Algorithm Theoretical Basis Document for Convection Products

NWC/CDOP2/GEO/MFT/SCI/ATBD/Convection, Issue 1, Rev. 1

15th October 2016

Applicable to

GEO-CI v1.0 (NWC-052)

GEO-RDT-CW v4.0 (NWC-055)

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REPORT SIGNATURE TABLE

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DOCUMENT CHANGE RECORD

Version	Date	Pages	Changes
1.0	29th November 2013		Initial version : baseline document for PDCR
1.1d	16th December 2015		Delivery version for STRR
1.2d	1st April 2016	70	Updates after STRR RIDs
1.1	15th October 2016	72	Updates after DRR

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List of Tables and Figures

1. INTRODUCTION

1.1 SCOPE OF THE DOCUMENT

The ATBD document provides the scientific description of the convection products algorithm. It points out assumptions done on algorithms and limitations of products. This document summarizes product validation result and describes the outputs. PGEs associated to convection products are PGE18 (CI) and PGE19 (RDT-CW)

1.2 SCOPE OF OTHER DOCUMENTS

The UM (User Manual) provides all useful information to users.

The VR (Validation Report) depicts the accuracy of each product

The Interface Control Documents ICD/1 (Interface Control Document n°1) describes the External and Internal Interfaces of the SAFNWC/MSG software.

The Interface Control Documents ICD/2 (Interface Control Document n°2) describes the input and output data formats of the SAFNWC/MSG software.

1.3 SOFTWARE VERSION IDENTIFICATION

This document describes the products obtained from the PGE18 GEO-CI v1.0 (Product Id NWC-052) from the PGE19 GEO-RDT-CW v4.0 (Product Id NWC-055) implemented in the release 2016 of the NWC/GEO software package.

1.4 IMPROVEMENT FROM PREVIOUS VERSION

PGE18 (GEO-CI) v2016 is the first release of the product. CI software takes advantage of common modules with RDT-CW, and shares some aspects of cell detection and tracking, over which movement analysis and pixel analysis superimpose to complete the processing.

PGE19 (GEO-RDT-CW) is a continuation of CDOP-PGE11 (RDT). The main changes implemented in v2016 concern :

- Adaptation to new v2016 NWCLIB interfaces and structures
- More optional inputs: new CMIC product for microphysics, HRW for movement analysis, NWP wind component as additional inputs for NWP parameters.
- Processing of a 2D movement field as guess field (from HRW and NWP winds) for initialization of cloud cell motion
- Improvement of spatial and temporal coherence of cloud cell motion, improvement of expansion rate processing
- Additional attributes related to CMIC product (phase, microphysics parameters), basic related icing index at high altitude, lightning trend, top pressure trend, synthetic severity index
- Improvement of discrimination modules that change a "No" convection diagnosis issued from statistical discrimination step of algorithm (for example in case of OT detection or, according to user's configuration, lightning activity or high CRR). Product keeps memory

of "forced" convection diagnosis too, and this characteristic is taken into account in the next slots. Improvement of the de-classification step.

- Optional parallax correction inserted before product encoding
- The compliance with NetCDF format for encoding SAFNWC v2016 outputs *(BUFR output may additionally be produced for non regression purposes, depending on user's configuration)*. NetCDF encoding refers to bulletin-like structure, but optional 2D map of type/phase of convective cells may be available into the output of analyzed cloud cells, depending on user's configuration.
- The development of a nowcast (+1h) module, activated through user's configuration, and leading to maximum four forecast products (+15', +30', +45', +60') additional to the analyzed one.
- The implementation of CTRAJ product as intermediate output.

1.5 Glossary, Acronyms and Abbreviations

See [R.D. 1] for a complete list of acronym for the NWC SAF project.

1.6 References

1.6.1 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: http://www.nwcsaf.org

Reference	Title	Code	Vers	Date
A.D. 1	User Manual	SAF/NWC/CDOP2/MFT/SCI/UM/Convection	1.0	15/10/2016
A.D. 2	Validation report	SAF/NWC/CDOP2/MFT/SCI/VR/Convection	1.0	15/10/2016
A.D. 3	Interface Control document for the External and Internal Interfaces	SAF/NWC/CDOP2/GEO/AEMET/SW/ICD/1	1.1	15/10/2016
A.D. 4	Output format for the NWC/GEO products	SAF/NWC/CDOP2/GEO/AEMET/SW/DOF	1.1	15/10/2016
A.D. 5	Interface Control Document for the input and output data formats	SAF/NWC/CDOP/INM/SW/ICD/3	1.1	15/10/2016
A.D. 6	Software User Manual for the SAFNWC/MSG Application, Software Part	SAF/NWC/CDOP2/INM/SW/SUM/2	1.1	15/10/2016
A.D. 7	NWC SAF CDOP-2 Project Plan	NWC/CDOP2/SAF/AEMET/MGT/PP	1.9	15/10/2016
A.D. 8	NWC SAF Product Requirements Document	NWC/CDOP2/SAF/AEMET/MGT/PRD	1.9	Aug 2016
A.D. 9	Configuration Management Plan for NWC SAF	NWC/CDOP2/SAF/AEMET/MGT/CMP	1.4	15/10/2016
A.D. 10	System and Documents Requirement document	NWC/CDOP2/GEO/AEMET/SW/SCRD	1.2	15/10/2016

Table 1: applicable documents

1.6.2 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.1]

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: http://www.nwcsaf.org

Ref	Title	Code	Vers	Date
R.D. 1	The Nowcasting SAF Glossary	NWC/CDOP2/SAF/AEMET/MGT/GLO	1.2	18/2/2014

2. DESCRIPTION OF CI (CONVECTION INITIATION) PRODUCT

2.1 PRODUCT OVERVIEW

2.1.1 Goal of the product

CI provides the probability for a cloudy pixel to become a thunderstorm in a given following period range. The product aims to catch the first steps of initiation of convection, when the first convective signs occur after the formation of clouds, or when those signs appear revealing a modification of environmental conditions.

2.1.2 Product description

Probability of the formation of a thunderstorm depends on evolution of local condition and on advection of clouds. For this second point, CI is unfortunately too scarce for a full object-approach that allows a good following of meteorological systems. CI is a pixel product.

CI is defined for three time-steps (0-30’, 0-60’ and 0-90’) and for four classes of probability (0-25%, 25-50 %, 25-50 %, 75-100%). For example if a given pixel at a given time T has a probability interval of 50-75% for the range 0-60’, it means that the pixel has a probability between 50% and 75% to become a thunderstorm between T and T+60 minutes.

