0,81	1,55	3,19

Table 6. Accuracy statistics for instantaneous rates

4.1.1.2 Categorical statistics

Algorithm	FAR (%)	POD (%)	CSI (%)	PC (%)
3-V function	30.6	58.1	45.9	65.4
2-V function	44.6	54.4	37.8	55.1

Table 7. Categorical statistics for instantaneous rates

4.1.2 Hourly accumulations

4.1.2.1 Accuracy statistics

Algorithm	N	Mean (mm/h)	ME (mm/h)	MAE (mm/h)	RMSE (mm/h)
3-V function	576334	0,39	0,38	0,79	1,99
2-V function	602462	0,41	0,54	0,97	2,15

Table 8. Accuracy statistics for hourly accumulations

4.1.2.2 Categorical statistics

Algorithm	FAR (%)	POD (%)	CSI (%)	PC (%)
3-V function	49.0	63.8	39.3	63.9
2-V function	58.2	58.6	32.3	55.4

Table 9. Categorical statistics for hourly accumulations

4.2 EXAMPLE OF CONVECTIVE RAINFALL RATE (CRR) VISUALISATION

4.2.1 Instantaneous Rates

Below is shown an image corresponding to CRR instantaneous intensities output. It has been obtained at full resolution and all corrections have been applied.
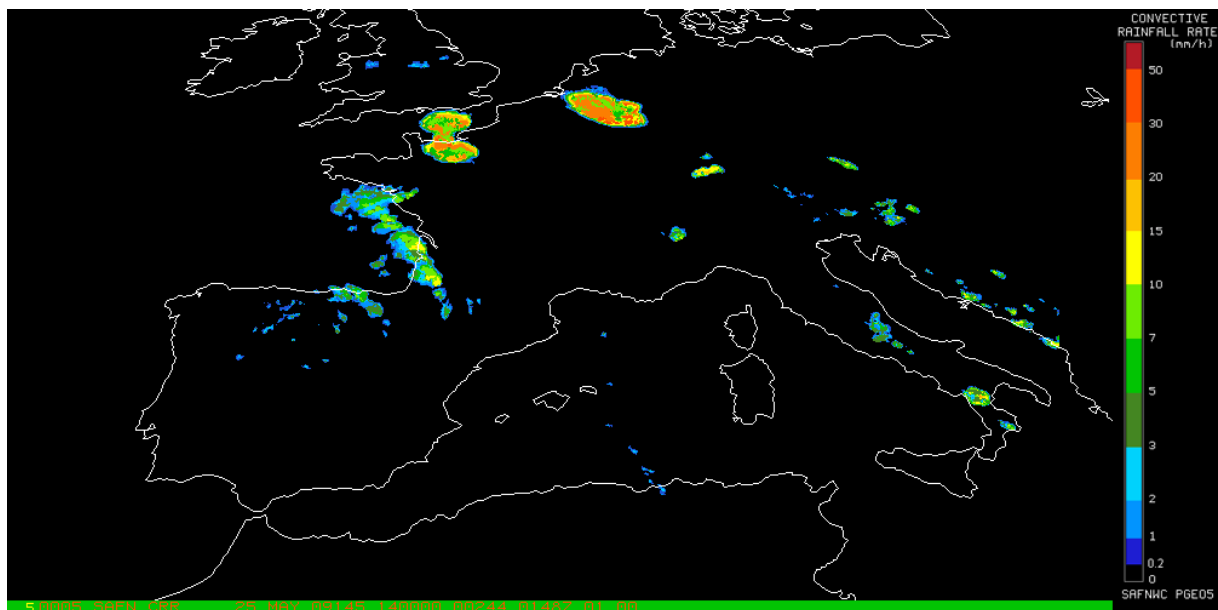

Figure 14. CRR instantaneous intensities output corresponding to 25th May 2009 at 14:00Z.

