Algorithm Theoretical Basis Document for SAFNWC/MSG "Precipitating Cloud" (PC-PGE04 v1.5)

SAF/NWC/CDOP2/SMHI/SCI/ATBD/4, Issue 1,

Document Revision 5.4

15 July 2013

Applicable to SAFNWC/MSG version 2013

Applicable to the following PGE:s:

PGE	Acronym	Product ID	Product name	Version number
PGE04	PC	SAFNWC/MSG/PGE04	Precipitating Clouds	1.5

Prepared by SMHI

REPORT SIGNATURE TABLE

Function	Name	Signature	Date
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DOCUMENT CHANGE RECORD

Version	Date	Pages	CHANGE(S)
1.5d	23 January 2009	20	New Document for v2009, replaces Scientific User Manual SAF-NWC-CDOP-SMHI-SCI-SUM-04_v1.4 No scientific updates for v2009
1.5	2 March 2009	21	Changes after DRI-2009: -Corrected some typos. -Corrected erroneous references. -Corrected the page numbering. -correctet output class description under 2.2.1 -Clarified of differences between v1.2 and v1.5 in 2.2.2 -Added short names for referenced documents -List of acronyms updated with MSG and SEVIRI -Applicable documents: added missing dates and corrected codes
1.5	10 March 2009	21	- Changed erroneous references to AVHRR/AMSU algorithm in chapter 4.1 - added content in section 4.2, on configurable parameters
1.5.1d	19 April 2010	21	- no scientific updates. Adapted date, issue and revision to v. 2010 - Included reference to VS report nov. 2009
1.5.1	25 May 2010	21	Added the full NWCSAF logotype on first page.
1.5.2d	11 February 2011	21	No scientific updates. Adapted date, issue and rev. to v2011.
1.5.3d	11 October 2011	21	No scientific updates. Adapted date, issue and rev. to v2012.
1.5.3	15 February 2012	21	Updated references
1.5.4	15 July 2013	21	No scientific updates. Adapted date, issue and rev. to v2013.

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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, SAFNWC. The main objective of SAFNWC 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 SAFNWC webpage, http://www.nwcsaf.org . This document is applicable to the SAFNWC processing package for Meteosat satellites meteorological satellites, SAFNWC/MSG.

1.1 Scope of the document

This document is the Algorithm Theoretical Basis Document for the PGE04 (PC, Precipitating Cloud) of the SAFNWC/MSG software package.

This document contains a description of the algorithm, including scientific aspects and practical considerations.

1.2 Software Version Identification

This document describes the algorithms implemented in the PGE04 version v1.5.3 of the 2012 SAFNWC/MSG software package delivery.

1.3 Definitions, Acronyms and Abbreviations

Acronym	Explanation
CDOP	Continuous Development and Operational Phase
CM	Cloud Mask (also PGE01)
CT	Cloud Type (also PGE02)
CTTH	Cloud Top Temperature, Height and Pressure (also PGE03)
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAR	False Alarm Rate
FOV	Field Of View
HDF5	Hierarchical Data format version 5
IR	Infrared
LUT	Look-Up-Table
MSG	Meteosat second Generation
NIR	Near Infrared
NORDRAD	Nordic Weather Radar Network
NWP	Numerical Weather Prediction
PC	Precipitating Cloud (also PGE04)
PCPN	Precipitation
PGE	Process Generating Element
PI	Precipitation Index
POD	Probability Of Detection
POFD	Probability Of False Detection
RGB	Red Green Blue
SAF	Satellite Application Facility
SAFNWC	Satellite Application Facility for support to NoWcasting
SEVIRI	Imager on MSG satellites
SMHI	Swedish Meteorological and Hydrological Institute
SW	SoftWare
TOA	Top Of Atmosphere
USGS	U.S. Geological Survey
VIS	Visible

For a list of SAF-acronyms see also [RD.1].

1.4 References

1.4.1 Applicable Documents

Reference	Title	Code	Vers	Date
[AD. 1]	Validation Report for Precipitating Clouds (PC-PGE04v1.4)	SAF/NWC/CDOP/SMH/VR/01	1.4	17/11/07
[AD. 2]	Software User Manual for "Precipitating Clouds": Scientific part (PC-PGE04 v1.5.3)	SAF/NWC/CDOP/SMHI/SCI/SUM/04	1.5.3	15/02/2012
[AD. 3]	Interface Control Document for the External and Internal Interfaces of the SAFNWC/MSG	SAF/NWC/CDOP/INM/SW/ICD/1	6.0	15/02/2012
[AD. 4]	SAFNWC/MSG Output Product Format Definition	SAF/NWC/CDOP/INM/SW/ICD/3	6.0	15/02/2012
[AD. 5]	Architectural Design Document for the SAFNWC	SAF/NWC/CDOP/INM/SW/AD/1	6.0	15/02/2012
[AD. 6]	Product User Manual for "Precipitating Clouds" (PC-PGE04 v1.5)	SAF/NWC/CDOP/SMHI/SCI/PUM/04	1.5.3	15/02/2012
[AD. 7]	Cross-Verification of the Rapid Development Thunderstorm and the Precipitation Products of the Nowcastion and Vert Short Range Forecasting SAF	Visiting scientist report by Eszter Lábó, Mária Putsay, Zsófia Kocsis and Ildikó Szenyán		15/11/2009