For the first release only the first [0-30'] period output is processed

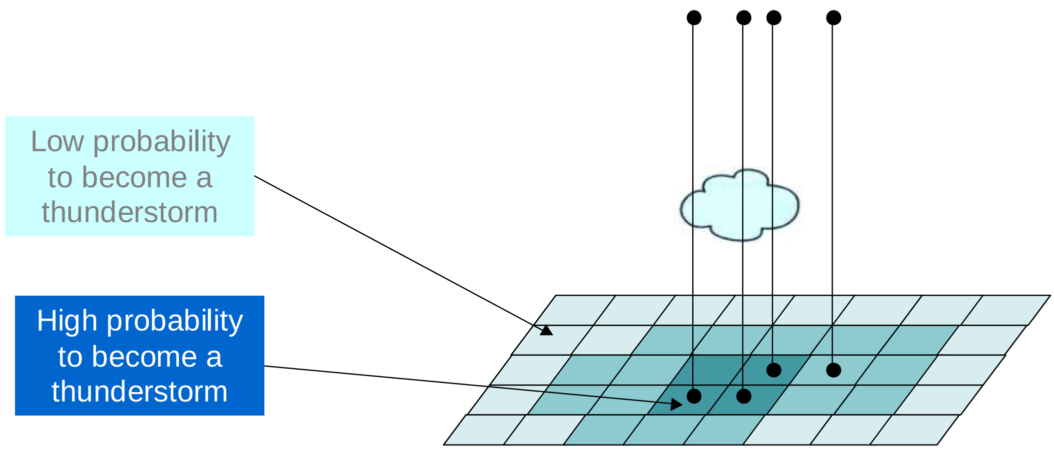


Figure 1: Convection Initiation (CI) Product

2.1.3 Terminology

For a given slot a time T

- Pixel ***eligible-CI***: a pixel passing a first filter verifying if basic conditions for convection are satisfied regarding cloudy environment, instability indices, etc. To avoid non-initiation phases, cold systems are not eligible-CI
- Pixel ***pre-CI***: a pixel eligible-CI passing a second filter verifying if convection has chance to start regarding BTD or BT values.
- Pixel ***CI***: a pixel that is likely to become a thunderstorm (information provided by Ground Truth, see further). Pixel CI-30 is a pixel that will become a thunderstorm within the intrerval [T,T+30']. CI-60 and CI-90 are defined in a similar way.

2.2 ALGORITHM DESCRIPTION

2.2.1 Theoretical Description

2.2.1.1 Overview

The CI by PGE18 is a mix of object and pixel analysis, of physical and statistical approach. The methodology is

1. to identify areas of interest, which are areas of ***eligible-CI*** pixels
2. to determine a guess of ***2D movement field*** to be representative of cloudy pixel movement
3. to undertake, over areas of interest, ***cloud cell detection and tracking*** in order to
   - *correct, update and complete* the 2D movement field
   - increase the number of slots from which the pixel is tracked
4. to calculate satellite characteristics of these pixels, including historic of the pixel thanks to 2D movement field (***static and dynamic characteristics***)
5. to determine ***pre-CI*** pixels using relevant thresholds of parameters
6. finally to evaluate convection through probability assessment, and localize corresponding ***CI*** pixels

Note: relevant parameters, thresholds and some part of the algorithm are inspired from « Best Practice Document, 2013, for EUMETSAT Convection Working Group, Eds J.Mecikalski, K. Bedka and M. König », especially SATCAST methodology for the definition of pre-CI pixels.

Note: Learning database is dedicated to calculate regression coefficients to evaluate a probably.

2.2.1.2 Description of the Algorithm

2.2.1.2.1 Area of interest / eligible-CI

This step requires in optimum configuration

- NWP data, to eliminate stable areas and focus on more unstable pixels,
- Cloudy filtering, to focus on cloudy pixels with NWCSAF cloud products,
- 10.8µm BT, to ignore cold cloudy pixels

Thus, large areas are ignored in the following processes, which focus on a restricted set of pixels to be analyzed.

2.2.1.2.2 2D movement field

A 2D movement field is estimated in optimum configuration with blending NWP wind field in the low level (850hPa) and last available HRW wind observations, remapped on grid-field and selected versus the corresponding pixel's brightness temperature. Priority in the blending is given to HRW wind observations, affected to a 9-pixels-box centred on the corresponding pixel.

This blended field is at first used as guess movement in the next process (tracking step in the object analysis process) for the movement initialization in "cold start" (first run) cases, or for orphan cells in the recovery analysis process (see 2.2.1.2.3).

In its final state (see next step) it will be considered as a pixel tracker for trends calculations.

2.2.1.2.3 Object image-analysis: Cloud cell detection & tracking

An object analysis process is undertaken like in RDT-CW software, and has been adapted to focus on warm cloud cells from lowest surfaces. The objectives of this step are

- To take benefit from techniques allowing to catch cloud cells movement
- To access cloud cells' parameters variations along its trajectory

More details about tracking can be found in chapter 2.2.1.2.3 of this document (RDT-CW description).

CI-specificities rely on

- Coldest limit for adaptative thresholding :the limit has been set to -25°C (instead of -75°C for RDT-CW) in order to limit the analysis to lowest levels
- Minimum vertical extension of objects, which has been set to 3° instead of 6° to focus on lower extended cloud systems

This step takes benefit from movement guess field as *input* to increase cell's speed reliability, and on the other hand delivers as *output* an updated movement field with the analyzed objects' speeds. All pixels belonging to a tracked cloud system are affected the corresponding movement speed instead of previous pixel's movement values.

This final blended movement field is a key point for further relevant trends calculations (see next step).

2.2.1.2.4 Pixel image-analysis: BTD and trends

Brightness Temperature Differences are processed for each *eligible-CI* pixel from various available channels, for current data and data from previous slot.

BTDs taken into account are

- WV6.2-WV7.3,
- WV6.2-IR10.8 ,
- IR10.8-IR8.7,
- IR12.0-IR10.8,
- IR13.4-IR10.8

Then, BT (IR10.8) and BTD trends are calculated for each eligible-CI pixel using the speed and direction of updated 2D movement field as guidance for identifying pairs of current and corresponding pixels in previous image.

When tracking of aggregated pixels (belonging to a tracked cloud system as object) is available, corresponding trends are used for some parameters instead of single pixel-trends, and should be able to provide trends over longer depth.

