NWC/CDOP3/GEO/AEMET/SCI/UM/Precipitation, Issue 2 , Rev. 0.1

28th February 2022

Applicable to

GEO-PC-v154 (NWC-022)
GEO-CRR-v402 (NWC-026)
GEO-PCPh-v30 (NWC-027)
GEO-CRRPh-v30 (NWC-084)

Prepared by AEMET

REPORT SIGNATURE TABLE

Function	Name	Signature	Date
Prepared by	José Alberto Lahuerta (AEMET)		28th February 2022
Reviewed by	Llorenç Lliso and Pilar Ripodas (GEO Managers)		28th February 2022
Authorised by	Pilar Rípodas NWC SAF Project Manager		28th February 2022

DOCUMENT CHANGE RECORD

Version	Date	Pages	CHANGE(S)
1.0	21 January 2019	53	First version of the User Manual for the Precipitation Product Processors NWC SAF SW Package GEO v2018 DRR. Content derived from the User Manual for the Precipitation Product Processors of the NWC/GEO v2016 NWC/CDOP2/GEO/AEMET/UM/Precipitation
2.0	10th January 2022	71	Version for v2021 DRR
2.0.1	28th February 2022	72	Updated accordingly to RIDS submission and DRR revision

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1. INTRODUCTION

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 geostationary meteorological satellites, NWC-GEO.

1.1 SCOPE OF THE DOCUMENT

This document is the User Manual (UM) for the precipitation products Precipitating Clouds (PC), Convective Rainfall Rate (CRR) and Precipitation products from Cloud Physical Properties (PPh) of the NWC/GEO software package. PPh generates two different products: Precipitating Clouds from Cloud Physical Properties (PCPh) and Convective Rainfall rate from Cloud Physical Properties (CRRPh).

UM document contains practical information on the characteristics of the products, including the input data and the outputs of the products. It also gives information about the algorithm's implementation and configuration.

1.2 SOFTWARE VERSION IDENTIFICATION

This document applies to the algorithms implemented in the release 2018 of the NWC/GEO software package (GEO-PC-v1.5.4, GEO-CRR-v4.0.2, GEO-PCPh-v3.0 and GEO-CRRPh-v3.0).

1.3 IMPROVEMENT FROM PREVIOUS VERSION

2021 precipitation products version includes these technical improvements:

- New CRRPh and PCPh algorithms based on a Principal Component Analysis. There is only one algorithm for each CRRPh and PCPh that includes both day and night conditions.
- Microphysical properties are simulated at night time and used in the algorithm.
- More information is extracted from the SEVIRI channels.
- CRRPh incorporates a Cloud Water Path enhancement correction factor along with a lightning module.
- Adaptation to Himawari9 and GOES17. This adaptation is purely technical in order to use Himawari9 and GOES17 channels, but no objective validation has been performed for these satellites.

Note:

PC and CRR keep the same from previous 2018.1 version

1.4 Definitions, Acronyms and Abbreviations

AEMET	Agencia Estatal de Meteorología
ATBD	Algorithm Theoretical Basis Document
BALTRAD	Baltic Radar Network
CAPPI	Constant Altitude Plan Position Indicator
CMIC	Cloud Microphysics
COT	Cloud Optical Thickness
CRRPh	Convective Rainfall Rate from Cloud Physical Properties
CRR	Convective Rainfall Rate
CSI	Critical Success Index
CT	Cloud Type
CWP	Cloud Water Path
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAR	False Alarm Ratio
HRIT	High Rate Information Transmission
ICD	Interface Control Document
ICP	Illumination Conditions Parameter
IQF	Illumination Quality Flag
IR	Infrared
KRR	Kernel Ridge Regression
MAE	Mean Absolute Error
CTMP	Cloud Top Microphysical Properties
ME	Mean Error
MRV	Maximum Reflectivity in the Vertical
MSG	Meteosat Second Generation
NIR	Near Infrared
NWCLIB	Nowcasting SAF Library
NWC SAF	Satellite Application Facility for Nowcasting
PC	Percentage of Corrects
PCPh	Precipitating Clouds from Cloud Physical Properties
PGE	Product Generation Element
POD	Probability of Detection
PoP	Probability of Precipitation
PPh	Precipitation from Cloud Physical Properties

PWRH	Moisture Correction Factor
R_{eff}	Effective Radius
RLR	Rainfall-Lightning Ratio
RMSE	Root Mean Square Error
RR	Rain Rate
SAF	Satellite Application Facility
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

1.5 REFERENCES

1.5.1 Applicable Documents

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.X].

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.

Current documentation can be found at the NWC SAF Helpdesk web: https://www.nwcsaf.org

Reference	Title	Code	Vers	Date
[AD. 1]	Proposal for the Third Continuous Development and Operations Phase (CDOP-3) March 2017-February 2022	NWC SAF: CDOP-3 proposal	1.0	11/04/16
[AD. 2]	NWCSAF Project Plan	NWC/CDOP3/SAF/AEMET/MGT/PP	1.6	01/12/21
[AD 3]	Configuration Management Plan for the NWC SAF	NWC/CDOP3/SAF/AEMET/MGT/CMP	1.1	15/04/20
[AD 4]	NWCSAF Product Requirements Document	NWC/CDOP3/SAF/AEMET/MGT/PRD	1.5	01/12/21

Table 1: List of Applicable Documents

1.5.2 Reference Documents

The reference documents contain useful information related to the subject of the project. These reference documents complement the applicable ones, and can be looked up to enhance the information included in this document if it is desired. They are referenced in this document in the form [RD.X].

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.

Current documentation can be found at the NWC SAF Helpdesk web: https://www.nwcsaf.org

Reference	Title	Code	Vers	Date
[RD 1]	Product User Manual for SAFNWC/MSG "Precipitating Cloud" (PC-PGE04 v1.5)	SAF/NWC/CDOP2/SMHI/SCI/PUM/4	1.5.4	15/07/13
[RD 2]	Data Output Format for the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/DOF	2.0.1	28/02/22
[RD 3]	User Manual for the NWC/GEO: Software Part	NWC/CDOP3/GEO/AEMET/SW/UM	2.0.1	28/02/22
[RD 4]	Interface Control Document for Internal and External Interfaces of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/ICD/1	2.0.1	28/02/22
[RD 5]	Algorithm Theoretical Basis Document for the Precipitation Product Processors of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SCI/ATBD/Precipitation	1.0.1	29/10/21
[RD 6]	Component Design Document for the Precipitation Product Processors of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/ACDD/Precipitation	2.0	27/02/17

Table 2: List of Referenced Documents

2. RECIPITATING CLOUDS (PC) PRODUCT

2.1 DESCRIPTION OF PRECIPITATION CLOUDS (PC)

2.1.1 Goal of Precipitating Clouds (PC)

Refer to section 2.1 of Product User Manual for SAFNWC/MSG "Precipitating Cloud" (PC-PGE04 v1.5) document *[RD 1]*.

2.1.2 Outline of Precipitating Clouds (PC)

Refer to section 2.2 of Product User Manual for SAFNWC/MSG "Precipitating Cloud" (PC-PGE04 v1.5) document *[RD 1]*.

2.1.3 Description of Precipitating Clouds (PC) output

The content of the PC output (stored in $SAFNWC/export/PC in netCDF format) is described in the Data Output Format Document [RD *2]*. A summary is given below:

NetCDF Common Atributes	
product_completeness	Percentage of pixels within the region containing data
product_quality	Weighted mean of the quality of all pixels with data, using the following weights: 1: Good pixels, 0.5: Questionable quality, 0.0: Bad quality

Container	Content
PC	NWC GEO PC Total Precipitation Likelihood:

Class	Total Precipitation Likelihood (%)
0	0
1	10
2	20
3	30
4	40
5	50
6	60
7	70
8	80
9	90
10	100
FillValue	No data or corrupted data

Geophysical Conditions

Field	Type	Description
Space	Flag	Set to 1 for space pixels
Illumination	Parameter	Defines the illumination condition 0: N/A (space pixel) 1: Night 2: Day 3: Twilight
Sunglint	Flag	Set to 1 if Sunglint
Land_Sea	Parameter	0: N/A (space pixel) 1: Land 2: Sea 3: Coast

Processing Conditions

Field	Type	Description
Satellite_input_data	Parameter	Describes the Satellite input data status 0: N/A (space pixel) 1: All satellite data are available 2: At least one useful satellite channel is missing 3: At least one mandatory satellite channel is missing
NWP_input_data	Parameter	Describes the NWP input data status 0: N/A (space pixel or NWP data not used) 1: All NWP data are available 2: At least one useful NWP field is missing 3: At least one mandatory NWP field is missing
Product_input_data	Parameter	Describes the Product input data status 0: N/A (space pixel or Auxiliary data not used) 1: All input Product data are available 2: At least one useful input Product is missing 3: At least one mandatory input Product is missing
Auxiliary_input_data	Parameter	Describes the Auxiliary input data status 0: N/A (space pixel or Auxiliary data not used) 1: All Auxiliary data are available 2: At least one useful Auxiliary field is missing 3: At least one mandatory Auxiliary field is missing

Quality

Field	Type	Description
Nodata	Flag	Set to 1 if pixel is NODATA
Internal_consistency	Flag	Set to 1 if an internal consistency check has been performed. Internal consistency checks will be based in the comparison of the retrieved meteorological parameter with physical limits, climatological limits, neighbouring data, NWP data, etc.
Temporal_consistency	Flag	Set to 1 if a temporal consistency check has been performedTemporal consistency checks will be based in the comparison of the retrieved meteorological parameters with data obtained in previous slots.
Quality	Parameter	Retrieval Quality 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated

Another file is generated including statistical information related to the product generation. It contains histograms of precipitation probability and processing flags, and it is generated in ascii format. This file may be useful to get statistics on general algorithm performance.

2.2 IMPLEMENTATION OF PRECIPITATION CLOUDS (PC)

Previous condition and licences

The right to use, copy or modify this software is in accordance with EUMETSAT Policy for the SAFNWC/MSG software package.

2.2.1 Installation of Precipitating Clouds (PC)

PC product is generated by the GEO-PC component of the NWC/GEO software package. Detailed information on how to run this software package is available in the software user manual [RD 3].

The software installation procedure does not require special resources. It is restricted to decompress the distribution files (a gzip-compressed tar files) and to successfully build the executable GEO-PC-v<version> file to be stored into the $SAFNWC/bin directory.

Once the GEO-PC-v<version> of the NWC-GEO is installed and configured in the system, its operational use requires the definition of some Configuration files in order to select the regions to be processed and some needed configurable parameters.

2.2.2 Preparation step for Precipitating Clouds (PC)

The configuration file in charge of the region where the product is going to be run, has an optional name and the ".cfg" extension. This file contains the region centre location and the size image. When the application is installed, some region configuration files appear in $SAFNWC/config. Each of them corresponds to a different region; nevertheless users can create their own region configuration file. Information on the region_conf_file can be found in the Interface Control Document for Internal and External Interfaces of the NWC/GEO document *[RD 4]*.

The configuration file in charge of the product settings is the PC model configuration file that has an optional name and the ".cfm" extension. Through this file the user can configure the way the product is going to be run choosing options such as the sun zenith angle threshold to choose between day and night algorithms. More information on this configuration file can be found in section 2.3.2.

In order to run PC product, NWP data (surface temperature) have to be available in $SAFNWC/import/NWP_data directory.

2.2.3 Execution of Precipitating Clouds (PC)

The GEO-PC execution step consists in the launch of the command:

% GEO-PC-v<version> <YYYY-MM-DDThh:mm:ssZ> <region_conf_file> <model_conf_file>

Information on the region_conf_file can be found in the Interface Control Document for Internal and External Interfaces of the NWC/GEO document *[RD 4]* and model_conf_file is described in section 2.3.2.

GEO-PC requires mainly ten steps:

- Setting the Date/Slot in a UTC structure.
- Definition of the Processing Region Reading read form the Processing Region Configuration File.
- Reading of the Model Configuration File and the Algorithm Configuration.
- Reading of Satellite input data according to the required slot in the required processing region.
- Reading of CT product for the current slot.
- Computation of Navigation data in the processing region.
- Reading of NWP Surface Temperature.
- Implementation of PC algorithm to compute precipitation probability in different classes.
- Writing the PC product file according to the specification provided in the DOF [RD *2]*.
- Creating and writing Statistics file containing histograms of precipitation probability in different classes.

More information on the GEO-PC execution steps can be found at the Component Design Document for the Precipitation Product Processors of the NWC/GEO document [RD 6].

2.3 INPUTS AND CONFIGURABLE PARAMETERS FOR PRECIPITATION CLOUDS (PC)

2.3.1 List of inputs for Precipitating Clouds (PC)

Satellite imagery:

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

VIS0.6	NIR1.6	IR3.9	IR6.2	IR7.3	IR10.8	IR12.0
Day-time	Day-time	Day-time	Day-time and Night-time	Day-time and Night-time	Day-time and Night-time	Day-time and Night-time

Table 3. PC SEVIRI inputs

The SEVIRI channels are input by the user in HRIT format and extracted on the desired region by NWC-GEO software package. These data must be located in the $SAFNWC/import/Sat_data directory.

Cloud type (CT) product output:

CT output, in netCDF format, is mandatory input to PC. This netCDF file must be located in $SAFNWC/export/CT directory.

NWP parameters:

The NWP files must be located in $SAFNWC/import/NWP_data directory. In real time operational mode, the NWC SAF package has predefined tools (coordinated by the NWC SAF Task Manager daemon) which check every minute for new NWP data making automatically the spatial remapping to the predetermined regions to process on to $SAFNWC/tmp directory. This avoids spending time in every call to each component to make the remapping process. In off-line operational mode, the "AllMapping" script allows to do the spatial remapping.

Surface temperature is a mandatory input for PC.

Sun and satellite angles associated to satellite imagery

This information is mandatory. It is computed by the PC software itself, using the definition of the region and the satellite characteristics.

2.3.2 Configurable parameters for Precipitating Clouds (PC): Model Configuration File

The PC model configuration file must be placed in the $SAFNWC/config directory and contains the following information:

Keyword	Description	Type	Default Value(s)

PGE_ID	Identifier of the product processor	Chain of characters	GEO-PC
SEV_BANDS	Satellite channels to be used by GEO-PC	Chain of characters	VIS06, NIR16, IR38, WV62, WV73, IR108, IR120
NWP_PARAM	Parameter :Temperature at surface level (K) sampling rate : (=segment size) interpolation method	Chain of characters	NWP_ST 4 BLM
PRODUCT_CONFIG_FILE	PC configuration file	Chain of characters	pge04_algorithm.conf

Table 4. Model configuration file keywords table applicable to PC product

Parameters to be configured by the user, included in the PC configuration file, are the following:

Keyword	Description	Type	Default Value(s)
SUNZEN_ANGLE	Solar zenith angle to select between day and night algorithms (in degrees). It is possible to configure the product to only use the night algorithm by setting the sun zenith angle threshold to 0. This would avoid discontinuities in the product at the day/night transition on the cost of degrading performance during day time	Double	70.0
PROBABILITY_THRESH	If the probability for "no rain" is lower or equal PROBABILITY_THRESH, the pixel will be processed as potentially raining, otherwise the probability of rain is set to zero	Integer	90

Table 5. Parameters to be configured included in the PC configuration file

It is also possible to configure which cloud classes are treated as potentially raining. This can be done through the keyword CLOUDTYPE_DEFINITION: CLOUDTYPES by configuring three values:

CLOUDTYPE (integer)

Used (1) / Not used (0) (integer)

CT algorithm to be used with this CT class (from 0 to 4) (integer)

PC configuration file is placed at the $SAFNWC/import/Aux_data/PC directory.