Table 1: List of Applicable Documents

1.4.2 Reference Documents

Reference	Title	Code	Vers	Date
[RD.1]	The Nowcasting SAF Glossary	SAF/NWC/CDOP/INM/MGT/GLO	1.5	15/04/2011
[RD.2]	SAFNWC Product Requirements Document	SAF/NWC/INM/MGT/PRD	1.2	17/11/2011

Table 2: List of Referenced Documents

1.5 List of TBD:s and TBC:s

There are no open TBD:s or TBC:s in this document.

1.6 Scientific Updates since MSG Version 2011

No scientific updates have been implemented since NWCSAF/MSG version 2011.

2. PRECIPITATING CLOUD ALGORITHM DESCRIPTION

2.1 GOAL OF THE PC PRODUCT

The relatively weak coupling between spectral features in the visible and infrared channels with precipitation rate for all situations except for strong convection makes it in most cases doubtful to try to assign precipitation rates from SEVIRI data alone. However it is possible to statistically determine the likelihood of from visible and infrared spectral signatures in a SEVIRI scene. The PC product for MSG is thus to be seen as a complement of the convective rain rate product, which specifically addresses convective situations, and the rapidly developing thunderstorm product, which also takes into account the time evolution of systems. The precipitating cloud product can serve as a general tool for Nowcasting of precipitation, especially for areas where no surface radar data is available. It should however be noted, that the nature of the input data usually leads to an overestimation of the precipitating area.

2.2 PC ALGORITHM DETAILED DESCRIPTION

2.2.1 General algorithm design

The precipitating clouds product gives the likelihood of precipitation. Validation and prototyping for earlier software versions have shown that there is no skill in trying to stratify Total precipitation likelihood into light to moderate precipitation and strong precipitation. As a consequence only the total precipitation likelihood is now reported as class 1:

- Class 1: precipitation >0.1 mm/h
- Class2: obsolete, set to zero

A linear combination of those spectral features, which have the highest correlation with precipitation, is used to construct a Precipitation index PI. For each value of the PI, the probability of precipitation in the respective classes is then determined from a comprehensive dataset of co-located satellite data, precipitation rates from rain gauge measurements and surface temperatures from NWP.

In the calculation of the PI special attention has been given to spectral features in the visible, which implicitly contain information on cloud microphysical properties at the cloud top, such as effective radius and cloud phase. The algorithm employed is cloud type dependent in the sense that mapping from PI to precipitation likelihood makes use of cloud type dependent lookup tables. For the PI calculation a day and a night version exists, where the night version only makes use of IR channels not influenced by sunlight.

2.2.2 Data used for algorithm development and tuning

Tuning had to be performed over the central Europe. Since not enough systematic radar data sets were available for tuning of the SEVIRI algorithm to radar, SYNOP current weather reports (October2003 – August 2004) and French rain gauge data (January 2004 – December 2004) were used for tuning. The current default configuration for algorithm version 1.5 has been unchanged since version 1.3 (released spring 2007) and uses a cloud type dependent tuning based on French Gauge data. There is also the option to configure the algorithm for a previous version of tuning released with v1.2. This older tuning is independent of cloud type, and based on European SYNOP reports for current weather. It is however not recommended to change to this option because of inferior algorithm performance Validation results for version

1.2 and the versions identical to the current default algorithm version are reported in the validation report [AD. 1].

A precipitation index PI is calculated using the same formula for all cloud types, but mapping to likelihood is performed cloud type dependent. Validation results are reported in [AD. 1] .

	Precipitation Frequency [%]	Precipitation Frequency [%]	Algorithm number used for potentially raining cloud types (
Cloud type	French gauges	Hungarian gauges	
1 –cloud free land	**0,6**	**0,1**	
2 –cloud free sea	**0,1**	**-**	
3 –snow/ice land	**4,0**	**3,9**	
4 –snow/ice sea	**-**	**-**	
5 –very low Cu	**-**	**-**	
6 –very low St	**1,9**	**0,5**	
7 –low Cu	**-**	**-**	
8 –low St	**7,7**	**4,3**	**Not considered raining, might need adjustment**
9 -medium Cu	**-**	**-**	**Algorithm 1**
10 -medium St	**21,5**	**13,3**	**Algorithm 1**
11 -high&opaque Cu	**-**	**-**	**Algorithm 2**
12 - high&opaque St	**30,3**	**31,4**	**Algorithm 2**
13 -v. high&op Cu	**-**	**-**	**Algorithm 2**
14 -v. high&op St	**43,6**	**35,4**	**Algorithm 2**
15 – thin Ci	**1,4**	**0,9**	
16 - mod. Thick Ci	**3,6**	**2,4**	
17 – thick Ci	**13,1**	**11,0**	**Algorithm 3**
18 –Ci above lower cloud	**5,1**	**3,9**	**Algorithm 4**
19[2)] Fractional cloud	**1,2**	**0,5**	

Table 3: Total likelihood of precipitation for different cloud types as compared to collocated French rain gauge data and Hungarian gauge data for Jan-Dec 2004. Rain gauge data averaged over 30 minutes

2.2.3 Algorithm details

It was investigated which spectral features of SEVIRI were most correlated with precipitation. The Precipitation Index PI is constructed as a linear combination of those spectral features which are most correlated with precipitation as to maximise the correlation of PI and precipitation.