2.2.1.2.5 Definition of Pixel pre-CI

Each *eligible-CI* has then a list of BT and BTD values and trends. According to previous studies about convection initiation, parameters are grouped as:

- Representative for Cloud-top Glaciation
  - IR10.8 Brightness temperature
  - Time spent below freezing level
  - IR10.8-IR8.7 BTD
- Representative for Cloud depth / vertical extension
  - WV6.2-IR10.8 BTD
  - IR13.4-IR10.8 BTD
  - IR12.0-IR10.8 BTD
- Representative for Cloud growth (updraft)
  - All BTDs trends
  - IR10.8 BT trends

Pre-CI pixels have at least on significant relevant value (see table below). All of the parameters for Pre-CI are not taken into account for CI diagnosis:

CI-diagnosis parameters are a subset of Pre-CI parameters.

In the last step, some parameters of all pre-CI pixels will be analyzed for a CI-diagnosis.

2.2.1.2.6 Diagnosis

2.2.1.2.6.1 Interest fields

Each pre-CI pixel is associated with a list of values from parameters groups mentioned above. In a first stage, a limited subset of those parameters will be considered for diagnosis, as illustrated in table below.

Parameter name	***Relevant value***	***Meaning***	***filter***	***CI-diagnosis***
BT IR10.8	> -25° > -20°C	Brightness temperature (***glaciation***)	Eligible-CI and pre-CI	X
BTZG	Within 30min	Time since crossing 0°C (***glaciation***)	Pre-CI	X
BTD4	]-10° , 0°C[	IR10.8-IR8.7 (***glaciation***)	Pre-CI	X
BTD	]-35° , -10°C[	WV6.2-IR10.8 (***height***)	Pre-CI	X
BTD6	]-25° , -5°C[	IR13.4-IR10.8 (***height***)	Pre-CI	X
BTD5	]-3° , 0°C[	IR12.0-IR10.8 (***height***)	Pre-CI	X

WBTD	]-25° , -3°C[	WV6.2-WV7.3 (***height***)	Pre-CI	X
TxBT 15'	] -4°/15' , -50°/15'[	Temperature change rate (***growth***)	Pre-CI	X
TxBT 30'	] -4°/15' , -50°/15'[	Temperature change rate (***growth***)	Pre-CI	X
TxBTD 15'	> 3°/15'	BTD 15 Trend (***growth***)	Pre-CI	X
TxBTD 30'		BTD 30 Trend (***growth***)		
TxBTD4 15'	]0°/15' , 10°/15'[	BTD 15 Trend (***growth***)	Pre-CI	
TxBTD4 30'		BTD 30 Trend (***growth***)		
TxBTD5 15'	]0°/15' , 10°/15'[	BTD 15 Trend (***growth***)	Pre-CI	
TxBTD5 30'		BTD 30 Trend (***growth***)		
TxBTD6 15'	> 3°/15'	BTD 15 Trend (***growth***)	Pre-CI	
TxBTD6 30'		BTD 30 Trend (***growth***)		

Table 2: Interest fields for pre-CI filter and CI-diagnosis

One can note that for this first release, most of 30min trends are not kept in consideration. Focus remains mainly on 15min trends.

2.2.1.2.6.2 Probability assessment – Tuning with Logistic regression

CI-diagnosis should be derived from statistical models using Interest fields' values of pre-CI pixels. Those models will rely preferentially on RDT-CW (population of convective cells), run in optimal configuration with lightning data, NWP data, other PGEs data and all required MSG channels. In logistic regression a pixel that belongs to a RDT convective cell path during a given period will be considered as ground truth. This tuning has been postponed to the next release.

2.2.1.2.6.3 Probability assessment - Empirical rules

The CI output is estimated with empirical rule defined by count of relevant criteria. The v2016 version proposes this possibility only. The principle is to sum up the number of relevant parameters (i.e. above relevant threshold given in the table above) by group, giving greater importance to *growth* family parameters, then *glaciation* parameters, and finally vertical extension (height) group.

Nb of Growth relevant parameters (over 3)	***Nb of Glaciation relevant parameters (over 3)***	***Nb of Height relevant parameters (over 4)***	***Result***
≥ 2	≥ 3	≥ 4	HIGHPROB
		≥ 3	MODPROB
		< 3	LOWPROB
	≥ 2	≥ 4	MODPROB
		≥ 3	LOWPROB
		<3	VLOWPROB
≥ 1	≥ 3	≥ 4	MODPROB
		< 4	LOWPROB

	≥ 2	≥ 4	LOWPROB
		≥ 3	VLOWPROB
0	≥ 3	≥ 3	LOWPROB
		<3	VLOWPROB
Other cases			0

Table 3: Empirical rules for CI-diagnosis. HIGHPROB means between 75 and 100%, MODPROB between 50 and 75%, LOWPROB between 25 and 50%, VLOWPROB between 0 and 25%.

2.2.2 Practical Considerations

2.2.2.1 Calibration and Validation

2.2.2.1.1 Calibration / Tuning

Tuning CI probability assessment will be undertaken using RDT-CW as Ground Truth..

CI probabilities concern a given period [0-xx mn]. Ground truth has to be compliant with this notion: not only convective cloud cells' positions at given slot have to be taken into account, but also all pixels along a cloud system path over the period. When applied to RDT, it has been decided to consider the envelope (convex hull) of all cloud cell contours during the period, to produce a mask of convective activity.

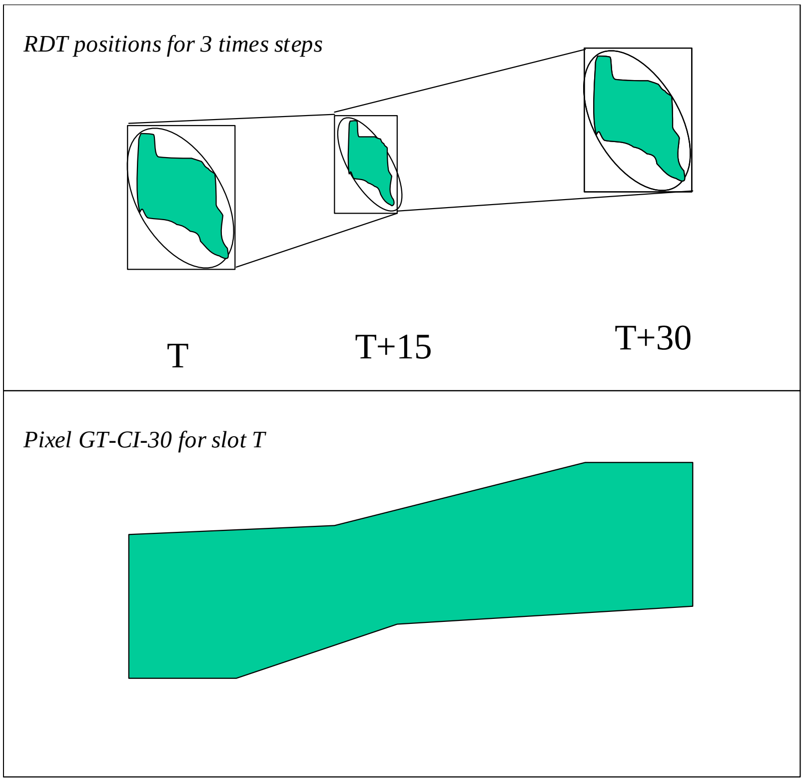


Figure 2: Ground truth: RDT path over [0-30min] period for CI

Thus, three different Ground truth masks have to be considered, corresponding to the three periods of convection initiation probabilities [0-30mn], [0-60mn], [0-90mn]. For each mask, Pixel GT-CI-xx are set to 1, the other are set to 0.