2.4 WARNING AND ERROR MESSAGES

The PGEs use generic exit codes to inform about the success or failure of the product generation process. These generic codes are:

Code (#)	Code (ID)	Description
0	OK	The product has been generated successfully
128	ERROR_COMMAND	The command line arguments, content or format is not correct
129	ERROR_FILE_ACCESS	Error opening a file to read and/or write
130	ERROR_FILE_IO	Error reading and/or writing data
131	ERROR_MEMORY	Error allocating memory
132	ERROR_MATH	Mathematical error (e.g. division by zero)
255	ERROR	Generic Error which disables processing

Table 6. : Generic PGE exit codes

In addition, the PGEs also generates detailed messages to inform the operator about the conditions of the processing. This information is particularly useful when the generation of a product fails, to identify the cause of the malfunction and to implement the corrective actions, if possible, to guarantee the generation of the product in next slots.

Some of these messages can be originated in low-level functions of the NWCLIB. In that case, an error message is sent by the NWCLIB function and specific warning/error codes are returned.

The following table shows the whole list of errors and warnings that can appear during the running of NWC/GEO-PC-v2021 executable, the reasons causing these errors and warnings, and the way the NWCSAF user can try to solve them. In any case, if the errors or warnings persist, the NWCSAF Helpdesk should be contacted.

Code (E/W)	Message	Comment	Recovery action
	GEO-PC High level Error messages		
E	"Error executing GEO-PC-vnnn *" "Error in date format (%s). Required YYYYMMDDThhmmssZ"	Unable to initiate the GEO-PC	Check command line arguments, content and format
E	"Error Setting the Region. Check Region and Satellite Configuration Files "	Unable to set the Region Configuration file	Check availability, access, content and format of the region configuration file. See error messages immediately preceding this one
E	"Error reading the Model Configuration File '%s'" "Could not get the PRODUCT_CONFIG_FILE from model configuration file"	Unable to read the model configuration file	Check availability, access, content and format of the model configuration file. See error messages immediately preceding this one
E	"Could not read the product configuration file '%s'"	Unable to read the product configuration file	Check availability, access, content and format of the product configuration file. See error messages immediately preceding this one
E	"Failed to initialize the Satellite data reading" "Failed reading Satellite data"	Unable to read required Satellite data	Check availability, access, content and format of Satellite Data. See error messages immediately preceding this one
E	"Failed reading CT product"	Unable to read required input CT product	Check availability, access, content and format of the CT product. See error messages immediately preceding this one
E	"Error while reading navigation data"	Unable to get lat/lon, sun or satellite angles	See error messages immediately preceding this one

Code (E/W)	Message	Comment	Recovery action
E	"Failed to read NWP data: Surface Temperature/4/BLM"	Unable to read required input NWP data	Check availability, access, content and format of NWP data (remapped and available in DATABUF). See error messages immediately preceding this one
E	"Could not generate precipitating cloud"	Error computing PC values	See error messages immediately preceding this one
E	"Failed to write precipitating cloud to disk"	Unable to generate the output PC product	Check access to $SAFNWC/export/PC and free disk space
E	"HAVE FINISHED THE PC GENERATION WITH ERROR"	The execution of the PC does not conclude successfully	See error messages immediately preceding this one
GEO-PC Low level Error messages			
E	"Failed to open *" "Failed to read *"	Unable to open, create, read or write referred file	Check file availability, disk access and free disk space
E	"Error reading CT for region %s-NR, slot %s" "Error reading <var> container"	Unable to load/read required CT product	Check of CT availability and format in $SAFNWC/export/CT directory
E	"Could not allocate memory *" "Error allocating memory *" "Failed to allocate/reallocate *"	Problem of memory allocation	Check memory
E	"There is no algorithm field for algorithm %d!"	Error reading algorithm data in PGE04 Algorithm configuration file	Check availability and content of PGE04 Algorithm Configuration File in $SAFNWC/import/Aux_data/PC
E	"Algorithm %d needs * field * in the sat_data"	Unable to access required satellite data	Check availability and content of required Satellite data to execute PGE04-PC
E	"Got an error while filling probability fields"	Error in FillProbabilityFields() procedure	See error messages immediately preceding this one
E	"Failed to generate pc algorithm 0 for li = %d, ci=%d"	Error executiong PCAlgorithm*n*() procedure	See error messages immediately preceding this one
E	"There is no support for algorithm %d"	Unconsistency of PGE04-PC configuration files	Check availability and content of PGE04 Algorithm Configuration Files in $SAFNWC/import/Aux_data/PC
E	"Failed to Initiate output product for writing" "Failed to write <var> container in output product"	Unable to create/write PC output product	See error messages immediately preceding this one
E	"The line %s did not contain 2 columns, check the configuration" "Illegal block id '%s' should be between 0 - 255" "Algorithm has already been defined '%s'" "Failed to parse algorithm block '%s'" "Cloudtype has already been defined, check configuration" "Failed to read the cloud type table" "Failed to read the global parameters" "Failure occurred while wasting block\n"	Error reading the Product Configuration file	Check availability, access, format and content of the Product Configuration File

Code (E/W)	Message	Comment	Recovery action
E	"Could not find any nearest index in the probability table for li=%d.ci=%d!?\n"	Error reading the Probability Table	Check availability, access, format and content of the Probability Table
E	Could not het lat/lon; sat; sun angles	Error getting lat/lon, sun or satellite angles	See error messages immediately preceding this one
E	"Failed to get environment variable '%s', check configuration."	Required environment variable is not set	Set the environment variable
E	"The line %s did not contain 2 columns, check configuration" "Multiple definition of PROB_DAY, check configuration" "Failed to read probability table for day '%s'" "Multiple definition of PROB_NIGHT, check configuration" "Failed to read probability table for night '%s'" "The row %s in file not legal, check configuration" "Both night and day for both coefficients and probability tables has to be defined"	Error reading an algorithm block from the configuration file	Check availability, access, format and content of the Algorithm Configuration File
E	"Failure occurred while reading global params" "The line %s did not contain 2 columns, check configuration" "Unknown identifier in global param block '%s'"	Error reading the global parameter block in the configuration file	Check availability, access, format and content of the Configuration File
E	"Failure occurred while reading cloud type table" "Could not parse '%s' in the cloudtype definition" "Configuration for CloudType precipitation contained index %d even though the range is 0<=v<255."	Error reading the table mapping cloud type and precipitation	Check availability, access, format and content of the table mapping cloud type and precipitation

Table 7. List of errors for NWC/GEO-PC-v2021.

2.5 TYPICAL KNOWN PROBLEMS AND RECOMMENDATION FOR USE

Refer to section 6 of Product User Manual for SAFNWC/MSG “Precipitating Cloud” (PC-PGE04 v1.5) document [RD *1*].

2.6 EXAMPLE OF PRECIPITATING CLOUDS (PC) VISUALIZATION

Examples of both day-time and night-time PC product can be found below:

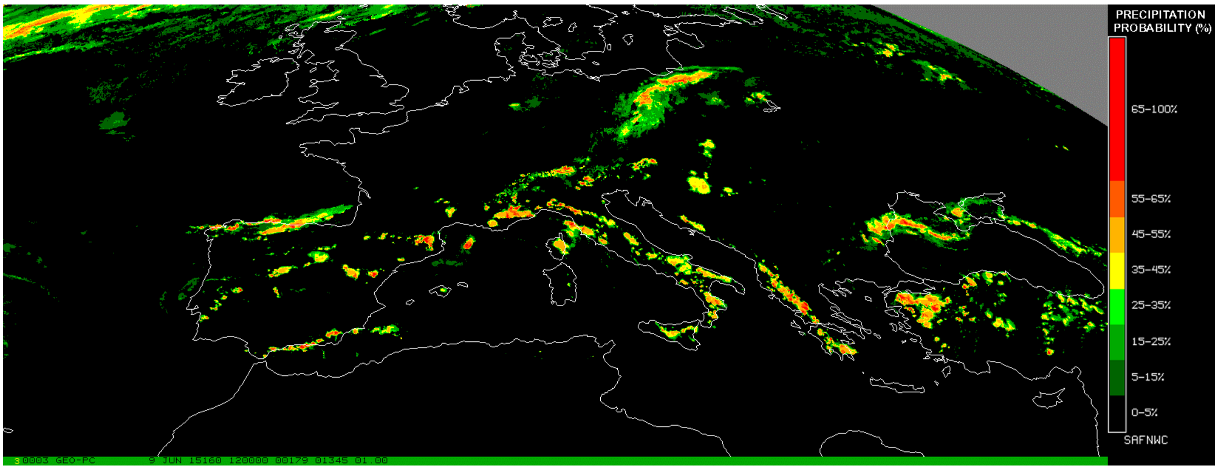

Figure 1. Example of the precipitating clouds product over a day-time scene on 9th June 2015 at 12:00 UTC

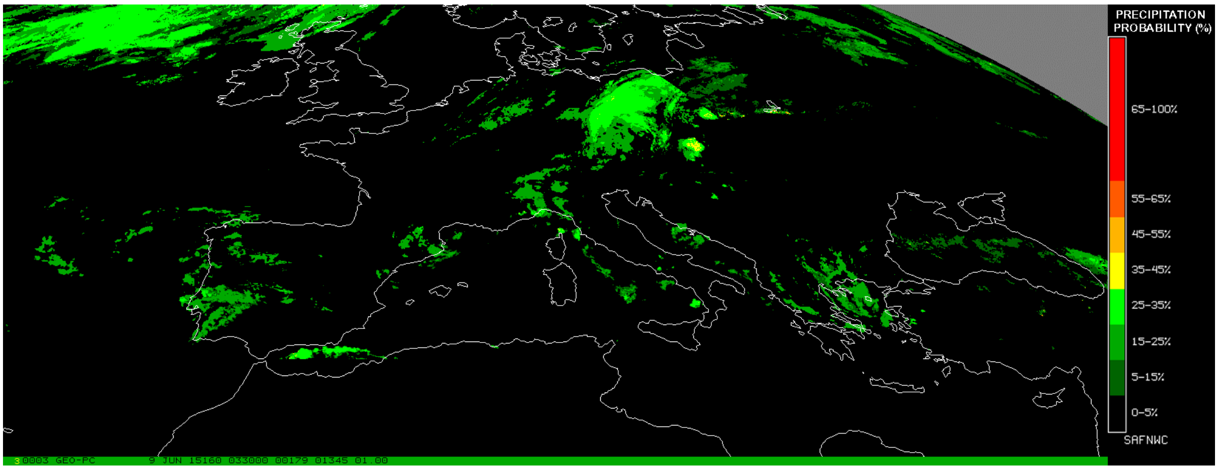

Figure 2. Example of the precipitating clouds product over a night-time scene on 9th June 2015 at 03:30 UTC

3. CONVECTIVE RAINFALL RATE (CRR) PRODUCT

3.1 DESCRIPTION OF THE CONVECTIVE RAINFALL RATE (CRR) PRODUCT

3.1.1 Goal of the Convective Rainfall Rate (CRR) product

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

This product can be obtained for every satellite slot, which in case of MSG is every 15 minutes, in the normal mode. It is also prepared to run in the Rapid Scan mode with a temporal resolution of 5 minutes.

This product does not distinguish the phase of the estimated precipitation.

3.1.2 Outline of Convective Rainfall Rate (CRR)

3.1.2.1 *Processing of the Convective Rainfall Rate (CRR)*

The basic CRR mm/h value for each pixel is obtained from calibration analytical functions.

Calibration analytical functions are generated by combining SEVIRI and Radar data. Composite radar data are compared pixel by pixel with geographically matched MSG data in the same resolution, and the rainfall rate RR is obtained, as a function of two or three variables (IR brightness temperature, IR-WV brightness temperature differences and normalised VIS reflectance):

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

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

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 semi-size (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 through the model configuration file.

To take into account the temporal and spatial variability of the 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 by the users. So that, the possible correction factors are the moisture correction, the cloud top growth/decaying rates or evolution correction, the cloud top temperature gradient correction, the parallax 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 the final values of the CRR rainfall rates are used in order to obtain five different outputs as described in section 3.1.3.

3.1.2.2 *Convective Rainfall Rate (CRR) correction factors*

3.1.2.2.1 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 consider 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. and the relative humidity, RH, (mean value between surface and 500 hPa. level), obtained from a numerical model.

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.

3.1.2.2.2 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.

The cloud growth correction factor, also designated as evolution correction factor, only changes the magnitude of the rain rate through a coefficient if the analysed pixel becomes warmer in the second image. 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).

The cloud growth rate correction factor cannot be applied when consecutive images are not available. In this case the alternative method of Cloud-top Temperature Gradient Correction is applied.

3.1.2.2.3 Cloud-top Temperature Gradient Correction Factor

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

This correction factor, also designated as gradient correction factor, is based on a search of the highest (coldest) and lowest (less cold) cloud tops. The idea is to search for the pixels that are below the average cloud top surface temperature (local temperature minima) and assume these pixels indicate active convection associated with precipitation beneath.

The hessian of the temperature field is analysed for each pixel with a temperature lower than 250K, in order to search for those pixels with extreme values as is explained in the Algorithm Theoretical Basis Document [*]*. Rain rate corresponding to those pixels which have a maximum (meaning that are warmer than its surroundings) is modified by multiplying a coefficient. The value of that coefficient can be selected by the user through the keyword COEFF_EVOL_GRAD_CORR_01 in the model configuration file (Default value: 0.25). In those pixels which have neither a local IR temperature maximum nor minimum, the rain rate is modified through a coefficient controlled by the keyword COEFF_EVOL_GRAD_CORR_02 (Default value: 0.50). Otherwise rain rate is not modified.

3.1.2.2.4 Parallax correction

To apply the orographic correction factor is necessary to know the exact cloud position with respect to the ground below. 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.

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 IR10.8 brightness temperature to height. By default, height is estimated using NWP data.

When the Parallax Correction is working, a spatial shift is applied to every pixel with precipitation according to the basic CRR value. If in this re-mapping process two pixels of the original image are assigned to the same pixel of the final image, the algorithm takes the maximum value of the rainfall rate, and if a pixel of the final image is not associated to any pixel of the original image (a "hole" appears in the final image), the software identifies the pixels with "hole" and assigns to them a value of the rainfall rate that is the result of applying a 3x3 median filter centred on the hole pixel.

3.1.2.2.5 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.

3.1.2.3 *Lightning algorithm*

As lightning activity is related with convection, an option to use this information to improve precipitation estimates has been added to the product. Only Cloud-to-Ground lightning flashes provided by ground based lightning detection networks 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

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.

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. To carry out the tuning of the lightning algorithm for a specific lightning network, the following steps should be performed:

- A representative set of convective storms should be chosen. Radar data and lightning data for each storm is needed.

- For each storm, the total amount of rainfall (in mm) according to the radar and the total number of lightning strokes occurred along the event should be measured. With this information the Rainfall-Lightning Ratio (RLR), which is the ratio between the total amount of mm of rainfall and the number of lightning strokes occurred, can be computed for each storm.