We have chosen a Precipitation Index of the form:

PI=a0 +a1*Tsurf +a2*T108+a3*(T108-T120) +a4*abs(a5-R06/R16)

+a6*R06+ a7*R16+a8*T062+a9*T073+a10*T039) *Eq.1*

This formulation will allow to specify different day and night algorithms and to easily tune the algorithm by just providing different coefficient files, for example for different cloud types. In the current implementation however, algorithms for different cloud type groups are using the same set of coefficients, but a cloud type specific mapping of PI to precipitation likelihood.

Cloud type groups are defined as follows:

Algorithm 0: all cloudtypes. In version 1.2 PI coefficients from tuning to synop current weather observations are supplied, together with tables for matching PI to precipitation likelihood. Use of this algorithm is not recommended. Instead the cloud type dependent algorithms tuned on French gauge data and outlined below should be used, as supplied in the standard configuration since version 1.3.

Algorithms 1 to 4 are tuned on French gauge data (average over 30 minutes). Coefficient sets for these algorithms are identical since version 1.3, but mapping of the resulting PI to precipitation likelihood is cloud type dependent:

Algorithm 1: cloud type 9,10 = medium level opaque cloud

Algorithm 2: cloud types 11 – 14 = high and very high opaque cloud

Algorithm 3: cloud type 17 = thick cirrus

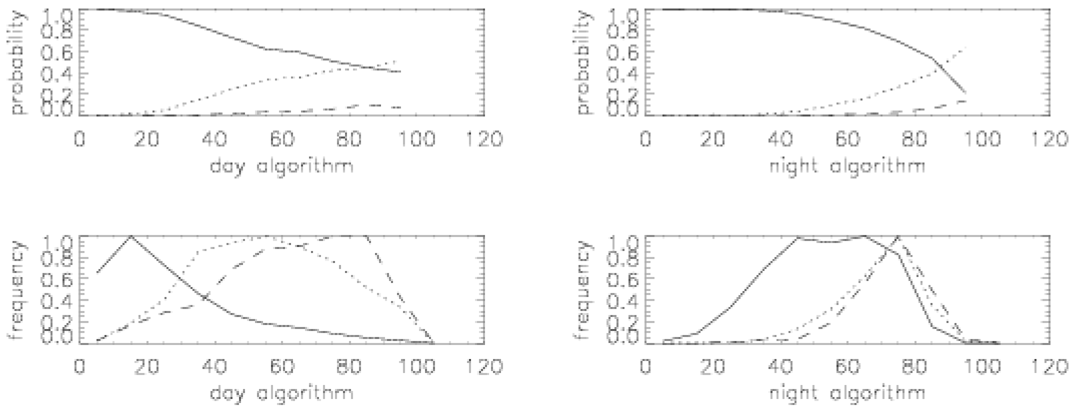
Algorithm 4: cloud type 18 = cirrus above lower clouds

Table 4 shows PC algorithm coefficients for day and night for all clouds, both for synop based tuning (Alg0), and for tuning to French gauge data which is currently identical to Algorithms 1 to 4.

Alg0-day Tuned on SYNOP (use not recommended)	130.0	-1.17841	0.193517	1.34862	-0.403661	3.2	1.21913	-1.14646	1.0137	-0.729214	0.482047
Alg0-night Tuned on synop (use not recommended)	130. 0	-0.808931	-0.660192	-1.3209	0.0	0.0	0.0	0.0	1.56148	-1.46149	0.
Alg1,2,3,4-day Tuned on rain gauges (default)	**230.0**	**-1.35**	**-0.63**	**-2.59**	**63.79**	**0.0**	**-0.40**	**0.0**	**-0.92**	**0.32**	**1.52**
Alg1,2,3,4-night Tuned on rain gauges(default)	**460.0**	**-0.90**	**-0.91**	**-5.34**	**0.0**	**0.0**	**0.0**	**0.0**	**-0.27**	**0.65**	**0.0**

Table 4: Coefficients a0 to a10 for current day and night algorithm according to tuning with current weather observations from synop (algorithm 0) and tuned on French gauge data (algorithms1 to 4)