Interest field values of ***pre-CI*** pixels of a given slot will be analyzed regarding the given ground truth mask. With a global approach, statistical regressions will lead to a set of coefficients to be applied. Thus, three sets of coefficients should result from three Ground truth masks for three probability periods.

The same approach, over different periods, will be applied for further validation of the results.

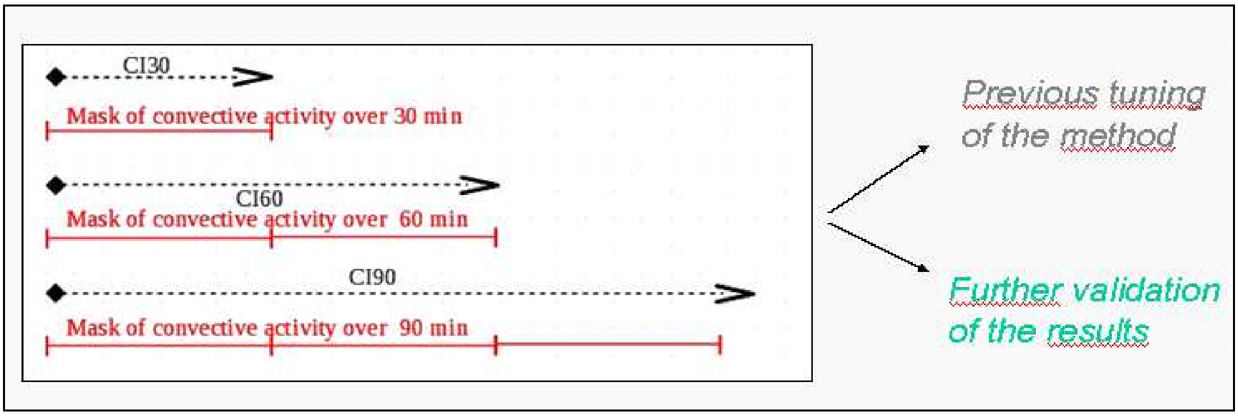


Figure 3: pre-CI pixels vs different Ground Truth masks

Note: a final step will check that the probability of CI for the range [0-60’] is above the probability of CI for the range [0-30’] and below the probability of CI for the range [0-90’]

Complementary additional Ground Truth may be used with radar data (smoothed path tracks of pixels above 30dBZ during a given period) or lightning data (enlarged cumulated strokes during a period), and should lead to additional tunings. It is foreseen in the optimal tuning/validation configuration to consider ground truth convective activity from:

- RDT convective mask
- RDT + radar (>30dBZ) convective masks
- RDT + radar (>30dBZ) + lightning strokes convective masks

2.2.2.1.2 Validation

2.2.2.1.2.1 Subjective validation

Subjective validation of data will be issued by PT or Météo-France forecasters. The principle is to check that CI-pixels with high value of probability are located in relevant areas, where RDT cells appear in the followings slots.

2.2.2.1.2.2 Objective validation

Verification will rely on RDT-CW on another period than the period used for tuning. Classical verification on probabilistic forecast has still to be performed. One of the main ideas is to verify that when (for example) CI probability is between 25 and 50% the convective pixel will develop into a thunderstorm in between 25 and 50% of the cases.

The objective validation of this new product is still to be undertaken.

PRD objectives for v*2016* threshold/target/optimal accuracies: FAR<0.6 POD>0.4/FAR<0.5 POD>0.5/ FAR<0.4 POD>0.6

For more details refer to Validation Report for GEO-Convection products.

2.2.2.2 Quality Control and Diagnostics

PGE18 doesn't process real time quality control on tracking or diagnosis result. Sanity check are in place to make, for example, the speeds realistic. But it is not used to create a quality control diagnosis..

2.2.2.3 Exception Handling

In case of missing satellite images, some error messages inform the user and CI fully recovers its quality few images later. . Nevertheless, it manages the flag quality of CT optional input product, and fill a flag_status container taking into account input data processed and used.

Moreover, the CI software produces some error messages in exception cases.

2.2.2.4 Outputs

The content of the output in NetCdF format is described in the Data Output Format document (A.D. 4). The product is an image-like product, whose target structure content three main containers dedicated to the three specified periods [0-30mn], [0-60mn] and [0-90mn]. Even if for this first release only the first [0-30mn] period output is processed, all ci_prob containers have same structure. [0-60mn] and [0-90mn] containers for v2016 are both set to FillValue.

<table>
<tr><th>Container</th><th>Content</th></tr>
<tr><td>ci_prob30</td><td>NWC GEO CI Probability next 30 minutes
<table>
<tr><th>Class</th><th>Cloud Type category</th></tr>
<tr><td>0</td><td>no probability to become thunderstorm</td></tr>
<tr><td>1</td><td>0-25% probability to become thunderstorm in the next 30minutes</td></tr>
<tr><td>2</td><td>25-50% probability to become thunderstorm in the next 30minutes</td></tr>
<tr><td>3</td><td>50-75% probability to become thunderstorm in the next 30minutes</td></tr>
<tr><td>4</td><td>75-100% probability to become thunderstorm in the next 30minutes</td></tr>
<tr><td>FillValue</td><td>No data or corrupted data</td></tr>
</table></td></tr>
<tr><td>ci_prob60</td><td>NWC GEO CI Probability next 60 minutes
Same classes and meaning than for ci_prob30, but referred to the next 60 minutes</td></tr>
<tr><td>ci_prob90</td><td>NWC GEO CI Probability next 90 minutes
Same classes and meaning than for ci_prob30, but referred to the next 90 minutes</td></tr>
<tr><td>ci_status_flag</td><td>6 bits indicating (if set to 1)
Bit 0: High_resolution_satellite_data_used
Bit 1: Visible_data_used
Bit 2: IR3.9µm_data_used
Bit 3: Cloud_type_data_used
Bit 4: Cloud_Microphysic_data_used
Bit 5: NWP_data_used</td></tr>
</table>

2.2.3 Assumptions and Limitations

This first version of GEO-CI offers a basic approach with most relevant parameters which have been previously identified by others studies for this topic. However, the objective is not to exactly clone the previous approaches, but to offer a different use of the output for nowcasting purposes, with the wish to take into account uncertainty of the forecast through probability information.