- The average of the RLR for the chosen set of storms should be computed. With this information the following keywords can be computed and updated in the model configuration file for CRR:

  Z1= 0.228 * RLR (RAIN_LIGHTNING_RATE_1 in Model configuration file for CRR)

  Z2= 0.074 * RLR (RAIN_LIGHTNING_RATE_2 in Model configuration file for CRR)

  Z3= 0.025 * RLR (RAIN_LIGHTNING_RATE_3 in Model configuration file for CRR)

  Z4= 0.010 * RLR (RAIN_LIGHTNING_RATE_4 in Model configuration file for CRR)

- For the same set of storms, and using the lightning information measured, a rain field should be computed for each storm at the same time that radar images were taken. To do this, since the tuning was done taking as ground truth the radar rain rates, each lightning stroke has to be allocated to a radar pixel. For each lightning stroke precipitation has to be spread, at and around the pixel allocated to it, in the following way:

Z4	$\frac{Z3+Z4}{2}$	Z3	$\frac{Z3+Z4}{2}$	Z4
$\frac{Z3+Z4}{2}$	$\frac{Z2+Z3}{2}$	Z2	$\frac{Z2+Z3}{2}$	$\frac{Z3+Z4}{2}$
Z3	Z2	Z1	Z2	Z3
$\frac{Z3+Z4}{2}$	$\frac{Z2+Z3}{2}$	Z2	$\frac{Z2+Z3}{2}$	$\frac{Z3+Z4}{2}$
Z4	$\frac{Z3+Z4}{2}$	Z3	$\frac{Z3+Z4}{2}$	Z4

At the same time, to take into account the temporal influence of the lightning occurrence, these rain amounts (Z1, Z2, Z3 and Z4) should be multiplied by COEF_τ:

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

Where Δτ is the time interval (in minutes) between the time of occurrence of the lightning stroke and the radar image.

- To tune the spatial density of lightning occurrence algorithm part, the rain rates obtained through the lightning information (RR_{light}) should be compared with the radar rain rates (RR_{radar}) pixel by pixel. For each pixel F(N)= RR_{radar}/ RR_{light} should be computed.

  Also, the spatial density of lightning occurrence for each pixel, N, should be computed in the image time interval. The time image interval is chosen as the time interval between two satellite images. In the case of MSG, this time interval in the normal mode is 15 minutes. N is computed at each pixel as the number of lightning strokes occurred in the time interval in a 11x11 pixels box centred on that pixel. With the pairs of values (F(N), N) for each pixel, the following function should be adjusted, and coefficients a and b should be obtained:

$$F(N) = a * (1 - b^N)$$

  To include this information in the model configuration file for CRR it should be taken into account that:

  COEFF_N_LIGHTNING_A = a

  COEFF_N_LIGHTNING_B = b

3.1.3 Description of the Convective Rainfall Rate (CRR) outputs

The content of the CRR output (stored in $SAFNWC/export/CRR in netCDF format) is described in the Data Output Format Document [RD 2]. A summary is given below:

NetCDF Common Atributes	
product_completeness	Percentage of pixels within the region containing data
product_quality	Weighted mean of the quality of all pixels with data, using the following weights: 1: Good pixels, 0.5: Questionable quality, 0.0: Bad quality

Container	Content
crr	NWC GEO CRR Convective Rainfall Rate Class: (see class table below)
crr_intensity	NWC GEO CRR Convective Rainfall Intensity: crr_intensity(mm/h) = scale_factor * counts + add_offset where: *scale_factor* = *0.1* *add_offset* = *0.0*

Class	**Rainfall Intensity (mm/h)**
0	[0.0, 0.2)
1	[0.2, 1.0)
2	[1.0, 2.0)
3	[2.0, 3.0)
4	[3.0, 5.0)
5	[5.0, 7.0)
6	[7.0, 10.0)
7	[10.0, 15.0)
8	[15.0, 20.0)
9	[20.0, 30.0)
10	[30.0, 50.0)
11	[50.0,)
FillValue	No data or corrupted data

Container	Content
crr_accum	NWC GEO CRR Convective Hourly Rainfall Accumulation: crr_accum(mm) = scale_factor * counts + add_offset where: *scale_factor = 0.1* *add_offset = 0.0*
crr_status_flag	13 bits indicating Applied Corrections: Bit 0: Humidity correction applied Bit 1: Evolution correction applied Bit 2: Gradient correction applied Bit 3: Parallax correction applied Bit 4: Orographic correction applied Use of optional data: Bit 5: Solar channel used Bit 6: Lightning data used Processing information Bit 7: crr_intensity set to 0 due to filtering process Bit 8: crr_intensity was a hole because of the parallax correction, and then was filled by the median filter Bit 9,10, 11: Use of bands for accumulation 1: All required bands were available 2: One previous CRR band is missing 3: At least two previous CRR bands are missing (no consecutive) 4: At least two previous CRR bands are missing (some are consecutive) Bit 12: Accumulation quality flag. Set to 1 if: not all crr values are available to perform the accumulation, OR any of the crr_intensity values was set to 0 due to filtering process OR Any of the crr_intensity values was a hole because parallax correction

Geophysical Conditions

Field	Type	Description
Space	Flag	Set to 1 for space pixels
Illumination	Parameter	Defines the illumination condition 0: N/A (space pixel) 1: Night 2: Day 3: Twilight
Sunglint	Flag	Set to 1 if Sunglint
Land_Sea	Parameter	0: N/A (space pixel) 1: Land 2: Sea 3: Coast

Processing Conditions

Field	Type	Description
Satellite_input_data	Parameter	Describes the Satellite input data status 0: N/A (space pixel) 1: All satellite data are available 2: At least one useful satellite channel is missing 3: At least one mandatory satellite channel is missing
NWP_input_data	Parameter	Describes the NWP input data status 0: N/A (space pixel or NWP data not used) 1: All NWP data are available 2: At least one useful NWP field is missing 3: At least one mandatory NWP field is missing
Product_input_data	Parameter	Describes the Product input data status 0: N/A (space pixel or Auxiliary data not used) 1: All input Product data are available 2: At least one useful input Product is missing 3: At least one mandatory input Product is missing
Auxiliary_input_data	Parameter	Describes the Auxiliary input data status 0: N/A (space pixel or Auxiliary data not used) 1: All Auxiliary data are available 2: At least one useful Auxiliary field is missing 3: At least one mandatory Auxiliary field is missing

Quality

Field	Type	Description
Nodata	Flag	Set to 1 if pixel is NODATA
Internal_consistency	Flag	Set to 1 if an internal consistency check has been performed. Internal consistency checks will be based in the comparison of the retrieved meteorological parameter with physical limits, climatological limits, neighbouring data, NWP data, etc.
Temporal_consistency	Flag	Set to 1 if a temporal consistency check has been performed Temporal consistency checks will be based in the comparison of the retrieved meteorological parameters with data obtained in previous slots.
Quality	Parameter	Retrieval Quality 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated

3.2 IMPLEMENTATION OF THE CONVECTIVE RAINFALL RATE (CRR) PRODUCT

Previous condition and licences

The right to use, copy or modify this software is in accordance with EUMETSAT Policy for the NWC-GEO software package.

3.2.1 Installation step for Convective Rainfall Rate (CRR)

CRR product is generated by the GEO-CRR component of the NWC/GEO software package. Detailed information on how to run this software package is available in the software user manual *[RD 3]*.

The software installation procedure does not require special resources. It is restricted to decompress the distribution files (a gz-compressed tar files) and to successfully build the executable GEO-CRR-v<version> file to be stored into the $SAFNWC/bin directory.

Once the GEO-CRR-v<version> of the NWC-GEO is installed and configured in the system, its operational use requires the definition of some Configuration files in order to select the regions to be processed and some needed configurable parameters.

3.2.2 Preparation step for Convective Rainfall Rate (CRR)

The configuration file in charge of the region where the product is going to be run, has an optional name and the ".cfg" extension. This file contains the region centre location and the size image. When the application is installed, some region configuration files appear in $SAFNWC/config. Each of them corresponds to a different region; nevertheless users can create their own region configuration file. Information on the region_conf_file can be found in the Interface Control Document for Internal and External Interfaces of the NWC/GEO document *[RD 4]*.

The configuration file in charge of the product settings is the CRR model configuration file that has an optional name and the ".cfm" extension. Through this file the user can configure the way the product is going to be run choosing options such as the type of calibration or the corrections to be used. More information on this configuration file can be found in section 3.3.2.

In order to apply some corrections, NWP data (*Convective Rainfall Rate (CRR) dynamic inputs*) have to be available in $SAFNWC/import/NWP_data directory.

In order to use the lightning information, the "Lightning information file for CRR" (*Convective Rainfall Rate (CRR) dynamic inputs*) have to be available in $SAFNWC/import/Obs_data/Lightning directory.

3.2.3 Execution step for Convective Rainfall Rate (CRR)

The GEO-CRR execution step consists in the launch of the command:

% GEO-CRR-v<version> <YYYY-MM-DDThh:mm:ssZ> <region_conf_file> <model_conf_file>

Information on the region_conf_file can be found in the Interface Control Document for Internal and External Interfaces of the NWC/GEO document *[RD 4]* and model_conf_file is described in section 2.3.2.

GEO-CRR requires mainly six steps:

- Initialise all variables and data structures according to input data. This includes computation of navigation data in the processing region read from the Processing Region Configuration File.
- Reading the input data required to execute the requested CRR processing in the processing region including Satellite input data, IR band for previous slot and previous CRR products (required to compute the hourly rainfall accumulation)
- Implementation of the algorithm to compute the base CRR values and filtering data to eliminate stratiform rain.
- Application of CRR corrections to base CRR data values computed in the previous step. Corrections to be applied are configurable and defined in the CRR Model Configuration file.
- Computation of the hourly rainfall accumulations using rainfall intensities from previous CRR slots

- Computation of CRR classes from CRR intensities as well as quality and processing information, and writing the CRR product file according to the specification provided in the DOF [RD 2].

More information on the GEO-CRR execution steps can be found at the Component Design Document for the Precipitation Product Processors of the NWC/GEO document [RD 6].

3.3 Inputs and configurable parameters for Convective Rainfall Rate (CRR) product

3.3.1 List of inputs for Convective Rainfall Rate (CRR)

3.3.1.1 *Convective Rainfall Rate (CRR) dynamic inputs*

Satellite imagery:

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

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

Table 8. CRR SEVIRI inputs

The SEVIRI channels are input by the user in HRIT format and extracted on the desired region by NWC-GEO software package. These data must be located in the $SAFNWC/import/Sat_data directory.

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

Numerical model:

The NWP files must be located in $SAFNWC/import/NWP_data directory. In real time operational mode, the NWC-GEO package has predefined tools (coordinated by the NWC-GEO Task Manager daemon) which check every minute for new NWP data making automatically the spatial remapping to the predetermined regions to process on to $SAFNWC/tmp directory. This avoids spending time in every call to product processor to make the remapping process. In off-line operational mode, the "AllMapping" script allows to do the spatial remapping.

NWP information is used by default for parallax correction. In case of lack of NWP parameters, parallax correction will be run using a climatological profile.

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

The NWP model fields used by CRR corrections are the following:

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 CRR:

A file with information on every lightning stroke occurred in a time interval is mandatory to choose the option of adjusting the CRR precipitation pattern with the lightning information provided by ground based lightning detection networks. Information about this lightning information file structure can be found in the Interface Control Document for Internal and External Interfaces of the NWC/GEO [RD *4*]. This file must be located in the $SAFNWC/import/Obs_data/Lightning directory.

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.

3.3.1.2 *Convective Rainfall Rate (CRR) static inputs*

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

Sun angles associated to satellite imagery

This information is mandatory for normalising the VIS image when the solar channel is used. It is also used to choose whether to run day-time or night-time algorithm.

Ancillary data sets:

Saturation Vapour table is mandatory for Humidity correction and is located in the $SAFNWC/import/Aux_data/CRR directory.

Saturation Vapour Polynomial Coefficients table is mandatory for Humidity correction and is located in the $SAFNWC/import/Aux_data/CRR directory.

Climatological profile is necessary as a back up for Parallax correction in case NWP is not available. This information is located in the $SAFNWC/import/Aux_data/CRR directory.

Elevation mask is mandatory for orographic correction and is located in the $SAFNWC/import/Aux_data/Common directory.

Model configuration file for CRR:

The CRR model configuration file, located in the $SAFNWC/config directory, contains configurable system parameters in the product generation process related with algorithm thresholds, ancillary datasets, numerical model data, corrections to be applied, etc. A complete list of these parameters and the explanation of the most useful ones can be found in section 3.3.2.

3.3.2 Configurable parameters for Convective Rainfall Rate (CRR): Model Configuration File

Model configuration file contains configurable items in the product generation process such as algorithm thresholds, satellite channels to be used by the product processor, coefficients, etc.

The CRR model configuration file needed for the execution of CRR must be placed at the $SAFNWC/config directory.

The only constraint in the use of any name is the key used to specify the parameters to be used from NWP models: NWP_PARAM. The use of this keyname is mandatory, and will be used by a pre-processing task in charge of remapping NWP incoming files (in GRIB format).