How the PI maps to probability for different intensity classes is illustrated in Figure 1. The normalised frequency distribution for different intensity classes as observed by gauge data is given in the lower panel. The total likelihood of precipitation is split into two intensity classes in these plots and would be represented by the sum of likelihood for light and heavy precipitation for each value of PI respectively. The likelihood that a certain value of the PI falls into a certain precipitation class is determined from the (not normalised) frequency distribution under the constraint that the total likelihood has to be 100% (upper panel). There seems to be no potential to differentiate intensity classes for the large majority of cases. A substantial overlap of all precipitating classes with the no-precipitation class is apparent in the normalized frequency distribution. This is especially true for the night algorithm. Generally better precipitation discrimination can be performed at day time since the daytime algorithm is strongly dependent on the R6/R16 feature, discontinuities between day and night algorithms could not be avoided. When deriving the probabilities that a given PI belongs to a certain precipitation class, the resulting distribution suffers from the fact that there is a wide overlap between the precipitating and non-precipitating classes, as well as from the generally much larger number of non-precipitating cases.



DAY **NIGHT**

Figure 1: algorithm1-4 for all potentially precipitating cloud types tuned on French gauge data. Left: day algorithm, right: night algorithm. Lower panels: normalised histogram for different precipitation classes (solid line: no precipitation, dotted: light to moderate precipitation, dashed: heavy precipitation). Upper panels: same as lower, but for probability, total precipitation likelihood would be the sum of the dotted and dashed lines in the upper panel X-axis: Precipitation Index PI

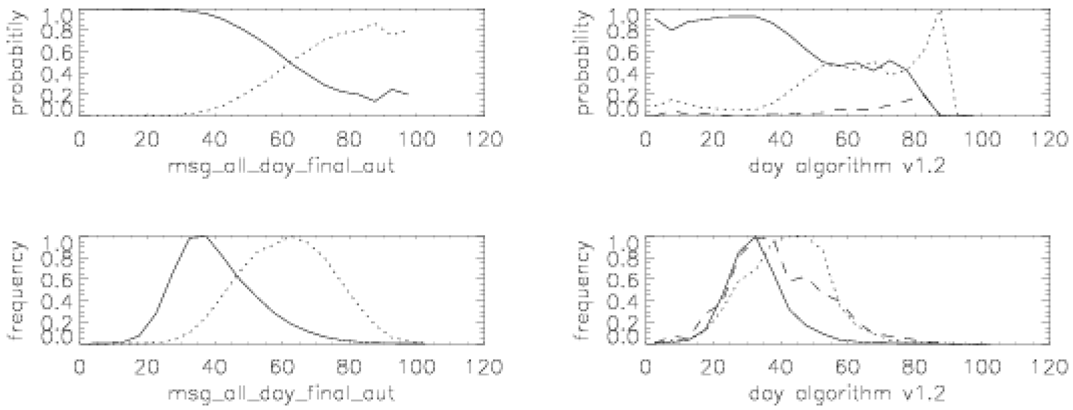


Figure 2 : left: day algorithm tuned on synop collocation data set (dotted: all precipitation). Right: same algorithm, but applied on rain gauge collocation data set (dotted light to moderate precipitation, dashed heavy precipitation). X-axis: Precipitation Index PI

An example of the precipitating clouds product is given in Figure 3.

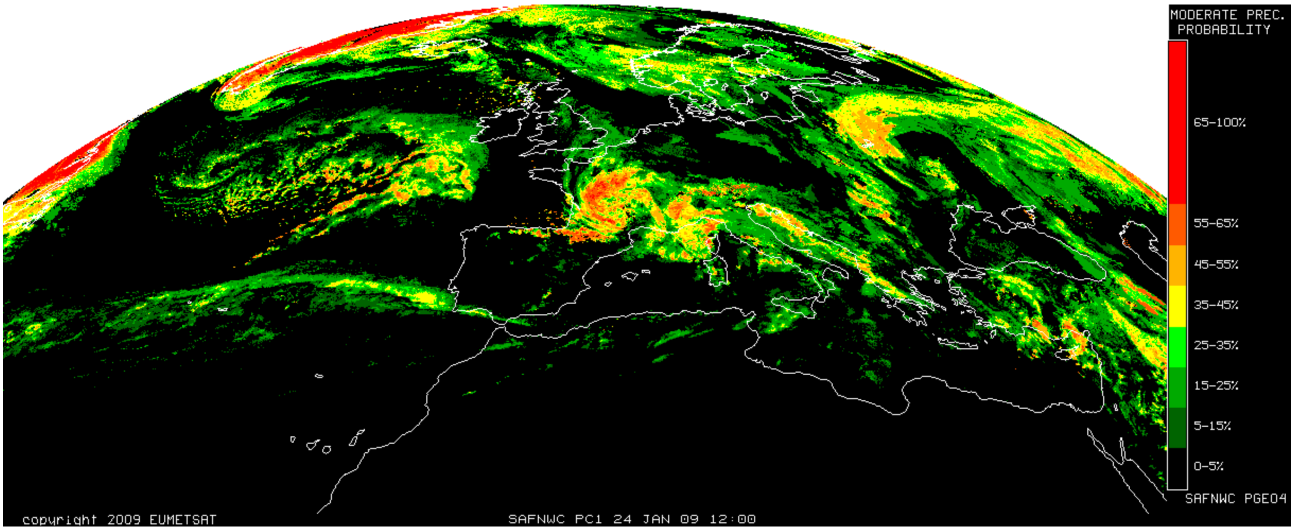


Figure 3: 200901241200 precipitating clouds product over MSG-N, configured for day algorithm. Dark green hues present precipitation likelihood 5%-25%,light green 25%-35%, yellow hues 35%-45% and orange/red red 45% and higher