The tuning of CI relies on the availability of ground truth. When RDT-CW is considered, this ground truth is available on the same domain. When radar data and/or lightning data is considered, tuning/validation is limited to areas covered by the corresponding networks.

3. DESCRIPTION OF RDT-CW PRODUCT

3.1 PRODUCT OVERVIEW

3.1.1 Name of product

RDT-CW is the new name of RDT. The aim is to distinguish three products linked to convection: RDT-CW (Convection Warning), RDT_CTRAJ (description of convective trajectories), CI (convection Initiation). In this document name RDT is sometimes still use to describe versions prior to v2016.

PGE number associated to RDT-CW is 19 while PGE number that was associated to RDT is 11.

3.1.2 Goal of the RDT-CW product

The RDT-CW product has been developed by Meteo-France in the framework of the EUMETSAT SAF in support to Nowcasting. Using mainly geostationary satellite data, it provides information on clouds related to significant convective systems, from meso scale (200 to 2000 km) down to smaller scales (tenth of km). It is provided to users in the form of list of numerical data stored in an output file (no image file). The objectives of RDT-CW are:

- The identification, monitoring and tracking of intense convective system clouds
- The detection of rapidly developing convective cells, where IR sensor allows for
- The forecast of the convective cells

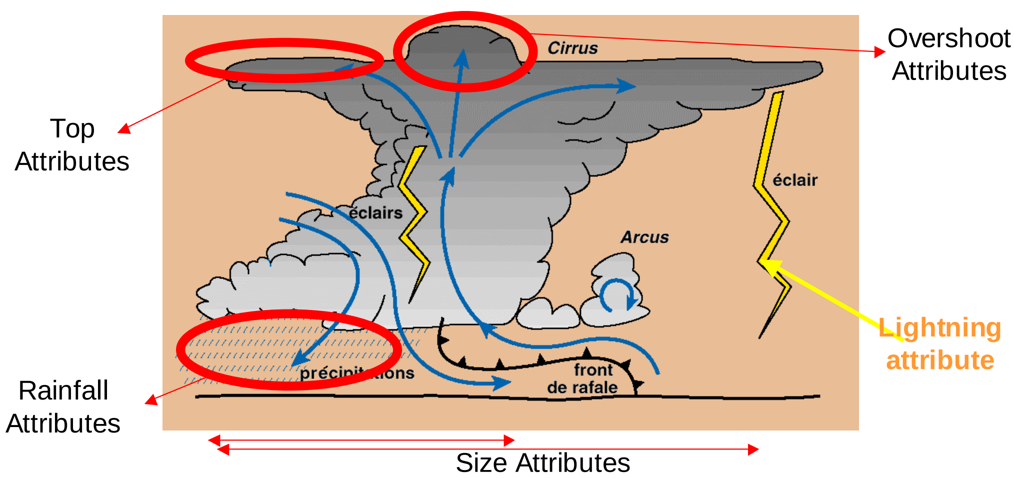


Figure 4: RDT-CW scheme

The object-oriented approach underlying the RDT-CW product allows to add value to the satellite image by characterizing convective, spatially consistent, entities through various parameters of interest for the forecaster such as motion vector, cooling and expansion rate, cloud top height,…, and their time series. It supports easy and meaningful downstream data fusion (surface observations, NWP fields, radar data...).

Thereby, RDT-CW is a tool for meteorological forecasters but can also be used by research teams and end-users like aeronautical users.

Finally, a Meteosat-based real-time demonstration is available for registered NMS on the Internet, at this address: http://www.meteorologie.eu.org/RDT/index.html. A training material is available on EUMETrain Website http://www.zamg.ac.at/eumetrain/.

3.1.3 The four steps of the algorithm

The RDT-CW algorithm could be divided into four parts:

- The detection of cloud systems
- The tracking of cloud systems
- The discrimination of convective cloud objects
- The forecast of convective cloud objects

Detection, tracking and discrimination can be grouped together in "analysis part"

3.1.4 First step: the detection of cloud systems

The detection algorithm allows to define "cells" which represent the cloud systems. In the RDT-CW algorithm, "cells" are defined on infrared images (channel IR10.8) by applying a threshold which is specific to each cloud system, and which chosen based on local brightness temperature pattern. A good understanding of this process is essential to make the best use of RDT-CW.
The main idea is to adapt the threshold used to the topography of the cloud tops:

- In the case of simple topography (like the simple, isolated, cloud associated to a single convective cell in clear air, at development stage), the threshold chosen corresponds to the outer limits of the cloudy zone
- In more complex cases, the principle is to use the warmest temperature threshold which allows to get one cell for each cloud "tower". A cloud tower is here formally defined as a local brightness temperature minima which is separated from the other, nearby, minima by a sufficiently warmer zone (6°C warmer)

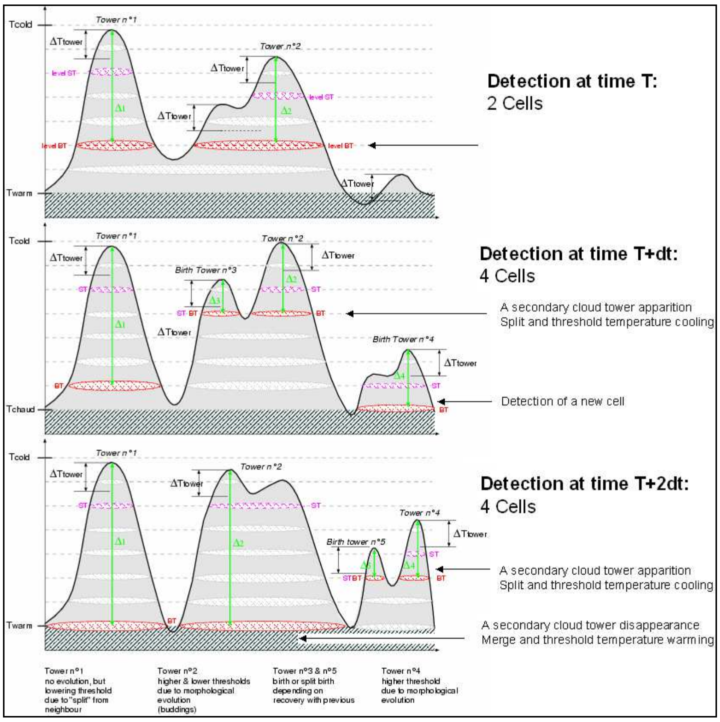


Figure 5: RDT-CW cell definition

Hence, the threshold used for a given cloud tower depends on the temperature pattern in the vicinity, and may evolve just because nearby towers do evolve (warmer zone or Deltat_tower=6°C for defining significant cloud towers, which contour are drawn in red).