3.3.2.1 *Keywords table for Convective Rainfall Rate (CRR)*

Model Configuration File, located in the $SAFNWC/config directory and identified by the extension ".cfm", contains the following information applicable to CRR product:

Keyword	Description	Type	Default Value(s)
PGE_ID	Identifier of the product processor	Chain of characters	GEO-CRR
SAT_BANDS	Satellite channels to be used by CRR	Chain of characters	VIS06 WV62 IR108
DAY_NIGHT_ZEN_THRESHOLD	Solar zenith angle to select between day and night cases (in degrees)	Double	70
USE_SOLAR_CHANNEL	Indicator whether the day-time algorithm should be used or not by indicating if the satellite solar channel has to be used in the computation of the CRR basic value (1 yes; 0 no)	Integer	1
WIN_FILTER_SEMISIZE	Semi-size of the window used to filter the Basic CRR image (in pixels). Window_Size=(2*WIN_FILTER_SEMISIZE +1) * (2*WIN_FILTER_SEMISIZE +1)	Integer	3
FILTER_THRESHOLD	Threshold for filtering process	Integer	3
APPLY_HUMIDITY_CORR	Indicator whether the Humidity correction should be applied or not (1 yes; 0 no)	Integer	1
APPLY_EVOL_GRAD_CORR	Indicator whether the Evolution/Gradient correction should be applied or not (1 yes; 0 no)	Integer	1
APPLY_PARALLAX_CORR	Indicator whether the Parallax correction should be applied or not (1 yes; 0 no)	Integer	1
APPLY_OROGRAPHIC_CORR	Indicator whether the Orographic correction should be applied or not (1 yes; 0 no)	Integer	1

APPLY_LIGHTNING_CORR	Indicator whether the Lightning information should be used or not (1 yes; 0 no)	Integer	0
COEFF_EVOL_GRAD_CORR_00	Coefficient used when the Evolution/Gradient correction is applied. When two consecutives IR images are available and the Evolution correction is applied, if in a pixel the IR brightness temperature increases, the CRR value computed in that pixel is multiplied by this coefficient.	Real	0.35
COEFF_EVOL_GRAD_CORR_01	Coefficient used when the Evolution/Gradient correction is applied. When the previous IR image is not available and the Gradient correction is applied, this coefficient multiplies the previous computed CRR value if the analysed pixel has a local IR temperature maximum.	Real	0.25
COEFF_EVOL_GRAD_CORR_02	Coefficient used when the Evolution/Gradient correction is applied. When the previous IR image is not available and Gradient correction is applied, this coefficient multiplies the previous computed CRR value if the analysed pixel has not a local IR temperature maximum or minimum.	Real	0.50
LIGHTNING_DELTA_TIME	Time interval in minutes to consider lightning data files	Integer	15
RAIN_LIGHTNING_RATE_1	Rain rate parameter 1 linked to observed lightning (in mm)	Real	2.3
RAIN_LIGHTNING_RATE_2	Rain rate parameter 2 linked to observed lightning (in mm)	Real	0.75
RAIN_LIGHTNING_RATE_3	Rain rate parameter 3 linked to observed lightning (in mm)	Real	0.25
RAIN_LIGHTNING_RATE_4	Rain rate parameter 4 linked to observed lightning (in mm)	Real	0.1
COEFF_N_LIGHTNING_A	Coefficient "a" to be applied during the lightning adjustment function	Real	0.45
COEFF_N_LIGHTNING_B	Coefficient "b" to be applied during the lightning adjustment function	Real	0.7
INT_PRODUCT	Indicator whether intermediate products have to be written (Y yes; N no)	Chain of characters	N
NWP_PARAM	Parameter : Wind velocity (u-component) (ms^{-1}) sampling rate : (=segment size) interpolation method.	Chain of characters	NWP_UW 1 BILIN
NWP_PARAM	Parameter : Wind velocity (v-component) (ms^{-1}) sampling rate : (=segment size) interpolation method.	Chain of characters	NWP_VW 1 BILIN
NWP_PARAM	Parameter : Relative humidity (%) sampling rate : (=segment size) interpolation method.	Chain of characters	NWP_RH 1 BILIN

NWP_PARAM	Parameter : 2m dewpoint temperature (K) sampling rate : (=segment size) interpolation method.	Chain of characters	NWP_2D 1 BILIN
NWP_PARAM	Parameter : 2m air temperature (K) sampling rate : (=segment size) interpolation method.	Chain of characters	NWP_2T 1 BILIN
NWP_PARAM	Parameter : Temperature (K) sampling rate : (=segment size) interpolation method.	Chain of characters	NWP_T 1 BILIN
NWP_PARAM	Parameter : Surface pressure (Pa) sampling rate : (=segment size) interpolation method.	Chain of characters	NWP_SP 1 BILIN
NWP_PARAM	Parameter : Geopotential (m^2s^{-2}) sampling rate : (=segment size) interpolation method.	Chain of characters	NWP_GEOP 1 BILIN

Table 9. Model configuration file keywords table applicable to CRR product

3.3.2.2 *Keywords description for Convective Rainfall Rate (CRR)*

Below there is a description of the most useful keywords defined in CRR model configuration file in order to make easier the user exploitation:

- DAY_NIGHT_ZEN_THRESHOLD: to choose the solar zenith angle that selects between 2-V and 3-V Calibrations. By default this keyword is set to 70º. It is possible to configure the product to only use the night algorithm by setting the day night zen threshold to 0. This would avoid discontinuities in the product at the day/night transition on the cost of degrading performance during day time.
- USE_SOLAR_CHANNEL: to choose whether the Software will use the solar channel (only for day time) or not. By default this keyword is set to 1 (the solar channel is going to be used and so 3-V calibration functions will be used during day-time).
- WIN_FILTER_SEMISIZE: The obtained basic CRR data are set to zero if all the pixels in a grid with a WIN_FILTER_SEMISIZE pixels semi-size (default value: 3pix) centred on the pixel have a value lower than a selected threshold. The size of this window will be:

  (WIN_FILTER_SEMISIZE*2+1) x (WIN_FILTER_SEMISIZE*2+1)
- FILTER_THRESHOLD: The basic CRR data obtained from the functions are set to zero if all the pixels in the selected window filter centred on the pixel have a value lower than FILTER_THRESHOLD. (Default value: 3 mm/h).
- APPLY_LIGHTNING_CORR: To decide whether the lightning information will be used (keyword set to 1) or not (keyword set to 0) to improve the CRR precipitation pattern. By default this keyword is set to 0.
- COEFF_EVOL_GRAD_CORR_00: When two consecutives IR images are available and the Evolution correction is applied, if the IR brightness temperature increases in a pixel, the

CRR value computed in that pixel is multiplied by this coefficient. (Default value for Normal Mode (0.35) is set in the configuration file. Recommended value for Rapid Scan mode is 0.55).

- COEFF_EVOL_GRAD_CORR_01: When the previous IR image is not available and the Gradient correction is working, this coefficient multiplies the initial CRR value if the analysed pixel has a local IR temperature maximum. (Default value: 0.25).
- COEFF_EVOL_GRAD_CORR_02: When the previous IR image is not available and the Gradient correction is working, this coefficient multiplies the initial CRR value if the analysed pixel has neither a local IR temperature maximum nor minimum. (Default value: 0.50).
- LIGHTNING_DELTA_TIME: Time interval before the scanning time of the processing region centre, where the lightning occurrences will be taken into account by the lightning algorithm. (Default value: 15 min).
- RAIN_LIGHTNING_RATE_1: Rain amount assigned to the pixels corresponding to the Z1 area according to the lightning algorithm. A detailed description of the lightning algorithm can be found in the Algorithm Theoretical Basis Document for the Precipitation Product Processors of the NWC/GEO [RD 5]. (Default value: 2,30 mm).
- RAIN_LIGHTNING_RATE_2: Rain amount assigned to the pixels corresponding to the Z2 area according to the lightning algorithm. A detailed description of the lightning algorithm can be found in the Algorithm Theoretical Basis Document for the Precipitation Product Processors of the NWC/GEO [RD 5]. (Default value: 0,75 mm).
- RAIN_LIGHTNING_RATE_3: Rain amount assigned to the pixels corresponding to the Z3 area according to the lightning algorithm. A detailed description of the lightning algorithm can be found in the Algorithm Theoretical Basis Document for the Precipitation Product Processors of the NWC/GEO [RD 5]. (Default value: 0,25 mm).
- RAIN_LIGHTNING_RATE_4: Rain amount assigned to the pixels corresponding to the Z4 area according to the lightning algorithm. A detailed description of the lightning algorithm can be found in the Algorithm Theoretical Basis Document for the Precipitation Product Processors of the NWC/GEO [RD 5]. (Default value: 0,10 mm).
- COEFF_N_LIGHTNING_A: Coefficient “a” of the equation that modifies the rain rate according to the density of lightning around each pixel in the lightning algorithm. (Default value: 0,45).
- COEFF_N_LIGHTNING_B: Coefficient “b” of the equation that modifies the rain rate according to the density of lightning around each pixel in the lightning algorithm. (Default value: 0,7).

3.4 WARNING AND ERROR MESSAGES

The PGEs use generic exit codes to inform about the success or failure of the product generation process. These generic can be checked in table 6 section 2.4

In addition, the PGEs also generates detailed messages to inform the operator about the conditions of the processing. This information is particularly useful when the generation of a product fails, to identify the cause of the malfunction and to implement the corrective actions, if possible, to guarantee the generation of the product in next slots.

Some of these messages can be originated in low-level functions of the NWCLIB. In that case, an error message is sent by the NWCLIB function and specific warning/error codes are returned.

The following table shows the whole list of errors and warnings that can appear during the running of NWC/GEO-CRR-v2021 executable, the reasons causing these errors and warnings, and the way the NWCSAF user can try to solve them. In any case, if the errors or warnings persist, the NWCSAF Helpdesk should be contacted.

Code (E/W)	Message	Comment	Recovery action
GEO-CRR High level Error messages			
E	"Usage: %s YYYYMMDDThhmmssZ region_conf_file model_conf_file" "Error in date format (%s). Required YYYYMMDDThhmmssZ"	Unable to initiate the GEO-CRR	Check command line arguments, content and format
E	"Error in CRR module <module>"	Error in the execution of CRR Module <module>	See error messages immediately preceding this one
E	"ERROR applying <correction> Correction"	Error in the execution of CRR Correction Module	See error messages immediately preceding this one
E	"Error in FilterCRR module"	Error in the execution of CRR FilterCRR Module	See error messages immediately preceding this one
E	"Error computing lightning-based CRR"	Error in the execution of CRR LightningRainfall Module	See error messages immediately preceding this one
E	"Unable to initiate the reading of Satellite " "Error initiating satellite data for slot %s" "Error reading <band> satellite data for slot %s" "Error reading <band> band in <cal> for slot %s"	Unable to open/read satellite data for referred band/calibration/slot	Check that satellite data files are available in $SAFNWC/import/Sat_data directory
E	"Error initiating CRR product for writing" "Error writing <var> container" "Error finalizing the CRR product"	Unable to initiate, write, finalize the netCDF output product	See error messages immediately preceding this one
GEO-CRR Low level Error messages			
E	All Messages including "Unable to allocate Memory"	Problem of memory allocation	Check memory
W	"Not CRR to compute accumulation"	Required previous CRR products to compute hourly accumulations are not available	Provide all required previous CRR products (1 hour)
E	"Error reading <model configuration file>" "Unable to read <key> from <model configuration file>" "<key> keyword not found in <model configuration file>"	The model configuration file has not the appropriate format and/or content	Check format and content of the Model Configuration file
W	"...Not enough NWP data to apply <correction> correction"	Required NWP fields to apply the referred correction are not available	Provide all NWP data required by the GEO-CRR
E	"Unable to open %s file" "<… file> %s not found"	Error accessing or reading the file	Check de existence, format and content of the file
W	"Correction factor < 0 in pixel i:%d j:%d"	Computed correction factor in CorrHumidity() should never be <0	
E	"Error reading lightning data"	Error reading Lightning Data from input Observation data files	Check the content and format of the Lightning Data Files (See [AD 5])

Code (E/W)	Message	Comment	Recovery action
E	"Unable to read topographic data"	Error accessing to topographic data	See error messages immediately preceding this one
E	"Cloud height cannot be calculated"	Error retrieving the height of the cloud for parallax correction	See error messages immediately preceding this one
W	"CorrParallax: Unable to correct pixel %d,%d, lat/lon=%f,%f, height=%f"	Error in the correction of the referred pixel due to view and geographical conditions	Just a warning for debugging purposes
E	"Unable to read the number of available NWP levels"	Unable to read the key AV_PRESSURE_LEVELS in the NWP Configuration File	Check the content and format of the NWP Configuration File
E	"… <nwp_key> at %d hPa not found for slot %s"	referred NWP data is not available in the DATABUF	Check that all required NWP data has been previously remapped and is available in the DATABUF
E	"Error setting the region from %s "	Unable to initialise the processing Region form referred Region configuration file	Check the content and format of the Region Configuration File
E	"Error computing lat/lon data" "Error computing Sun angles" "Error computing Sat angles"	Unable to compute lat/lon, sun or satellite data for the Processing Region	See error messages immediately preceding this one
W	"Unable to open CRR product for slot %s", "Unable to read <var> container for slot %s"	Error reading referred product or container from a CRR product related to the referred a lot	Check the content and format of the CRR products (provided as input, previous slots)
E	"writeIntProduct: …	Error creating/writing intermediate products in the DATABUF	Check directory permissions and free space

Table 10. List of errors for NWC/GEO-CRR-v2021

3.5 TYPICAL KNOWN PROBLEMS AND RECOMMENDATION FOR USE

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.

- The limited availability of radar data at the time of carrying out the CRR calibration caused that three different radar datasets, with different radar products, had to be used. In the case of the Spanish radar data, PPI product were used and a quality control, taking advantage of a quality image generated for the radar national composite products (Gutierrez and Aguado, 2006), was used. In the case of the Hungarian radar data, rain rates based on Maximum reflectivity in the vertical were used, while in the case of Baltrad network, pseudo-CAPPI at 2Km were used to derive rain rates. Is should be borne in mind that no quality control methods were used for Baltrad and Hungarian radar datasets.

- Data from the radar networks in different areas were not compared to an independent reference.

Regarding the lightning algorithm:

- The CRR lightning algorithm in CRR v4.0.1, 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.

This product does not distinguish the phase of the estimated precipitation.

As a summary, according to the feedback of the users, the CRR product provides useful information as a complement to Radar products allowing the forecasters to identify convective areas.

3.6 Example of Convective Rainfall Rate (CRR) product visualisation

3.6.1.1 *Instantaneous Rates*

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

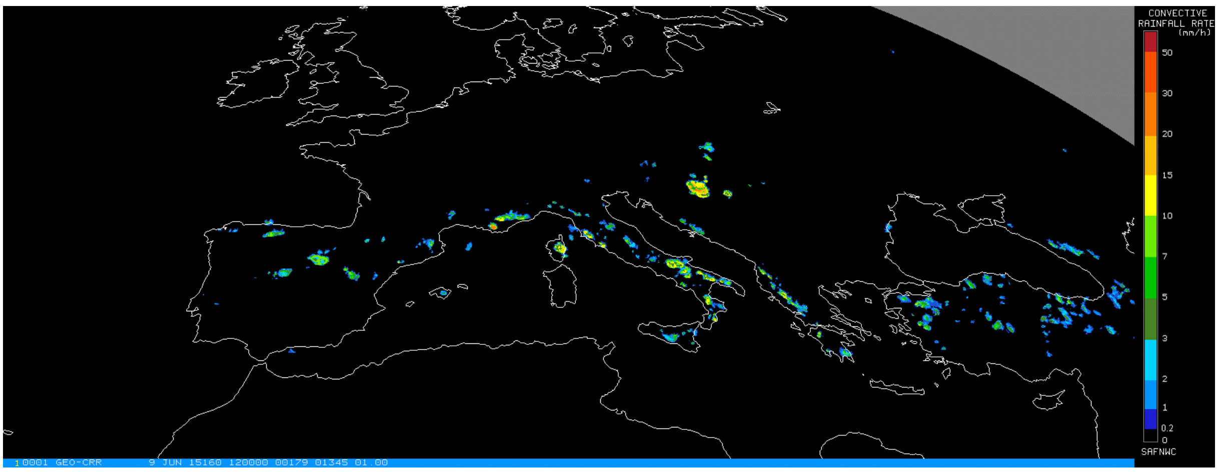

Figure 3. CRR instantaneous intensities output corresponding to 9th June 2015 at 12:00Z

3.6.1.2 *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.