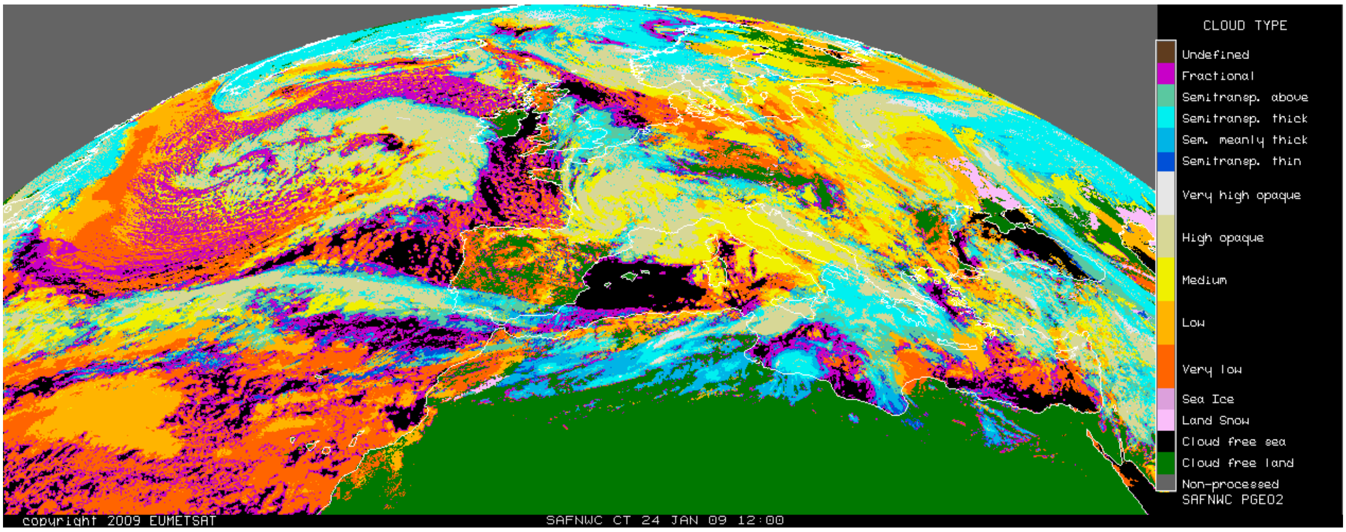


Figure 4: Cloud type input 200901241200 over MSG-N.

2.3 OVERVIEW OF ALGORITHM PERFORMANCE AND VALIDATION

The PC product can be validated against co-located radar data, synop current weather observations or rain gauge data. For more information on product validation see validation report [AD. 1]. When verifying likelihood results of the PC product, it is important to somehow quantify the algorithm performance and give some guidance to answer the question whether it is raining or not. It is important to understand that a simplified "categorical estimate", which has been derived from the likelihood distribution, degrades the product on the one hand (no "fair" comparison) but, on the other hand, makes it more practical to use for the forecaster.

A simple way to convert likelihood estimates into easily verifiable estimates of precipitation would be to perform a hard-clustering, assigning the precipitation to the most likely class. In the case of a pure IR/VIS algorithms however, this is not a viable option since the general skill of the algorithm is limited. Most pixels would be assigned to be non-precipitating. But how can a threshold for precipitation be derived?

We propose the following, more flexible, approach to determine thresholds of rain:

- Set the threshold for rain according to algorithm performance. Which threshold of total precipitation likelihood does best divide the precipitating from the non-precipitating events? (Usually 20% or 30% of total precipitation likelihood!)

The performance of this "hard-clustering" is verified using contingency tables. Evaluating the performance at different threshold levels gives also an overview of how closely assigned probability values match real occurrence of rain.

When comparing to rain gauge data, the results can be seen in Figure 5 and Figure 6.

Result depends also on the length of time interval considered in the collocations. About half an hour averaging of gauge data seems to give best results.