Thus, the RDT-CW cells linked in time to form a trajectory do not necessarily really depict the same phenomena along time. But the advantage of the method used (adaptive threshold) is to focus on convective parts of cloud systems and thus to perform the discrimination process.

Even if the cloud tracker is able to detect and to track cloud object on pixel resolution, it is advised to limit at the minimum area of an object in order to improve quality of discriminating parameters processed (60 squared kilometres up-to-now recommended , i.e. more or less 5 pixels with MSG-IR resolution over Europe). On the other hand, an upper limitation of the systems is necessary in order to avoid tracking huge non convective cloud systems (200000 squared kilometres up-to-now recommended, which is enough to meet the objectives of RDT-CW). Both values are defined into configuration file.

3.1.5 Second step: the tracking of cloud systems

The use of an adaptive threshold makes complex the cell comparability due to various phenomena depicted. This method induces numerous merges and splits too.

The tracking algorithm is mainly built on the overlapping between cells in two successive images. Before the cells overlap processing, the previous cells are moved according to their move and speed that have been formerly analyzed. Nevertheless, correlation or neighbourhood methods are applied when overlapping method doesn't succeed. The temporal links are processed as follow:

- *No match*: the current cell is a new one and begins a new trajectory
- *Merge*: more than one former cell match with one current cell. The trajectory of the "largest" former cell is kept; the other ones are closed. Due to adaptive threshold temperature use, the largest former cell is not directly defined on its area attribute but on a area defined at a common threshold.

- *Split*: One former cell match with several current cells. The "largest" current cell carries out the time series. The other ones are processed like new cells.
- *Merge and split*: Several former cells match witch several current cells: In this case (less than 3% of trajectories), all trajectories are closed and the current cells are processed like new cells.

The temporal links allows computing move, speed and trends of all cloud objects. When no temporal link has been found, moving speed is initiated from movement guess field previously initiated by blending HRW observations and 700hPa U/V NWP winds.

Once the main temporal link has been identified, time series of cloud's characteristics (peripheral gradient, volume, cooling rate...) may be used as key input for the discrimination algorithm. Moreover, temporal coherence of moving speed estimation is undertaken.

3.1.6 Third step: the discrimination of convective objects

As it was mentioned previously, the RDT-CW detection algorithm is able to detect cloud structure from meso-alpha scale (200 to 2000 km) down to pixel scale. The goal of the discrimination method is to identify the convective RDT-CW objects among all cloud cells, adding a strong constraint that is that the discrimination should be effective as soon as possible after the first detection by RDT-CW software.

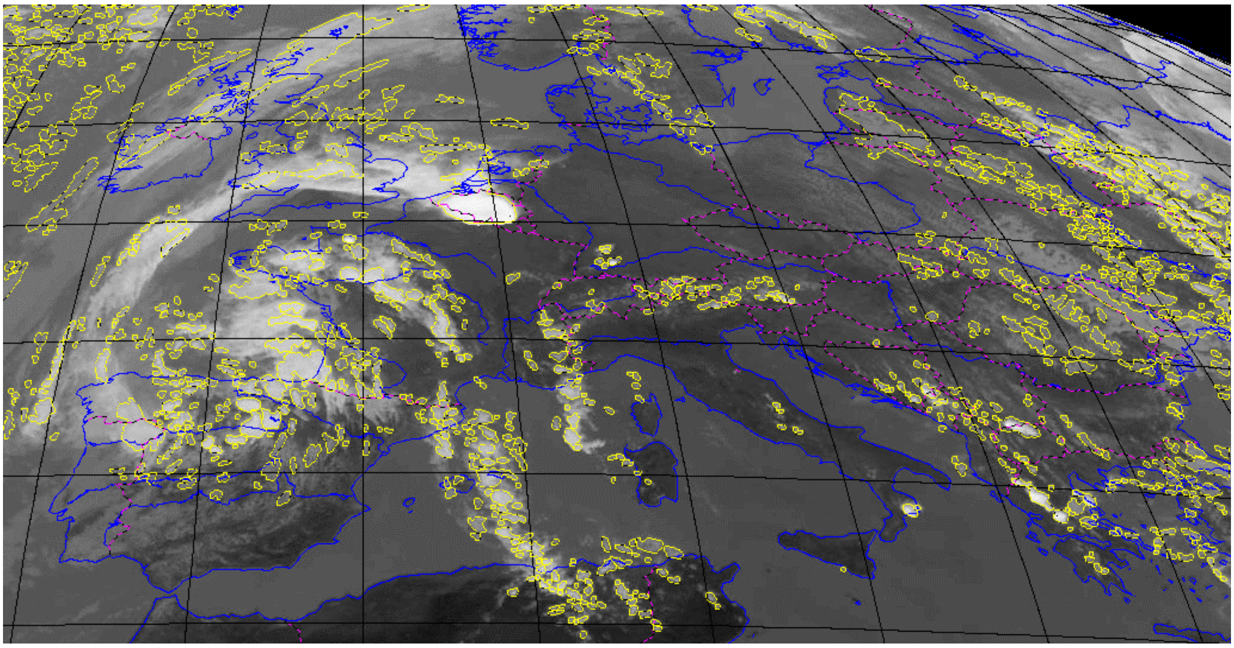


Figure 6: 25th May 2009, 12UTC - RDT-CW objects (yellow outline) before convective discrimination

The picture above displays all RDT-CW detected cells. This picture points out the detection and tracking efficiency of RDT-CW. We can notice the phenomena and scale diversity of RDT-CW objects.

The next image displays convective objects only. The ratio between no convective and convective objects is about 100.