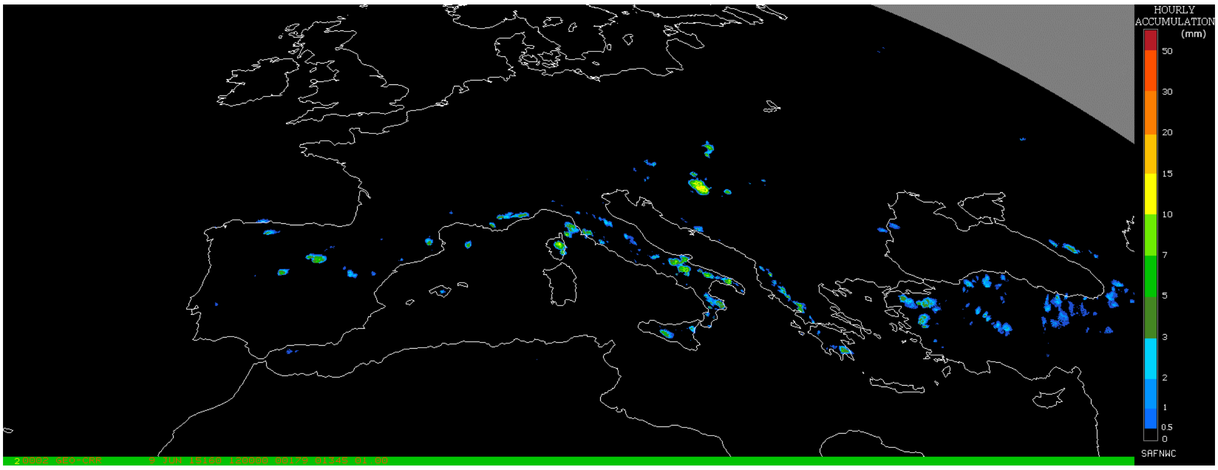

Figure 4. CRR hourly accumulations output corresponding to 9th June 2015 at 12:00Z.

4. PRECIPITATING CLOUDS FROM CLOUD PHYSICAL PROPERTIES (PCPH) PRODUCT

4.1 DESCRIPTION OF PRECIPITATING CLOUDS FROM CLOUD PHYSICAL PROPERTIES (PCPH)

4.1.1 Goal of Precipitating Clouds from Cloud Physical Properties (PCPh)

Precipitating Clouds from Cloud Physical Properties (PCPh) product, developed within the NWC SAF context, is a Nowcasting tool that provides estimation on the probability of precipitation (PoP) occurrence. In this context, PoP is defined as the instantaneous probability that a rain rate greater than or equal to 0.2 mm/h occurs at the pixel level.

This product can be obtained for every satellite slot, which in case of MSG is every 15 minutes, in the normal mode. It is also prepared to run in the Rapid Scan mode with a temporal resolution of 5 minutes.

4.1.2 Outline of Precipitating Clouds from Cloud Physical Properties (PCPh)

4.1.2.1 *Day time*

The PoP estimation has been done using information on the cloud physical properties, Effective Radius (R_{eff}) and Cloud Optical Thickness (COT). Using these two parameters the Cloud Water Path ($CWP=2/3*COT*R_{eff}$) is computed. Along with the microphysical information, SEVIRI channels are also used: five infrared channels ($IR_{8.7}$,$IR_{9.7}$,IR_{108},IR_{120},IR_{134}), one visible channel ($VIS_{0.6}$) that has been normalized and corrected with the sun-earth distance and two water vapour channels ($WV_{6.2}$,$WV_{7.3}$).

The algorithm is based on a Principal Component Analysis (PCA) which is a statistical procedure that uses an orthogonal transformation which converts a set of correlated variables into a set of uncorrelated one. This way a complex problem with many dimensions to deal with is compressed and reduced into a lower number of variables keeping the same information.

Only the first two principal components that explain the majority of the variance are kept while developing the algorithm.

To compute PoP, several steps have been followed:

1. For each pixel every input is normalised according to the following expression:

Normalized value$_{CHANNEL}$=(Pixel value $_{CHANNEL}$ –Mean value $_{CHANNEL}$)/Standard Deviation $_{CHANNEL}$

2. Then, for every pixel, the first two principal components (P1 and P2) are computed

P_1=CWP normalized *v_{11}+$IR_{10.8}$ normalized *v_{12}+IR120*v_{13}+.......+$WV_{7.3}$normalized*v_{19}
P_2=CWP normalized *v_{21}+$IR_{10.8}$ normalized *v_{22}+IR120*v_{23}+.......+$WV_{7.3}$normalized*v_{29}

v_{ij} stands for the eigenvectors

3. Once P1 and P2 have been calculated, the correspondence with PoP values is found in a LUT.

PCPh=LUT(x=p1, y=p2)

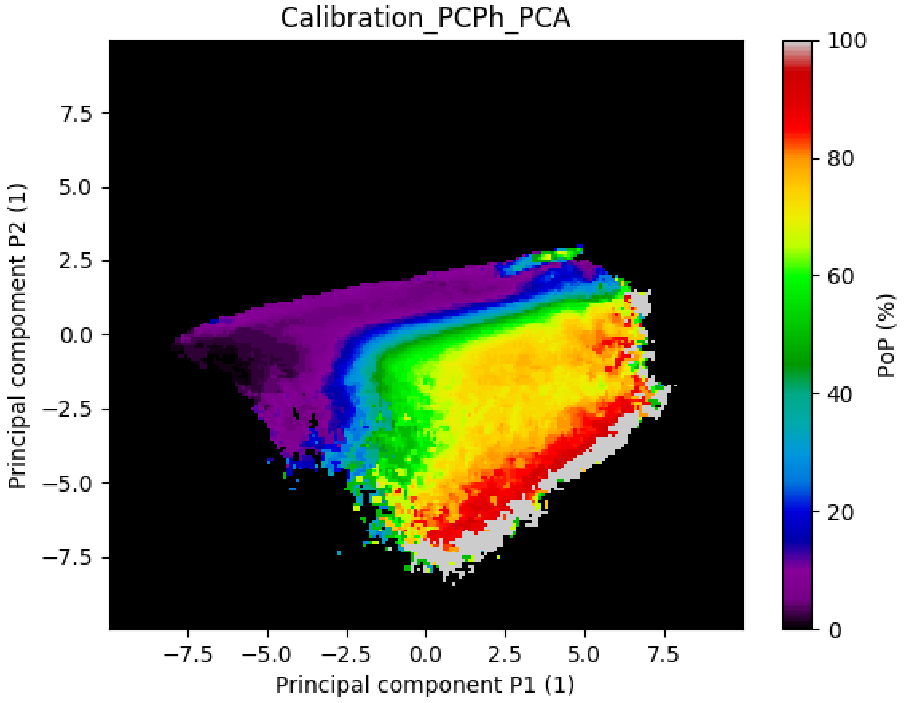

Figure 5. PCPh calibrating Look up Table

X and Y axis are the first and the second principal component respectively .Z axis is the colour palette and represents the probability of rain.

Radar pixels with rain rates greater than or equal to 0.2 mm/h have been considered as rainy.

Once the two projections have been calculated, it is necessary to associate them with a probability of rain. Then, for every pair of points (p1, p2) the proportion of radar rainy pixels is evaluated by dividing the number of rainy pixels among all the radar pixels.

The LUT has been smoothed in 3*3 boxes with a median filter to reduce some noise.

Normalizing parameters for PCPh, eigenvectors (v_{ij}) to compute the projections p1 and p2 and more additional information can be found in the "Algorithm Theoretical Basis Document for the Precipitation Product Processors of the NWC/GEO" [*RD 5*].

4.1.2.2 *Night time*

One single algorithm is used for the whole day. That means the same inputs used at day time are required at night time. Since CWP and the VIS0.6 channel are only available at day time, an artificial method has been developed to create a pseudo-CWP and a pseudo-VIS06 derived from infrared and water vapour channels.

The method to generate CWP and $VIS_{0.6}$ is based on a Principal Component Analysis.

As at night there are only infrared and water vapour channels, those have been the inputs two train the dataset.

Inputs

$IR_{8.7}$ µm	$IR_{9.7}$ µm	$IR_{10.8}$ µm	$IR_{12.0}$ µm	$IR_{13.4}$ µm	$VW_{6.2}$ µm	$WV_{7.3}$ µm

For more detailed information go to section 6 in the Algorithm Basis Document for the Precipitation Product Processors of the NWC/GEO [RD 5].

The quality of the product at night decreases with respect to day time, because of the unavailability of the VIS06 and the cloud microphysics product (CWP). The estimated VIS0.6 and CWP input variables at night time introduces additional uncertainties.

4.1.2.3 *PCPh Correction Factors*

4.1.2.3.1 Stability Correction

Like other NWC SAF products do, such as the RDT-CI (Rapidly Developing Thunderstorm – Convection Warning) a stability mask is used. This mask uses NWP data to compute several convective indexes: K Index (KI), Showalter (SHW) and Lifted Index (LI). The combination of such indexes allow to identify stable regions where convection is unlikely to happen.
If pixel value of LI index stable (>0) and pixel value of SHW index stable (>3) and pixel value of KI index stable (< 20), then it will considered full stable case at pixel level.

Precipitation output for CRRPh and PCPh is removed in those stable regions. This stability mask is an optional parameter and configurable by the user. It is set to use it by default.

4.1.2.3.2 Parallax Correction

To eliminate parallax effects, a parallax correction can also be applied (see section 3.1.2.2.4 Parallax correction).

4.1.3 Description of Precipitating Clouds from Cloud Physical Properties (PCPh) outputs

The content of the PCPh output (stored in $SAFNWC/export/PCPh in netCDF format) is described in the Data Output Format Document [RD *2]*. A summary is given below:

NetCDF Common Atributes	
product_completeness	Percentage of pixels within the region containing data
product_quality	Weighted mean of the quality of all pixels with data, using the following weights: 1: Good pixels, 0.5: Questionable quality, 0.0: Bad quality

Container	Content
pcph	NWC GEO PCPh Precipitating Clouds from cloud Physical Properties

DAY ALGORITHM

GEO-CMIC-PHASE INPUT	GEO-CMIC-PHASE PHASE INPUT CLASS	COTT OR REFF FROM CMIC	PCPH OUTPUT
Liquid	1	NO DATA	NO DATA
		DATA AVAILABLE	pcph(%) = scale_factor * counts + add_offset
Ice	2	NO DATA	NO DATA
		DATA AVAILABLE	pcph(%) = scale_factor * counts + add_offset
Mixed	3	NO DATA	NO DATA
		DATA AVAILABLE	pcph(%) = scale_factor * counts + add_offset
Cloud-free	4	NOT APPLICABLE	0
Undefined	5	NOT APLLICABLE	NO DATA
No data or corrupted data	FillValue	NOT APPLICABLE	NO DATA

NIGHT ALGORITHM

GEO-CMIC-PHASE INPUT	GEO-CMIC-PHASE PHASE INPUT CLASS	PCPH OUTPUT
Liquid	1	pcph(%) = scale_factor * counts + add_offset
Ice	2	pcph(%) = scale_factor * counts + add_offset
Mixed	3	pcph(%) = scale_factor * counts + add_offset
Cloud-free	4	0
Undefined	5	NO DATA
No data or corrupted data	FillValue	NO DATA

pcph(%) = scale_factor * counts + add_offset

where:

scale_factor = 1.0

add_offset = 0.0

Container	Content
pcph_status_flag	6 bits indicating Data Availability: Bit 0: R_{eff} or COT not computed (out of cloud, night time or undefined phase) Bit 1: Phase not computed or undefined Bit 2: IR band missing (used in parallax correction) Applied Correction: Bit 3: Parallax correction applied Bit 4: Stability correction applied Other information Bit 8: pcph was a hole because of the parallax correction, and then was filled by the median filter

Geophysical Conditions

Field	Type	Description
Space	Flag	Set to 1 for space pixels
Illumination	Parameter	Defines the illumination condition 0: N/A (space pixel) 1: Night 2: Day 3: Twilight
Sunglint	Flag	Set to 1 if Sunglint
Land_Sea	Parameter	0: N/A (space pixel) 1: Land 2: Sea 3: Coast

Processing Conditions

Field	Type	Description
Satellite_input_data	Parameter	Describes the Satellite input data status 0: N/A (space pixel) 1: All satellite data are available 2: At least one useful satellite channel is missing 3: At least one mandatory satellite channel is missing
NWP_input_data	Parameter	Describes the NWP input data status 0: N/A (space pixel or NWP data not used) 1: All NWP data are available 2: At least one useful NWP field is missing 3: At least one mandatory NWP field is missing
Product_input_data	Parameter	Describes the Product input data status 0: N/A (space pixel or Auxiliary data not used) 1: All input Product data are available 2: At least one useful input Product is missing 3: At least one mandatory input Product is missing
Auxiliary_input_data	Parameter	Describes the Auxiliary input data status 0: N/A (space pixel or Auxiliary data not used) 1: All Auxiliary data are available 2: At least one useful Auxiliary field is missing 3: At least one mandatory Auxiliary field is missing

Quality

Field	Type	Description
Nodata	Flag	Set to 1 if pixel is NODATA
Internal_consistency	Flag	Set to 1 if an internal consistency check has been performed. Internal consistency checks will be based in the comparison of the retrieved meteorological parameter with physical limits, climatological limits, neighbouring data, NWP data, etc.
Temporal_consistency	Flag	Set to 1 if a temporal consistency check has been performed Temporal consistency checks will be based in the comparison of the retrieved meteorological parameters with data obtained in previous slots.
Quality	Parameter	Retrieval Quality 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated

4.2 Implementation of Precipitating Clouds from Cloud Physical Properties (PCPh)

Previous condition and licences:

The right to use, copy or modify this software is in accordance with EUMETSAT Policy for the NWC-GEO software package.

4.2.1 Installation of Precipitating Clouds from Cloud Physical Properties (PCPh)

PCPh product is generated by the GEO-PCPh component of the NWC/GEO software package. Detailed information on how to run this software package is available in the software user manual *[RD 3]*.

The software installation procedure does not require special resources. It is restricted to decompress the distribution files (a gzip-compressed tar files) and to successfully build the executable GEO-PCPh-v<version> file to be stored into the $SAFNWC/bin directory.

Once the GEO-PCPh-v<version> of the NWC-GEO is installed and configured in the system, its operational use requires the definition of some Configuration files in order to select the regions to be processed and some needed configurable parameters.

4.2.2 Preparation of Precipitating Clouds from Cloud Physical Properties (PCPh)

The configuration file in charge of the region where the product is going to be run, has an optional name and the “.cfg” extension. This file contains the region centre location and the size image. When the application is installed, some region configuration files appear in $SAFNWC/config. Each of them corresponds to a different region; nevertheless users can create their own region configuration file. Information on the region_conf_file can be found in the Interface Control Document for Internal and External Interfaces of the NWC/GEO document *[RD 4]*.

The configuration file in charge of the product settings is the PCPh model configuration file that has an optional name and the ".cfm" extension. Through this file the user can configure the way the product is going to be run choosing options such as whether the parallax correction or the stability correction should be applied or not. GEO-PCPh component is in charge of computing PCPh product on demand. More information on this configuration file can be found in section 4.3.2.

In order to apply the optional PCPh corrections (parallax correction or the stability correction), NWP data required have to be available in $SAFNWC/import/NWP_data directory.

4.2.3 Execution of Precipitating Clouds from Cloud Physical Properties (PCPh)

The GEO-PCPh execution step consists in the launch of the command:

% GEO-PCPh-v<version> <YYYY-MM-DDThh:mm:ssZ> <region_conf_file> <model_conf_file>

Information on the region_conf_file can be found in the Interface Control Document for Internal and External Interfaces of the NWC/GEO document *[RD 4]* and model_conf_file is described in section 4.3.2.

GEO-PCPh, to compute PCPh product, requires mainly five steps:

- Initialise all variables and data structures according to input data. This includes computation of navigation data in the processing region read from the Processing Region Configuration File.
- Reading the input data required to execute the requested PCPh processing in the processing region including 8 satellite channels and the cloud microphysics (CMIC) at day time and 7 satellite channels at night time.
- Implementation of the algorithm to compute the base PCPh values and some other quality and processing information.
- Application of PCPh corrections, if required in the PCPh Model Configuration file, to the base PCPh values computed in the previous step.
- Writing the PCPh product file according to the specification provided in the DOF [RD *2]*.