Year 2004 (238095)	**Day CT tuned (default)**	**Night CT tuned (default)**	**Day synop tuned (option)**	**Night synop tuned (option)**
	10% threshold			

POD	0.85	0.87	0.80	0.90
FAR	0.76	0.79	0.80	0.83
POFD	0.19	0.24	0.23	0.30
HK	0.66	0.63	0.57	0.60
Bias	3.54	4.21	4.05	5.20
ACC	0.81	0.77	0.77	0.71
	20% threshold			
POD	0.77	0.77	0.57	0.75
FAR	0.71	0.76	0.72	0.77
POFD	0.13	0.18	0.11	0.18
HK	0.64	0.59	0.46	0.57
Bias	2.61	3.27	2.06	3.29
ACC	0.86	0.82	0.87	0.82
	30% threshold			
POD	0.57	0.47	0.42	0.33
FAR	0.58	0.66	0.64	0.71
POFD	0.06	0.07	0.05	0.06
HK	0.51	0.41	0.36	0.27
Bias	1.35	1.39	1.15	1.11
ACC	0.92	0.90	0.91	0.90

Table 5 : Precipitation detection performance when thresholding precipitation at different likelihood threshold (10%, 20%,30%). Detailed description of scores used is given in the validation report [AD1]. On the left synop based CT independent tuning as supplied with v1.2 and optionally configurable in the current version. Validation against Hungarian dataset over the whole year.

A detailed validation of the algorithm is given in the validation and prototyping report [AD. 1].

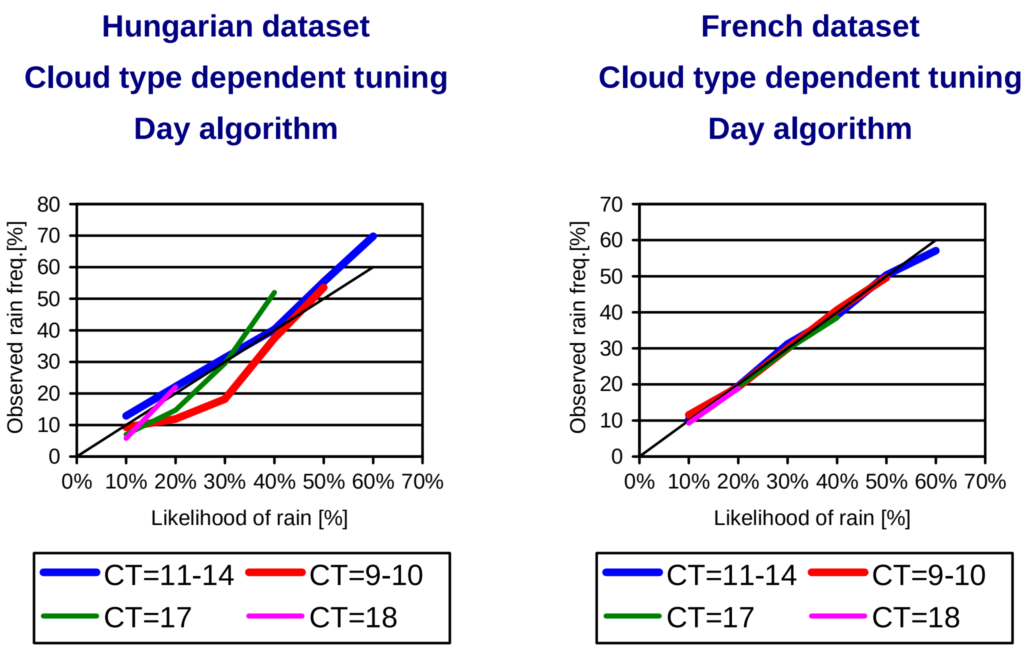


Figure 5: Likelihood of rain from PC product versus observed rain frequency. Cloud type dependent tuning on French gauge data. Left: independent validation against Hungarian gauge data 2004, right: performance on dependent French gauge data set 2004. verified against 30 min averages in gauge data.