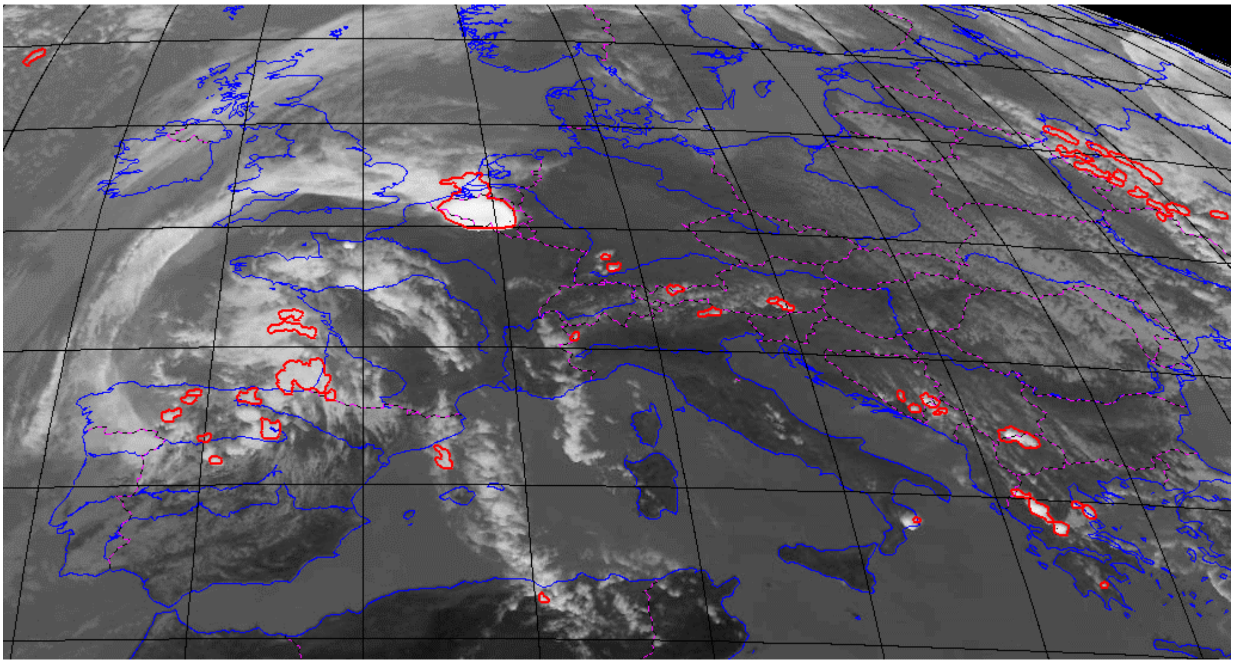


Figure 7: 25th May 2009, 12UTC – RDT-CW objects (red outline) after convective discrimination

The discrimination method makes use of discrimination parameters calculated from three MSG channels: IR 10.8µm, IR 8.7µm, IR 12µm, WV 6.2µm and WV 7.3µm. Two kinds of such discrimination parameters are computed:

- Spatial characteristics (peripheral gradient, surface, etc.)
- Temporal characteristics (rate, extremes on various past period)

The discrimination scheme relies on statistical models tuned on a learning database. The current learning database is made over widened France. The ground truth used for building the database is cloud to ground lightning occurrence.

The discrimination scheme will be applied to non convective cloud system which reveal an ascending / growing trajectory. Once the statistical method has lead to identify a system as convective, this diagnosis will be later "managed" through empirical rules in the next slots :

- First, the convective diagnosis is inherited from one "father" cell to its "daughter", to initiate a temporal continuity for a convective system
- But when this diagnosis lasts more than a given period (default 45min), it is checked against vertical evolution of the cloud system (did the cloud system continue to grow, or did this growth stop or invert ?) or against other parameters (temperature trends, BTD values or trends for mature systems). This step may lead to a de-classification of the convective characteristic

Thus, the operational implementation of convective discrimination scheme is a mix between statistical models for identifying convective systems, and empirical rules for managing the diagnosis, confirming or removing this characteristic by analyzing the temporal evolution of a cloud system.

3.1.7 Fourth step: the forecast of cloud systems

Before v2016, RDT was mainly an analysis tool. In order to improve its usefulness in forecasting application (CW) a forecast up to 1 hour is proposed at each slot since v2016, depending on user's configuration.

The forecast relies on the moving speed estimate of each cloud cell object, representative of its dynamic. For that reason moving speed estimate has been improved in RDT-CW, to get a better coherence with environmental movement field, and also to improve temporal continuity.

- NWP winds in low-mid levels and HRW AMV observations are taken into account and blended to provide a movement “guess” field prior to cell tracking. Cold start cases and new or orphan cells can take benefit of this guess field for initiating a reliable movement diagnosis even without cloud cell tracking
- Then, in order to avoid non-representative or erratic speed estimate and in order to propose a useful forecast, the motion vector temporal coherence is checked against previous estimates, and again checked against guess field.

The resolution of forecast is 15 minutes whatever the time-resolution of satellite data input.

3.2 ALGORITHM DESCRIPTION

3.2.1 Theoretical Description

3.2.1.1 Physics of the Problem

The thunderstorm detection by PGE19 is a mix of physical and statistical approach. The methodology is first to identify and track cloud system, then to define satellite characteristics of these cloud systems during different phases (triggering, development and mature). Learning databases are then built on the most significant parts of the trajectories of the cloud systems, for a pre-conditional tuning.

3.2.1.2 Description of the Algorithm

3.2.1.2.1 The detection of cloud systems

3.2.1.2.1.1 Main principle

The goal of the detection algorithm is to define “cells” which represent the cloud systems as seen in the infrared 10.8 µm channel. Once the “cells” are detected, a number of morphological (area, aspect ratio…) and radiative features (average and minimum brightness temperature, etc.) of the “cells” are computed in order to characterize the corresponding cloud systems. More precisely, “cells” are connected zones (8-connectivity) of pixels i) having a brightness temperature lower than a given temperature threshold T_{th} (which is not the same for all the “cells” detected in a given image) and ii) being larger than a given area threshold A_{min} (which is the same for all the detected “cells”).

The use of a detection algorithm based on a fixed temperature thresholding is problematic. Indeed, the choice of a rather low temperature threshold leads to a late first detection of convective systems and the use of rather high temperature threshold leads to a merging of different convective systems into one single “cell” when these systems are embedded in a warm layer of clouds.

The RDT-CW detection method is based upon an adaptive temperature thresholding of infrared images. Thus, each cloud system is represented by one or several cells defined by its own, cell-specific, temperature threshold, ranged between a warm threshold T_{warm} and a cold threshold T_{cold}. More precisely, possible temperature thresholds are: T_{warm}, $T_{warm} - \Delta T$, $T_{warm} - 2\Delta T$, ..., T_{cold} where ΔT is the temperature step of possible temperature thresholds.

RDT-CW cells point out the bottom of cloud towers included inside cloud system. The temperature threshold used to define the bottom of an RDT-CW object is the warmest one which allows to distinguish it from others nearby temperature extremes. As described in Figure 8, only strong enough temperature extremes are taken into account.