More information on the GEO-PCPh execution steps can be found at the Component Design Document for the Precipitation Product Processors of the NWC/GEO document [RD 6] [RD 6].

4.3 Inputs and configurable parameters for Precipitating Clouds from Cloud Physical Properties (PCPh)

4.3.1 List of inputs for Precipitating Clouds from Cloud Physical Properties (PCPh)

SATELLITE:

- $IR_{8.7}$, $IR_{9.7}$, $IR_{10.8}$, $IR_{12.0}$, $IR_{13.4}$ (Brightness temperature)
- $VIS_{0.6}$ (Normalized reflectance and corrected with Sun distance)
- $WV_{6.2}$, $WV_{7.3}$ (Brightness temperature)

IR10.8 SEVIRI brightness temperature at full IR spatial resolution is a mandatory input to compute Parallax Correction. It must be placed by the user in HRIT format in the $SAFNWC/import/Sat_data directory. Then it will be extracted on the desired region by NWC-GEO software package.

NWC/GEO software:

- GEO-cloud microphysics ($CMIC_{\text{Cloud Optical Thickness}}$, $CMIC_{\text{Effective Radius}}$, $CMIC_{\text{Phase}}$)

  - CMIC Phase, Cloud Optical Thickness (COT) and Effective Radius (R_{eff}) parameters are mandatory inputs to PCPh day algorithm.
  - CMIC Phase is mandatory input to compute the PCPh night algorithm.

These parameters will be read from CMIC NetCFD file which must be located in $SAFNWC/export/CMIC directory

Numerical model:

- 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.

Ancillary data sets:

- Climatic profile is necessary as a backup for Parallax correction in case NWP is not available.

This information is included in the software package and is located in the $SAFNWC/import/Aux_data/PCPh directory.

The NWP files must be located in $SAFNWC/import/NWP_data directory. In real time operational mode, the NWC-GEO package has predefined tools (coordinated by the NWC-GEO Task Manager daemon) which check every minute for new NWP data making automatically the spatial remapping to the predetermined regions to process on to $SAFNWC/tmp directory. This avoids spending time in every call to product processor to make the remapping process. In off-line operational mode, the "AllMapping" script allows to do the spatial remapping.

This information is used by default for parallax correction. In case of lack of NWP parameters, parallax correction will be run using a climatological profile.

Model configuration file for PCPh:

PCPh model configuration file contains configurable system parameters in the generation process of PCPh product. This file is placed in the $SAFNWC/config directory. The PCPh product related parameters refers to ancillary datasets, numerical model data, parallax and stability correction. The complete list of these parameters and the explanation of the most useful ones is available on section 4.3.2.

Region configuration file (region.cfg):

This file set the dimensions and positions where PCPh product will be obtained and is located in $SAFNWC/config directory.

4.3.2 Configurable parameters for Precipitating Clouds from Cloud Physical Properties (PCPh)

Model configuration file contains configurable items in the product generation process such as corrections to be run, NWP parameters to be used by the PCPh product processor, etc.

The PCPh model configuration file needed for the execution of PCPh must be placed at the $SAFNWC/config directory.

The only constraint in the use of any name is the key used to specify the parameters to be used from NWP models: NWP_PARAM. The use of this keyname is mandatory, and will be used by a pre-processing task in charge of remapping NWP incoming files (in GRIB format).

4.3.2.1 *Keywords table for Precipitating Clouds from Cloud Physical Properties (PCPh)*

The PCPh model Configuration File, located in the $SAFNWC/config directory and identified by the extension ".cfm", contains the following information applicable to PCPh product:

Keyword	Description	Type	Default Value(s)
PGE_ID	Identifier of the product processor	Chain of characters	GEO-PCPh
SEV_BANDS	Satellite channels to be used by PCPh	Chain of characters	IR87,IR97,IR108,IR120,IR134, VIS06, WV62, WV73
DAY_NIGHT_ZEN_THRESHOLD	Solar zenith angle to select between day and night cases (in degrees). It is possible to configure the product to only use the night algorithm by setting the sun zenith angle threshold to 0. This would avoid discontinuities in the product at the day/night transition on the cost of degrading performance during day time	Double	70
APPLY_PARALLAX_CORR	Indicator whether the Parallax correction should be applied or not (1 yes; 0 no)	Integer	1
APPLY_STABILITY_CORR	Indicator whether the Stability correction should be applied or not (1 yes; 0 no)	Integer	1

NWP_PARAM	Parameter : Temperature (K) sampling rate : (=segment size) interpolation method.	Chain of characters	NWP_T 1 BLI
NWP_PARAM	Parameter : Geopotential (m^2s^{-2}) sampling rate : (=segment size) interpolation method.	Chain of characters	NWP_GEOP 1 BLI
NWP_PARAM	Parameter : Lifted index sampling rate : (=segment size) interpolation method.	Chain of characters	NWP_LI 1 BLI
NWP_PARAM	Parameter : K index sampling rate : (=segment size) interpolation method.	Chain of characters	NWP_KI 1 BLI
NWP_PARAM	Parameter : Showalter Index sampling rate : (=segment size) interpolation method.	Chain of characters	NWP_SHW 1 BLI

Table 11. Model configuration file keywords table applicable to PCPh product

4.3.2.2 *Keywords description for Precipitating Clouds from Cloud Physical Properties (PCPh)*

Below there is a description of the most useful keywords defined in PCPh model configuration file and applicable to PCPh product in order to make easier the user exploitation:

- DAY_NIGHT_ZEN_THRESHOLD: to choose the solar zenith angle that selects between day and night algoritms. By default this keyword is set to 70º. It is possible to configure the product to only use the night algorithm by setting the day night zen threshold to 0. This would avoid discontinuities in the product at the day/night transition on the cost of degrading performance during day time.
- APPLY_PARALLAX_CORR: To decide whether the Parallax correction should be applied to PCPh basic values or not (1 yes; 0 no). By default this keyword is set to 1.
- APPLY STABILITY_CORR: To decide whether the Stability correction should be applied to PCPh basic values or not (1 yes; 0 no). By default this keyword is set to 1.

4.4 WARNING AND ERROR MESSAGES

The PGEs use generic exit codes to inform about the success or failure of the product generation process. These generic can be checked in table 6 section 2.4

In addition, the PGEs also generates detailed messages to inform the operator about the conditions of the processing. This information is particularly useful when the generation of a product fails, to identify the cause of the malfunction and to implement the corrective actions, if possible, to guarantee the generation of the product in next slots.

Some of these messages can be originated in low-level functions of the NWCLIB. In that case, an error message is sent by the NWCLIB function and specific warning/error codes are returned.

The following table shows the whole list of errors and warnings that can appear during the running of NWC/GEO-PPh-v2021 executable (Both PCPh or CRRPh), the reasons causing these errors and warnings, and the way the NWCSAF user can try to solve them. In any case, if the errors or warnings persist, the NWCSAF Helpdesk should be contacted.

Code (E/W)	Message	Comment	Recovery action
		GEO-PPh High level Error messages	
E	"Error executing GEO-PPh-vnnn *" "Error in date format (%s). Required YYYYMMDDThhmmssZ"	Unable to initiate the GEO-PPh	Check command line arguments, content and format
E	"Error setting the region from %s "	Unable to initialise the processing Region form referred Region configuration file	Check the content and format of the Region Configuration File
E	"Error in PPh module <module>"	Error in the execution of PPh Module <module>	See error messages immediately preceding this one
E	"ERROR applying Parallax Correction"	Error executing the Parallax Correction Process	See error messages immediately preceding this one
E	"ERROR applying Lightning Correction"	Error executing the Lightning Correction Process	See error messages immediately preceding this one
E	"Unable to open <product> product for slot %s" "Unable to read <var> container for slot %s"	Error reading referred product or variablet	Check availability, format and content of NWC/GEO product. See error messages immediately preceding this one
W	"Error initiating satellite data for slot %s" "Unable to initiate the reading of Satellite Data for slot %s" "Error reading IR108/WV62 satellite data for slot %s"	Unable to open/read required input Satellite data	Check availability, format and content of Satellite data
E	"Error initiating <product> product for writing" "Error writing <var> container" "Error finalizing the <product> product"	Unable to initiate, write, finalize the netCDF output product	See error messages immediately preceding this one
		GEO-PPh Low level Error messages	
E	All Messages including "Unable to allocate Memory"	Problem of memory allocation	Check memory
E/W	"Error reading <model configuration file>" "Unable to read <key> from <model configuration file>" "<key> keyword not found in <model configuration file>"	The model configuration file has not the appropriate format and/or content	Check format and content of the Model Configuration file
E	"Error reading lightning data"	Unable to read data from lighting data files	Check availability, content and format of Lightning data files
E	"Cloud height cannot be calculated"	Unable to estimate the cloud height	See error messages immediately preceding this one
E	"Climatological Profiles file %s not found"	Unable to read referred file	Check availability, format and content of the climatological profiles file
E	"Unable to read the number of available NWP levels"	Unable to read the key AV_PRESSURE_LEVELS in the NWP Configuration File	Check the content and format of the NWP Configuration File
E	"Error computing lat/lon data" "Error computing Sun angles" "Error computing Sat angles"	Unable to compute lat/lon, sun or satellite data for the Processing Region	See error messages immediately preceding this one

Code (E/W)	Message	Comment	Recovery action
E	"Unable to read the CRRPh LUT %slut"	Unable to read CRRPh LUT files to compute the product at night time	Check availability, content and format of LUT files
E	"Unable to read the PCPh LUT %s.lut"	Unable to read PCPh LUT file to compute the product at night time	Check availability, content and format of LUT files

Table 12. List of errors for NWC/GEO-CRRPh (see section 5) and NWC/GEO-PCPh.

4.5 TYPICAL KNOWN PROBLEMS AND RECOMMENDATIONS FOR USE

As one mandatory input of the product is the Cloud Water Path that derives from CMIC, there exists the need to run CMIC previous to run PCPh at day time.

For undefined phase pixels, R_{eff} and COT values, are not computed by CMIC, in these cases the PCPh algorithm assigns NO DATA value.

It has been observed that pixels located in the surroundings of snow according to CMIC take sometimes high values of CWP, so a probability of precipitation higher than 0% is assigned erroneously.

It is highly recommended to apply parallax correction for a better location of precipitation areas with respect to the ground below.

Stability correction is used to remove PCPh output from areas where it is not likely to have rain based on NWP models. This correction is especially useful at night, during winter season in high latitudes. If a black hole inside a precipitating area appears, this effect may be directly attributed to this correction. The more accurate the NWP model is, the more precise the stability correction will be when excluding precipitating areas in the PCPh output.

Additionally to the appearance of some holes in a precipitating area due to a faulty NWP performance, it has visually checked that the orography may produce unrealistic shapes. These artefacts produced by mountains are steady and it appears in the same places so it can be easily detected.

The stability correction factor finally depends on the NWP model. If a specific meteorological pattern is wrongly reproduced, it will have an impact on the precipitation product.

This product obtains the best results for convective events in terms of a categorical validation.

The quality of the product at night decreases with respect to day time, because of the no availability of the visible channels and the cloud microphysics. For this reason VIS0.6 and CWP are simulated at night introducing somehow additional uncertainties.

4.6 EXAMPLE OF PRECIPITATING CLOUDS FROM CLOUD PHYSICAL PROPERTIES (PCPH) VISUALIZATION

Below is shown an example of the PCPh product at day time.

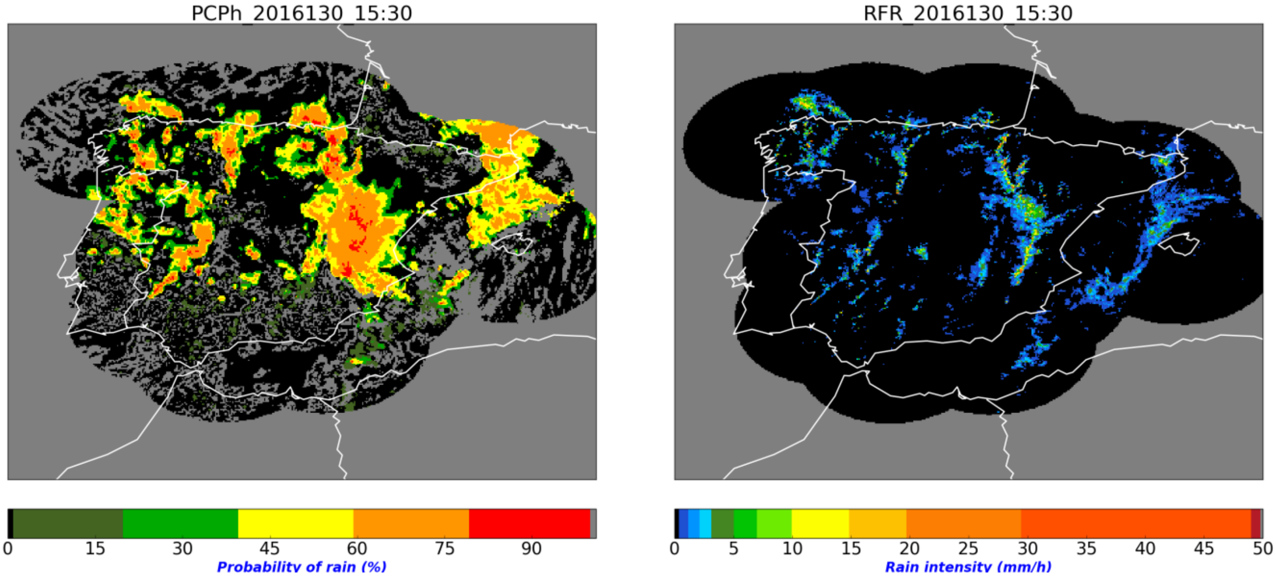

Figure 6. PCPh probability of precipitation over Spain the 9th May 2016 at 15:30Z.

5. CONVECTIVE RAINFALL RATE FROM CLOUD PHYSICAL PROPERTIES (CRRPH) PRODUCT

5.1 DESCRIPTION OF CONVECTIVE RAINFALL RATE FROM CLOUD PHYSICAL PROPERTIES (CRRPH)

5.1.1 Goal of Convective Rainfall Rate from Cloud Physical Properties (CRRPh)

Convective Rainfall Rate from Cloud Physical Properties (CRRPh) product, developed within the NWC SAF context, is a Nowcasting tool that provides information on convective, and stratiform associated to convection, instantaneous rain rates and hourly accumulations.

This product can be obtained for every satellite slot, which in case of MSG is every 15 minutes, in the normal mode. It is also prepared to run in the Rapid Scan mode with a temporal resolution of 5 minutes.

5.1.2 Outline of Convective Rainfall Rate from Cloud Physical Properties (CRRPh)

5.1.2.1 *Day time*

Rainfall rate estimation has been elaborated by extracting information from the Cloud Top Microphysical Parameter (Cloud Phase, Cloud Effective Radius and Cloud Optical Thickness) to compute the cloud water path (CWP=2/3*COT*REFF), five infrared channels ($IR_{8.7}$,$IR_{9.7}$,IR_{108},IR_{120},IR_{134}), one visible channel ($VIS_{0.6}$) that has been normalized and corrected with the sun-earth distance and two water vapour channels ($WV_{6.2}$,$WV_{7.3}$).