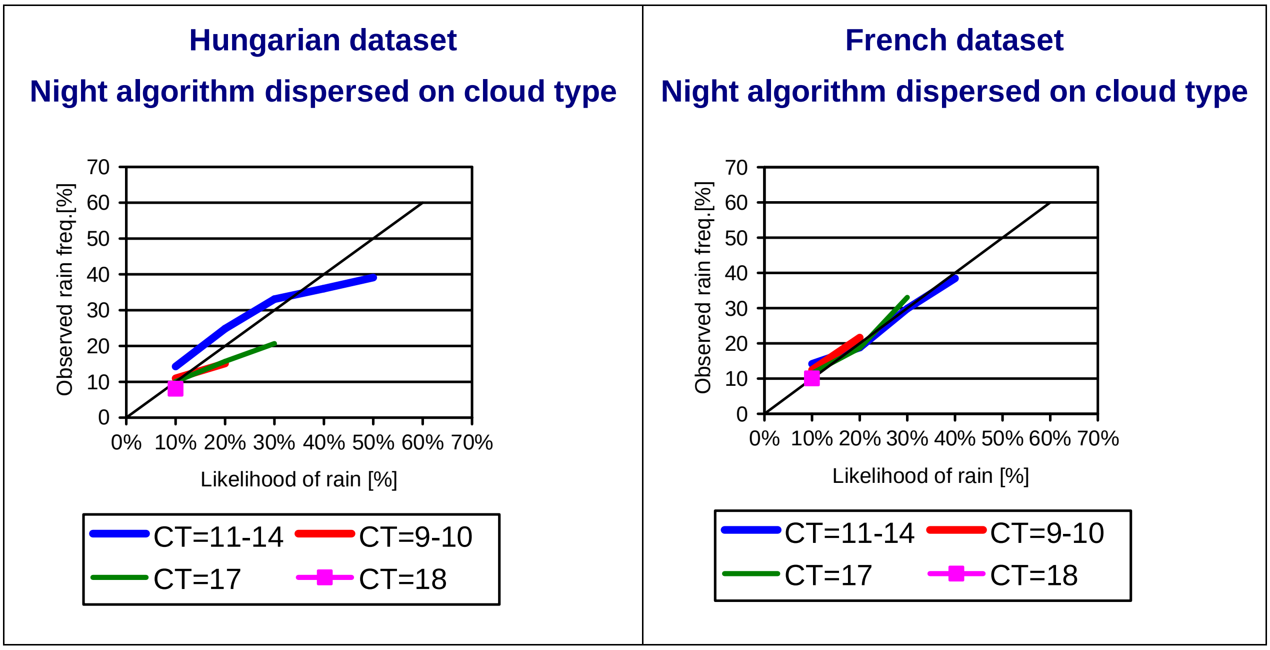


Figure 6: Likelihood of rain versus observed rain frequency. Cloud type dependent tuning on French gauge data. Left: independent validation against Hungarian gauge data 2004, right: performance on dependent French gauge data set 2004. verified against 30 min averages in gauge data.

Algorithm performance can be summarized as follows:

- **The default configuration for version 1.5 (cloud type dependent gauge tuned) is clearly superior to the optional configuration for synop tuned dataset during day time (active in v1.2). Nightime performance is slightly improved with version 1.5 over version 1.2.**
- The night algorithm is somewhat more improved than the day algorithm by cloud type dependent tuning, especially with regard to a more even performance over the year see [AD. 1]. In winter precipitation occurrence is more strongly overestimated, in summer more actual precipitation is missed. Both at 20% and 30 % threshold precipitation occurrence is overestimated.
- There are big differences between the cloud types. The cloud type dependent tuning seems to improve results for some cloud types, for some not.
- The work with separating cloud types has also shown that:
    - Cloud type class 9-10 precipitation is overestimated at 20 percent detection level especially at night time
    - Cloud type class 17 and 18 give bad results overall, but large biases seen before at 20%detection level could be reduced significantly by introducing cloud type dependent tuning.
    - Cloud type class 11-14 seems to be the easiest to handle
    - Considering cloud low clouds (CT 8) as possibly precipitating might be considered in the following versions

- Day and night algorithms still exhibit different characteristics, but differences are less than in version 1.2.
- **At the 20% detection threshold day and night algorithms perform almost equally well, whereas the day algorithm clearly exhibits more skill at the 30% threshold than the night algorithm. 20%can be used as a kind of hardclustering threshold for precipitation, but thresholding at 30% generally gives a better subjective fit to radar precipitation areas.**

  Service specification requirements are met at the 20% threshold level.