4.2.2 Hourly Accumulations

Below is shown an image corresponding to CRR hourly accumulations output. It has been obtained at full resolution and all corrections have been applied
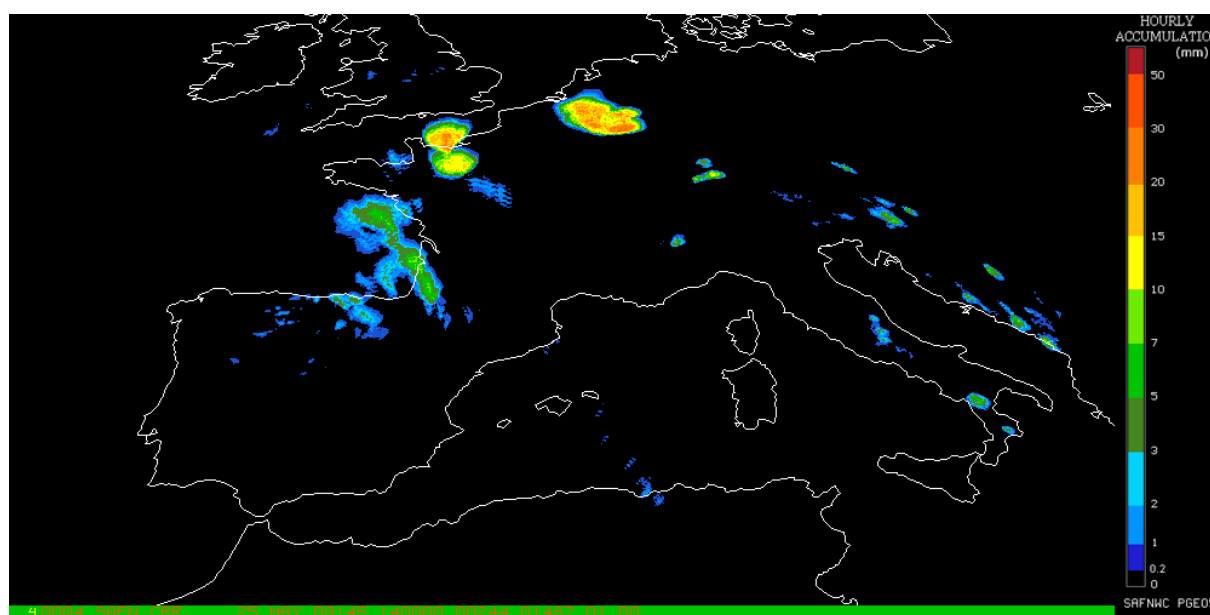

Figure 15. CRR hourly accumulations output corresponding to 25th May 2009 at 14:00Z

4.3 IMPLEMENTATION OF CONVECTIVE RAINFALL RATE (CRR)

The execution step is the real-time process of the SEVIRI images over the region. This process consists of the launch of the command PGE05 along with the required parameters: slot, region file name and model configuration file.

PGE05 requires mainly six steps:

- First step consists of an initialisation, which performs the environment settings for a given region, and the Day/Night mask for all the pixels processed.

- Second step is intended to read the external data as SEVIRI bands.

- Third step is to normalise the VIS image, in case the solar channel is used.

- Fourth step holds the core process for the computation of the CRR product. For each pixel the next parameters are calculated: CRR mm/h basic values, Quality and Data flags.

- Fifth step develops those corrections that have been chosen to be applied using the output data from the previous step. CRR mm/h values, Quality and Data flags are updated.

- Sixth step computes rain rates from lightning information if this option has been chosen. This data are combined with the output data from the previous step. CRR mm/h values, Quality and Data flags are updated.

- Last step computes the hourly accumulations and writes the product outputs in SAFNWC format.

4.4 CONVECTIVE RAINFALL RATE (CRR) ASSUMPTIONS AND LIMITATIONS

The CRR product is based on a calibration method which requires the availability of a training set of precipitation data derived from radar information, to be used as ground truth to derive the relationship between satellite information and rainfall rate.

Regarding the radar data:

- The drop size distribution, used to obtain the radar rainfall rates (mm/h) from the radar reflectivity (Dbz), has been assumed to be the Marshall Palmer type throughout the calibration and validation procedures.

- No online operational method has been applied in order to adjust the radar rainfall intensities using rain gauge measurements.

Regarding the lightning algorithm:

- The CRR lightning algorithm and the coefficients applied have been derived for Spain using the lightning information from the AEMET lightning detection network. Concerning this particular, it is important to highlight that ground based lightning detection networks provide information with different performances in detection efficiency and location accuracy. For this reason, in the model configuration file the keyword APPLY_LIGHTNING is set to 0 and by default the lightning information is not used.

- Before to use the lightning algorithm it is highly recommended to the user to adapt the coefficients to the specific performances of the lightning detection network serving that information.

- This issue could be solved in a satisfactory manner in the future with the use of lightning information provided by MTG Lightning Imager which will be able to provide lightning information with uniform and controlled performances all around the coverage area.