Like PCPh, CRRPh uses an algorithm based on a Principal Component Analysis (PCA). CRRPh has been calibrated in convective areas. By using PCA's satellite information has been compressed in two principal components that keep the 95% of the whole variance.

To compute CRRPh, several steps have been followed:

1. For each pixel every input is normalised according to the following expression:

Normalized $value_{CHANNEL}$=(Pixel value $_{CHANNEL}$ –Mean value $_{CHANNEL}$)/Standard Deviation $_{CHANNEL}$

2. Then, for every pixel, the first two principal components (P1 and P2) are computed

P_1=CWP normalized $*v_{11}$+$IR_{10.8}$ normalized $*v_{12}$+IR120$*v_{13}$+.......+$WV_{7.3}$normalized$*v_{19}$
P_2=CWP normalized $*v_{21}$+$IR_{10.8}$ normalized $*v_{22}$+IR120$*v_{23}$+.......+$WV_{7.3}$normalized$*v_{29}$

v_{ij} stands for the eigenvectors

3. Once P1 and P2 have been calculated, the correspondence with instantaneous rain intensities values is found in a LUT

CRRPh=LUT(x=p1, y=p2)

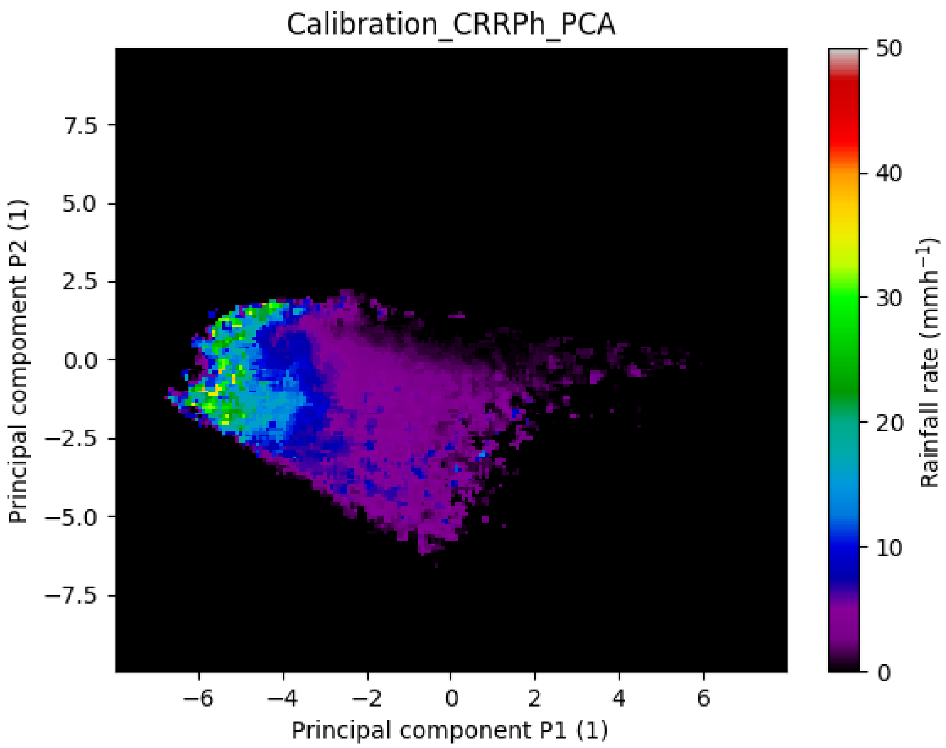

Figure 7. CRRPh calibration LUT

X and Y axis are the first and the second principal component respectively. Z axis is the colour palette and represents the rainfall rate (mmh^{-1}).

For every pixel of the image (p1, p2), there are different brightness temperatures and radiances.

P1 and p2 are connected with the rain intensities provided by the Spanish radar. Since it has been processed 70 days throughout a year, for every (p1, p2) there are a large amount of rain intensities values. The rainfall rate intensity data has many values that are zero. Because of this, the radar rainfall rate ninety percentile within a (p1, p2) bin has been chosen. In this way, a uni-valued function of rainfall rate versus (p1, p2) can be extracted from the data.

The LUT has been smoothed in 3*3 boxes with a median filter to reduce some noise.

Normalizing parameters for CRRPh, eigenvectors (v_{ij}) to compute the projections p1 and p2 and more additional information can be found in the “Algorithm Theoretical Basis Document for the Precipitation Product Processors of the NWC/GEO” [*RD 5*].

Rain rates estimation from geostationary satellite data cannot be very accurate so trying to estimate rain rates higher than 50 mm/h using this type of data is not realistic. For this reason a maximum limit of 50 mm/h has been established.

For a better location of the precipitation area, the parallax correction can be applied to this product (see section 3.1.2.2.4 Parallax correction). This option is chosen by the user through the product model configuration file and it is applied by default.

At the end of the process the final values of the CRRPh rainfall rates in mm/h are used to obtain hourly accumulations and four different outputs as described in section 5.1.3 are completed.

5.1.2.2 *Night time*

One single algorithm is used for the whole day. That means the same inputs used at day time are required at night time. Since CWP and the VIS0.6 channel are only available at day time, an artificial method has been developed to create a pseudo-CWP and a pseudo-VIS06 derived from infrared and water vapour channels, also based on a principal component analysis.

Inputs

$IR_{8.7}$ µm	$IR_{9.7}$ µm	$IR_{10.8}$ µm	$IR_{12.0}$ µm	$IR_{13.4}$ µm	$VW_{6.2}$ µm	$WV_{7.3}$ µm

The quality of the product at night decreases with respect to day time, because of the unavailability of the VIS06 and the cloud microphysics product (CWP). The estimated VIS0.6 and CWP input variables at night time introduces additional uncertainties.

For more detailed information go to section 6 in the Algorithm Basis Document for the Precipitation Product Processors of the NWC/GEO [RD5].

5.1.2.3 *CRRPh Correction Factors*

5.1.2.3.1 Stability Correction

It applies the same as 4.1.2.3.1 section.

5.1.2.3.2 Parallax Correction

To eliminate parallax effects, a parallax correction can also be applied (see section 3.1.2.2.4 Parallax correction).

5.1.2.3.3 Cloud Water Path Correction Factor

An enhancement correction factor based on the Cloud Water Path (CWP) has been incorporated, when activated it applies to day and night time conditions. This way, the CRRPh output have been modified, providing with more rainfall rate in those areas with more content of water. For more detailed information go to section 4.3.5 in the Algorithm Theoretical Basis Document for the Precipitation Product Processors of the NWC/GEO [RD 5].

5.1.2.3.4 Lightning Correction Factor

CRRPh includes the same lightning algorithm as CRR. This lightning algorithm has been explained in section 3.1.2.3

5.1.3 Description of Convective Rainfall Rate from Cloud Physical Properties (CRRPh) outputs

The content of the CRRPh output (stored in $SAFNWC/export/CRRPh in netCDF format) is described in the Data Output Format Document [RD *2]*. A summary is given below:

NetCDF Common Atributes	
product_completeness	Percentage of pixels within the region containing data

product_quality	Weighted mean of the quality of all pixels with data, using the following weights: 1: Good pixels, 0.5: Questionable quality, 0.0: Bad quality

crrph_intensity

NWC GEO CTMP-CRR Convective Rainfall Intensity

DAY ALGORITHM			
GEO-CMIC-PHASE INPUT	GEO-CMIC PHASE INPUT CLASS	COTT OR REFF FROM CMIC	CRR-PH OUTPUT
Liquid	1	NO DATA	NO DATA
		DATA AVAILABLE	crrph_intensity(mm/h) = scale_factor * counts + add_offset
Ice	2	NO DATA	NO DATA
		DATA AVAILABLE	crrph_intensity(mm/h) = scale_factor * counts + add_offset
Mixed	3	NO DATA	NO DATA
		DATA AVAILABLE	crrph_intensity(mm/h) = scale_factor * counts + add_offset
Cloud-free	4	NOT APPLICABLE	0
Undefined	5	NOT APPLICABLE	NO DATA
No data or corrupted data	FillValue	NOT APPLICABLE	NO DATA

NIGHT ALGORITHM		
GEO-CMIC-PHASE PHASE INPUT CLASS	GEO-CMIC PHASE INPUT CLASS	CRR-PH OUTPUT
Liquid	1	crrph_intensity(mm/h) = scale_factor * counts + add_offset
Ice	2	crrph_intensity(mm/h) = scale_factor * counts + add_offset
Mixed	3	crrph_intensity(mm/h) = scale_factor * counts + add_offset
Cloud-free	4	0
Undefined	5	NO DATA
No data or corrupted data	FillValue	NO DATA

crrph_intensity(mm/h) = scale_factor * counts + add_offset

where:

scale_factor = 0.1

add_offset = 0.0

crrph_accum	NWC GEO CTMP-CRR Convective Hourly Rainfall Accumulation crrph_accum(mm) = scale_factor * counts + add_offset where: *scale_factor = 0.1* *add_offset = 0.0*
crrph_status_flag	13 bits indicating Data Availability: Bit 0: R_{eff} or COT not computed (out of cloud, night time, phase not defined) Bit 1: Phase not computed or undefined Bit 2: IR band missing (used in parallax correction) Applied Correction: Bit 3: Parallax correction applied Bit 4: Cloud water path correction applied Bit 5: Stability correction applied Use of optional data: Bit 6: Lightning data used Other information Bit 8: crrph_intensity was a hole because of the parallax correction, and then was filled by the median filter Bit 9, 10, 11:Use of bands for accumulation 1: All required bands were available 2: One previous CRRPh band is missing 3: At least two previous CRRPh bands are missing (no consecutive) 4: At least two previous CRRPh bands are missing (some are consecutive) Bit 12: Accumulation quality flag. Set to 1 if: not all crrph values are available to perform the accumulation, OR any of the crrph_intensity values was set to 0 due to filtering process OR Any of the crrph_intensity values was a hole because parallax correction Bit 13: Accumulation illumination flag: 1: Accumulation computed only with day algorithm. 2: Accumulation computed only with night algorithm 3: Accumulation computed with mixed algorithms.

Geophysical Conditions

Field	Type	Description
Space	Flag	Set to 1 for space pixels
Illumination	Parameter	Defines the illumination condition 0: N/A (space pixel) 1: Night 2: Day 3: Twilight
Sunglint	Flag	Set to 1 if Sunglint
Land_Sea	Parameter	0: N/A (space pixel) 1: Land 2: Sea 3: Coast

Processing Conditions

Field	Type	Description
Satellite_input_data	Parameter	Describes the Satellite input data status 0: N/A (space pixel) 1: All satellite data are available 2: At least one useful satellite channel is missing 3: At least one mandatory satellite channel is missing
NWP_input_data	Parameter	Describes the NWP input data status 0: N/A (space pixel or NWP data not used) 1: All NWP data are available 2: At least one useful NWP field is missing 3: At least one mandatory NWP field is missing
Product_input_data	Parameter	Describes the Product input data status 0: N/A (space pixel or Auxiliary data not used) 1: All input Product data are available 2: At least one useful input Product is missing 3: At least one mandatory input Product is missing
Auxiliary_input_data	Parameter	Describes the Auxiliary input data status 0: N/A (space pixel or Auxiliary data not used) 1: All Auxiliary data are available 2: At least one useful Auxiliary field is missing 3: At least one mandatory Auxiliary field is missing

Quality

Field	Type	Description
Nodata	Flag	Set to 1 if pixel is NODATA
Internal_consistency	Flag	Set to 1 if an internal consistency check has been performed. Internal consistency checks will be based in the comparison of the retrieved meteorological parameter with physical limits, climatological limits, neighbouring data, NWP data, etc.
Temporal_consistency	Flag	Set to 1 if a temporal consistency check has been performed Temporal consistency checks will be based in the comparison of the retrieved meteorological parameters with data obtained in previous slots.
Quality	Parameter	Retrieval Quality 0: N/A (no data) 1: Good 2: Questionable 3: Bad 4: Interpolated

5.2 Implementation of Convective Rainfall Rate from Cloud Physical Properties (CRRPh)

Previous condition and licences:

The right to use, copy or modify this software is in accordance with EUMETSAT Policy for the NWC-GEO software package.

5.2.1 Installation of Convective Rainfall Rate from Cloud Physical Properties (CRRPh)

CRRPh product is generated by the GEO-CRRPh component of the NWC/GEO software package. Detailed information on how to run this software package is available in the software user manual *[RD 3]*.

The software installation procedure does not require special resources. It is restricted to decompress the distribution files (a gzip-compressed tar files) and to successfully build the executable GEO-CRRPh-v<version> file to be stored into the $SAFNWC/bin directory.

Once the GEO-CRRPh-v<version> of the NWC-GEO is installed and configured in the system, its operational use requires the definition of some Configuration files in order to select the regions to be processed and some needed configurable parameters.

5.2.2 Preparation of Convective Rainfall Rate from Cloud Physical Properties (CRRPh)

The configuration file in charge of the region where the product is going to be run, has an optional name and the ".cfg" extension. This file contains the region centre location and the size image. When the application is installed, some region configuration files appear in $SAFNWC/config. Each of them corresponds to a different region; nevertheless users can create their own region configuration file. Information on the region_conf_file can be found in the Interface Control Document for Internal and External Interfaces of the NWC/GEO document *[RD 4]*.

The configuration file in charge of the product settings is the CRRPh model configuration file that has an optional name and the ".cfm" extension. Through this file the user can configure the way the product is going to be run choosing options such as whether the parallax correction should be applied or not. GEO-CRRPh component is in charge of computing CRRPh product on demand. More information on this configuration file can be found in section 4.3.2.

In order to apply parallax correction or the stability correction, NWP data required have to be available in $SAFNWC/import/NWP_data directory. Lightning data must be placed in the $SAFNWC/import/Obs_data/Lightning directory to run Lightning algorithm.

5.2.3 Execution of Convective Rainfall Rate from Cloud Physical Properties (CRRPh)

The GEO-CRRPh execution step consists in the launch of the command:

% GEO-CRPh-v<version> <YYYY-MM-DDThh:mm:ssZ> <region_conf_file> <model_conf_file>

Information on the region_conf_file can be found in the Interface Control Document for Internal and External Interfaces of the NWC/GEO document *[RD 4]* and model_conf_file is described in section 4.3.2.

GEO-CRRPh, to compute CRRPh product, requires mainly six steps:

- Initialise all variables and data structures according to input data. This includes computation of navigation data in the processing region read from the Processing Region Configuration File.

- Reading the input data required to execute the requested CRRPh processing in the processing region including 8 satellite channels and required the cloud microphysics (CMIC) day time (7 satellite channels at night time), and previous CRRPh products in the requested processing region (required to compute the hourly rainfall accumulation).

- Implementation of the algorithm to compute the base CRRPh values and some other quality and processing information.

- Application of CRRPh corrections (parallax, lightning, stability and cloud water path corrections factors), if required in the CRRPh Model Configuration file, to the base CRRPh values computed in the previous step.

- Computation of the hourly rainfall accumulations using rainfall intensities from previous CRRPh products.

- Writing the CRRPh product file according to the specification provided in the DOF [RD *2]*.