2.4 GRAPHICAL OVERVIEW OF PGE04

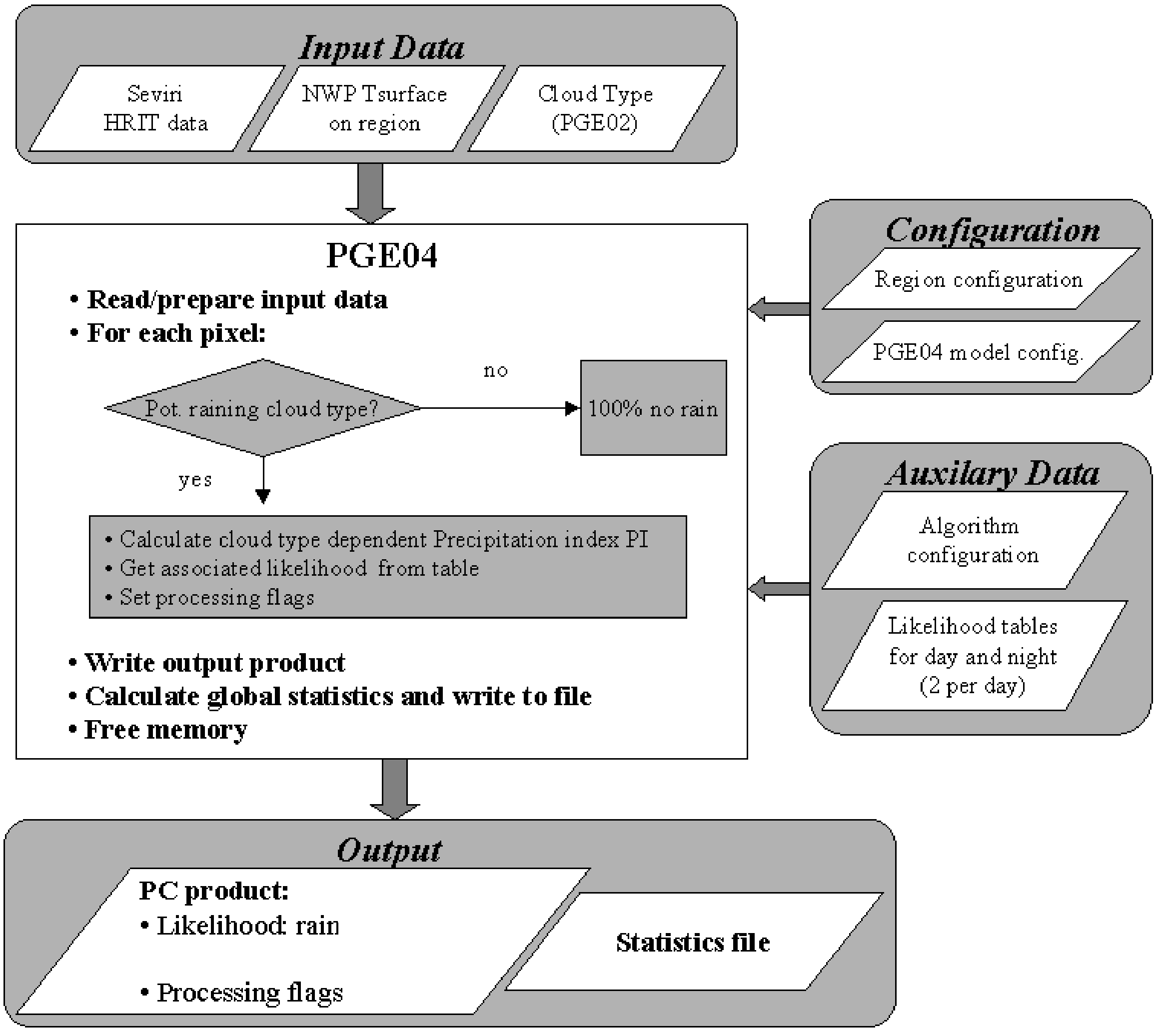


Figure 7: schematic overview over the PGE04 software

3. KNOWN PROBLEM AREAS AND LIMITATIONS

- The current version of the product contains a certain dependence on sun zenith angle.
- There is also a clear jump in algorithm performance between day and night algorithm, which cannot be totally avoided.
- The product degrades considerably at high viewing angles and use for viewing angles greater than 60 degrees is not recommended.
- The algorithm does currently not detect any precipitation from low clouds

4. PRACTICAL CONSIDERATIONS

4.1 PC INPUTS

Satellite data

The following Meteosat SEVIRI channels are used in the PC algorithm:

Daytime: vis0.6, NIR1.6, IR3.9, IR6.2, IR7.3, IR10.8, IR12.0

Nighttime: IR6.2, IR7.3, IR10.8, IR12.0

Sun and satellite angles

Sun and satellite angle files are mandatory input to the PC product. Currently only the sun zenith angle is actively used by the algorithm.

NWP data

From NWP data only the Surface temperature field is required.

PGE02

The cloud type product, PGE02 is a mandatory input to the PC module.

4.2 CONFIGURABLE PARAMETERS

The Precipitating Cloud product has been designed to allow a full configuration and flexibility to update/tune the algorithm without having to modify the code. However most of these configurable parameters are only of interest to the developer. The only configurable parameters potentially of interest to the users are the configuration of when to switch from day- to nighttime scheme, and that it is in principle possible to define which cloud types are treated as potentially raining.

- The default configuration is that the night time algorithm is activated when the sun zenith angle is greater than 80 degrees. It is possible to configure the product to only use the night algorithm by setting the sun zenith angle threshold to 0 in the algorithm configuration file. This would avoid discontinuities in the product at the day/night deliminator on the cost of degrading performance during day time.
- In principle it is possible to configure which cloud classes are treated as potentially raining. Please consult the NWCSAF helpdesk before changing the validated default configuration.

The possible configurable parameters are described in the Software User Manual [AD. 2].

4.3 OUTPUT

Two outputs are generated under $SAFNWC/export/PGE04:

- Precipitating Clouds (PC) product

- Statistics file

4.3.1 PC product

The precipitating clouds product gives the likelihood of precipitation in three intensity classes:

- Class 0: No precipitation 0 – 0.1 mm/h
- Class 1: total precipitation likelihood > 0.1 mm/h
- Class2: obsolete, set to 0

The likelihood for "no precipitation" is not explicitly given, but can be calculated as:

P(class 0)=100%-P(class1)

The likelihood is given in intervals of 10%. For further details see [AD. 6].

4.3.2 Statistics file

The statistics file is an ASCII file summarising the distribution of probabilities over the complete region. It can be easily used for verification whether 2 runs are identical. Files may also be used to easily accumulate statistics on general algorithm performance.

4.4 VISUALISATION

In the HDF file a look-up-table is included, which can be used for visualisation. Visualising the data in different colour schemes is straight forward.

4.5 LIKELIHOOD THRESHOLD FOR RAIN

As discussed in section 2.3 a 20% threshold is recommended for rain discrimination. A 30% level does however give a better subjective fit to radar data.