More information on the GEO-CRPh execution steps can be found at the Component Design Document for the Precipitation Product Processors of the NWC/GEO document [RD 6] [RD 6].

5.3 Inputs and configurable parameters for Convective Rainfall Rate from Cloud Physical Properties (CRRPh)

5.3.1 List of inputs for Convective Rainfall Rate from Cloud Physical Properties (CRRPh)

SATELLITE:

- $IR_{8.7}$, $IR_{9.7}$, $IR_{10.8}$,$IR_{12.0}$,$IR_{13.4}$ (Brightness temperature)
- $VIS_{0.6}$ (Normalized reflectance and corrected with Sun distance)
- $WV_{6.2}$,$WV_{7.3}$ (Brightness temperature)

IR10.8 SEVIRI brightness temperature at full IR spatial resolution is a mandatory input to compute Parallax Correction. It must be placed by the user in HRIT format in the $SAFNWC/import/Sat_data directory. Then it will be extracted on the desired region by NWC-GEO software package.

NWC/GEO software:

- GEO-cloud microphysics (CMIC $_{\text{Cloud Optical Thickness}}$, CMIC $_{\text{Effective Radius}}$, CMIC $_{\text{Phase}}$)

  - CMIC Phase, Cloud Optical Thickness (COT) and Effective Radius (R_{eff}) parameters are mandatory inputs to CRRPh day algorithm.
  - CMIC Phase is mandatory input to compute the CRRPh night algorithm.

These parameters will be read from CMIC NetCFD file which must be located in $SAFNWC/export/CMIC directory.

Numerical model:

- 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.

The NWP files must be located in $SAFNWC/import/NWP_data directory. In real time operational mode, the NWC SAF package has predefined tools (coordinated by the NWC SAF Task Manager daemon) which check every minute for new NWP data making automatically the spatial remapping to the predetermined regions to process on to $SAFNWC/tmp directory. This avoids spending time in every call to product processors to make the remapping process. In off-line operational mode, the "AllMapping" script allows to do the spatial remapping.

This information is used by default for parallax correction. In case of lack of NWP parameters parallax correction will be run using a climatological profile.

Lightning information file for CRRPh:

CRRPh and CRR incorcorate the same Lighning correction factor. Hence, the same file located in the $SAFNWC/import/Obs_data/Lightning directory is used by both convective products.

Lightning information contained in section 3.1.2.3 applies to this section.

Ancillary data sets:

Climatological profile is necessary as a backup for Parallax correction in case NWP is not available. This information is included in the software package and is located in the $SAFNWC/import/Aux_data/CRRPh directory.

Model configuration file for CRRPh:

CRRPh model configuration file contains configurable system parameters in the generation process of CRRPh product. This file is placed in the $SAFNWC/config directory. The CRRPh product related parameters refers to ancillary datasets, numerical model data, parallax correction, lightning module, stability correction and cloud water path correction. The complete list of these parameters and the explanation of the most useful ones is available on section 5.3.2.

Region configuration file (region.cfg):

This file set the dimensions and positions where CRRPh products will be obtained and is located in $SAFNWC/config directory.

5.3.2 Configurable parameters for Convective Rainfall Rate from Cloud Physical Properties (CRRPh)

Model configuration file contains configurable items in the product generation process such as corrections to be run, NWP parameters to be used by the CRRPh product processor, etc.

The PPh model configuration file needed for the execution of PPh must be placed at the $SAFNWC/config directory.

The only constraint in the use of any name is the key used to specify the parameters to be used from NWP models: NWP_PARAM. The use of this keyname is mandatory, and will be used by a pre-processing task in charge of remapping NWP incoming files (in GRIB format).

5.3.2.1 *Keywords table for Convective Rainfall Rate from Cloud Physical Properties (CRRPh)*

The CRRPh model Configuration File, located in the $SAFNWC/config directory and identified by the extension ".cfm", contains the following information applicable to CRRPh product:

Keyword	Description	Type	Default Value(s)
PGE_ID	Identifier of the product processor	Chain of characters	GEO-CRRPh
SEV_BANDS	Satellite channels to be used by PPh	Chain of characters	IR87,IR97,IR108,IR120,IR134, VIS06, WV62, WV73
DAY_NIGHT_ZEN_THRESHOLD	Solar zenith angle to select between day and night cases (in degrees). It is possible to configure the product to only use the night algorithm by setting the sun zenith angle threshold to 0. This would avoid discontinuities in the product at the day/night transition on the cost of degrading performance during day time	Double	70
APPLY_PARALLAX_CORR	Indicator whether the Parallax correction should be applied or not (1 yes; 0 no)	Integer	1
APPLY_STABILITY_CORR	Indicator whether the Stability correction should be applied or not (1 yes; 0 no)	Integer	1
APPLY_CLOUD_WATER_PATH_CORR	Indicator whether the Cloud Water Path correction should be applied or not (1 yes; 0 no)	Integer	1
APPLY_LIGHTNING_CORR	Indicator whether the Lightning information should be used or not (1 yes; 0 no)	Integer	0
LIGHTNING_DELTA_TIME	Time interval in minutes to consider lightning data files	Integer	15
RAIN_LIGHTNING_RATE_1	Rain rate parameter 1 linked to observed lightning (in mm)	Real	2.3
RAIN_LIGHTNING_RATE_2	Rain rate parameter 2 linked to observed lightning (in mm)	Real	0.75
RAIN_LIGHTNING_RATE_3	Rain rate parameter 3 linked to observed lightning (in mm)	Real	0.25
RAIN_LIGHTNING_RATE_4	Rain rate parameter 4 linked to observed lightning (in mm)	Real	0.1
COEFF_N_LIGHTNING_A	Coefficient "a" to be applied during the lightning adjustment function	Real	0.45
COEFF_N_LIGHTNING_B	Coefficient "b" to be applied during the lightning adjustment function	Real	0.7
NWP_PARAM	Parameter : Temperature (K) sampling rate : (=segment size)	Chain of characters	NWP_T 1

	interpolation method.		BLI
NWP_PARAM	Parameter : Geopotential (m^2s^{-2}) sampling rate : (=segment size) interpolation method.	Chain of characters	NWP_GEOP 1 BLI
NWP_PARAM	Parameter : Lifted index sampling rate :(=segment size) interpolation method.	Chain of characters	NWP_LI 1 BLI
NWP_PARAM	Parameter : K index sampling rate :(=segment size) interpolation method.	Chain of characters	NWP_KI 1 BLI
NWP_PARAM	Parameter : Showalter Index sampling rate :(=segment size) interpolation method.	Chain of characters	NWP_SHW 1 BLI

Table 13. Model configuration file keywords table applicable to CRRPh product

5.3.2.2 *Keywords description for Convective Rainfall Rate from Cloud Physical Properties (CRRPh)*

Below there is a description of the most useful keywords defined in CRRPh model configuration file applicable to CRRPh product in order to make easier the user exploitation:

- DAY_NIGHT_ZEN_THRESHOLD: to choose the solar zenith angle that selects between day and night algoritms. By default this keyword is set to 70º. It is possible to configure the product to only use the night algorithm by setting the day night zen threshold to 0. This would avoid discontinuities in the product at the day/night transition on the cost of degrading performance during day time.
- APPLY_PARALLAX_CORR: To decide whether the Parallax correction should be applied to CRRPh basic values or not (1 yes; 0 no). By default this keyword is set to 1.
- APPLY STABILITY_CORR: To decide whether the Stability correction should be applied to CRRPh basic values or not (1 yes; 0 no). By default this keyword is set to 1.
- APPLY_LIGHTNING_CORR: To decide whether the lightning correction should be applied or not to the CRRPh basic values (1 yes; 0 no). By default it is not applied
- APPLY_CLOUD_WATER_PATH_CORR: To decide whether including or not and enhancement in the CRRPh basic output based on the cloud content of water (1 yes; 0 no). By default it is set to 1, and hence it is applied.
- LIGHTNING CONFIGURATION OF THIS PRODUCT IS IDENTICAL TO CRR (See section 3.3.2.2)

5.4 WARNING AND ERROR MESSAGES

Typical warnings and error messages concerning CRRPh and PCPh products have been explained in section 4.4. Therefore Table 12 apply to this section.

5.5 TYPICAL KNOWN PROBLEMS AND RECOMMENDATIONS FOR USE

As a mandatory input (CWP=2/3*COT*REFF) derive from CMIC, there exists the need to run CMIC previous to run CRRPh.

For undefined phase pixels, R_{eff} and COT values are not computed by CMIC, so a NO DATA value is assigned in these cases by the algorithm.

It has been observed that pixels located in the surroundings of snow according to CMIC take sometimes high values of CWP, so a probability of precipitation higher than 0% is assigned erroneously.

It is highly recommended to apply parallax correction for a better location of precipitation areas with respect to the ground below. This correction is set by default.

Stability correction is used to remove CRRPh output from areas where it is not likely to have rain based on NWP models, because those regions are considered stable. This correction is especially useful at night, during winter season in high latitudes, because in these situations a more proportion of False Alarms has been detected. However, it has also been observed that at day time it removes precipitation areas well depicted. This correction is set by default because it seems to be beneficial on average for the whole year and Europe extension. However, at mid and low latitudes in summer time it may be beneficial not to apply it. This way POD increases.

The stability correction factor finally depends on the NWP model. If a specific meteorological pattern is wrongly reproduced, it will have an impact on the precipitation product. It has visually checked that the orography may produce unrealistic shapes. These artefacts produced by mountains are steady and it appears in the same places so it can be easily detected.

If a black hole inside a precipitating area appears, this effect may be directly attributed to this correction. The more accurate the NWP model is, the more precise the stability correction will be when excluding precipitating areas in the CRRPh basic output. In conclusion, stability correction factor may produce some steady artefacts always in the same places due to the orography and some black holes inside precipitating areas while excluding stable pixels based on the NWP analysis.

The relatively weak coupling between spectral features in the visible and infrared channels with precipitation rate for all situations except for convection makes it in most cases doubtful to try to assign precipitation rates from GEO data alone. For this reason, this product has been calibrated only for convective events.

The product is calibrated and optimize for convective events, and so, it obtains the best results for convective events. This product does not distinguish the phase of the estimated precipitation.

It must be borne in mind that these kind of cloud top based precipitation indirect methods necessarily have uncertainties. Although not found during the calibration and validation processes, according to the literature it is possible to find small ice particles in high-level strong updrafts of deep convective clouds (Rosenfeld et al., 2008). This could cause erroneous rain rate estimations.

The quality of the product at night decreases with respect to day time, because of the no availability of the visible channels and the cloud microphysics. For this reason VIS0.6 and CWP are simulated at night introducing somehow additional uncertainties.

5.6 Example of Convective Rainfall Rate from Cloud Physical Properties (CRRPh) visualization

An example of the CRRPh instantaneous rain rates and CRRPh hourly accumulation is shown below. It has been obtained at full resolution.

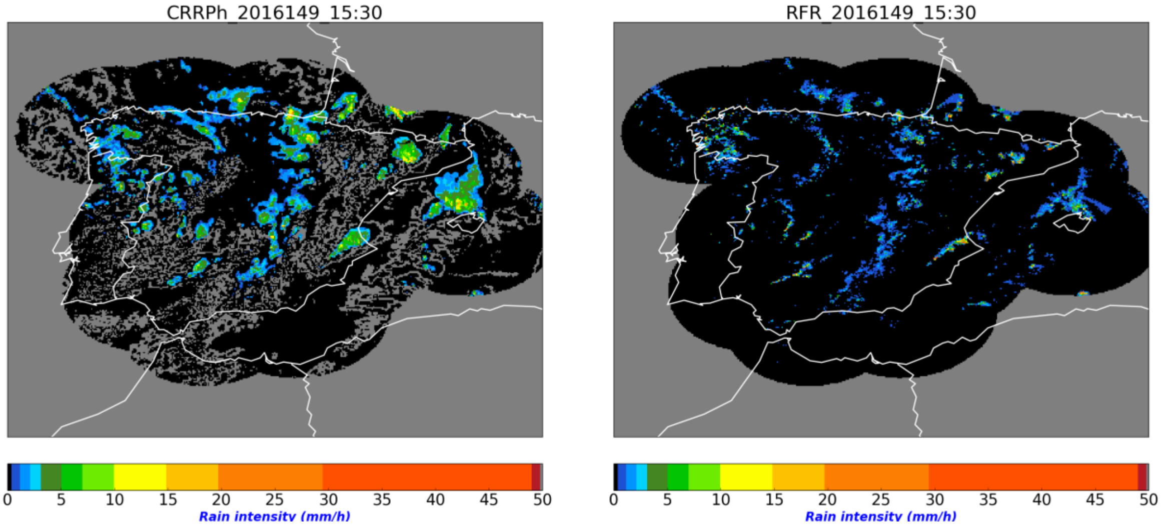

Figure 8. CRRPh instantaneous rain rates the 28th May 2016 at 15:30 UTC over Spain

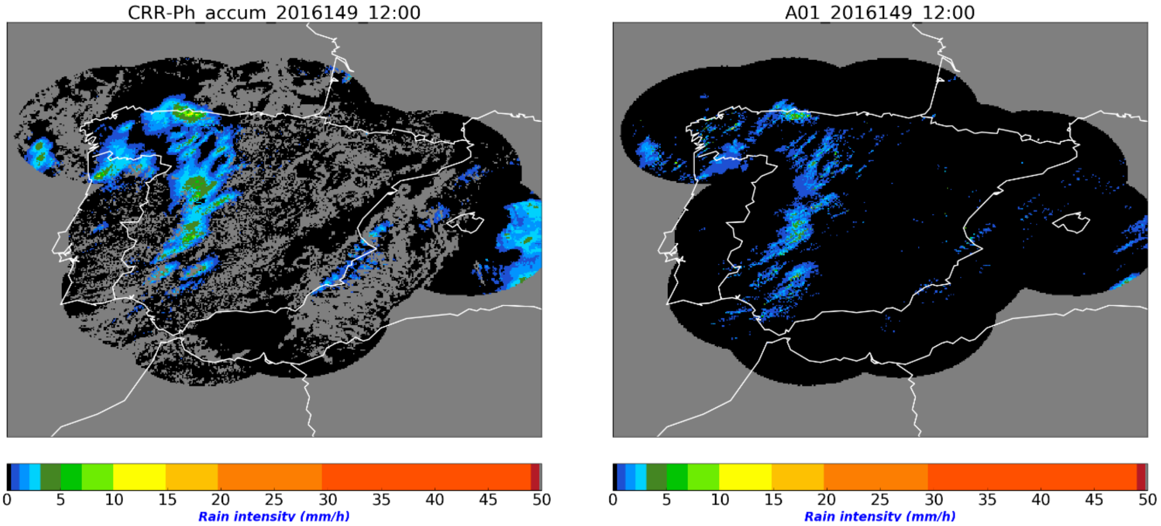

Figure 9. Comparison of CRRPh hourly accumulation day product and radar hourly accumulation on 28th May 2016 at 12:00UTC

6. REFERENCES

Daniel Rosenfeld, William L. Woodley, Amit Lerner, Guy Kelman, Daniel T. Lindsey, 2008. Satellite detection of severe convective storms by their retrieved vertical profiles of cloud particle effective radius and thermodynamic phase. J. Geophys. Res. D4, 113hour.