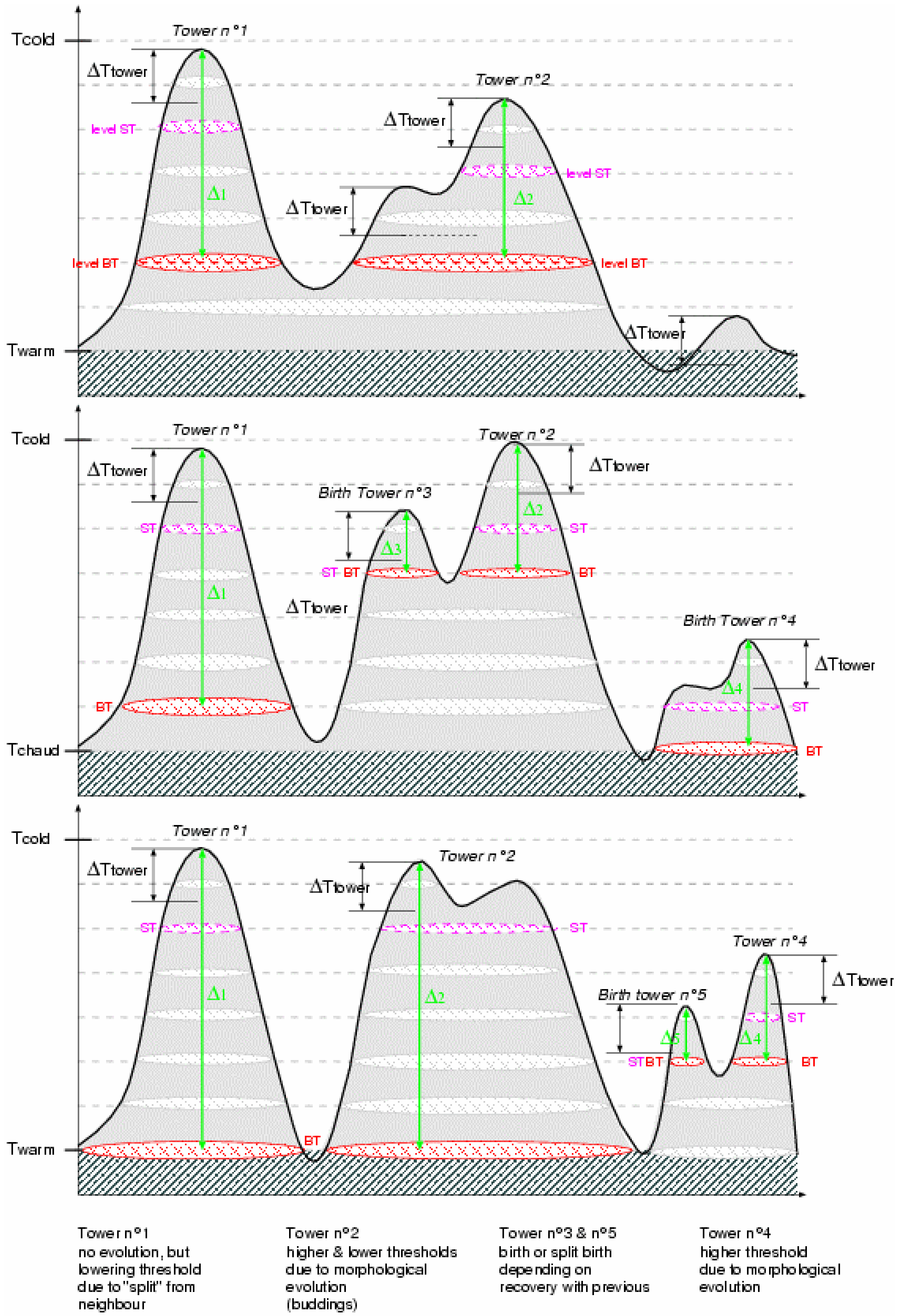


Figure 8: the principle of the detection algorithm

3.2.1.2.1.2 BT re-definition for some special cases

In order to increase the relevancy of the cloud contour, two modifications have been added in v2012. The modifications concern the definition of the value of BT. The modification are applied when both following conditions are satisfied

- The vertical morphology of the cloud presents particular shapes, with cloud systems defined by only one tower
- The representative threshold, automatically set to the warmest value, leads to a bottom contour much larger than the horizontal extension of the top tower itself in its coldest part.

In case of a single budding rising up from a cloud layer, the algorithm described in previous paragraph identifies the bottom of the layer rather than bottom of the tower. The modification consists in detecting, between BT and ST levels, the level of maximum vertical rate of cloud cell area. The algorithm considers the vertical area ratio between two successive temperature levels S_{n+1}/S_n. The goal is to catch a more "realistic" bottom of tower (dashed red level in Figure 9)

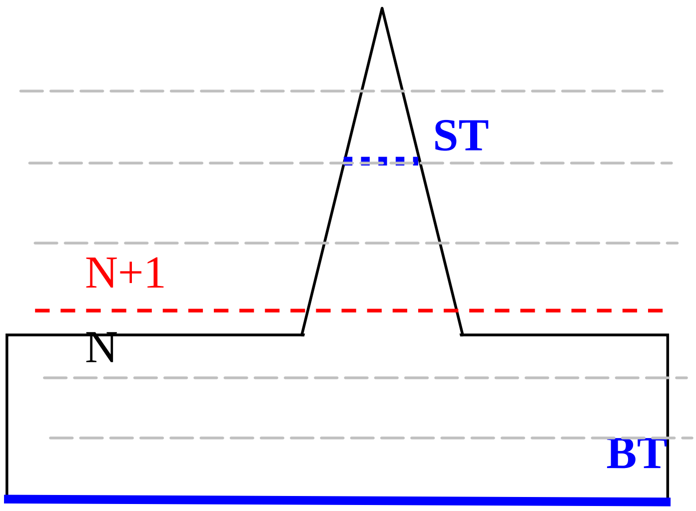


Figure 9: Single tower from cloud layer. Bottom (BT) and Top (ST) level of Tower are represented

Figure 10 plots surface ratio between bottom and top levels (S_{ST}/S_{BT}, Y-axis), for convective and non-convective populations against the maximum surface ratio between two successive temperature levels (max S_{n+1}/S_n, X-axis) .
It reveals that even for the convective population there is a level of significant surface ratio. A value of 0.7 (dotted black vertical line) seems to be an acceptable threshold for a maximum vertical ratio of surfaces, to represent a more realistic bottom of tower, particularly for convective systems.

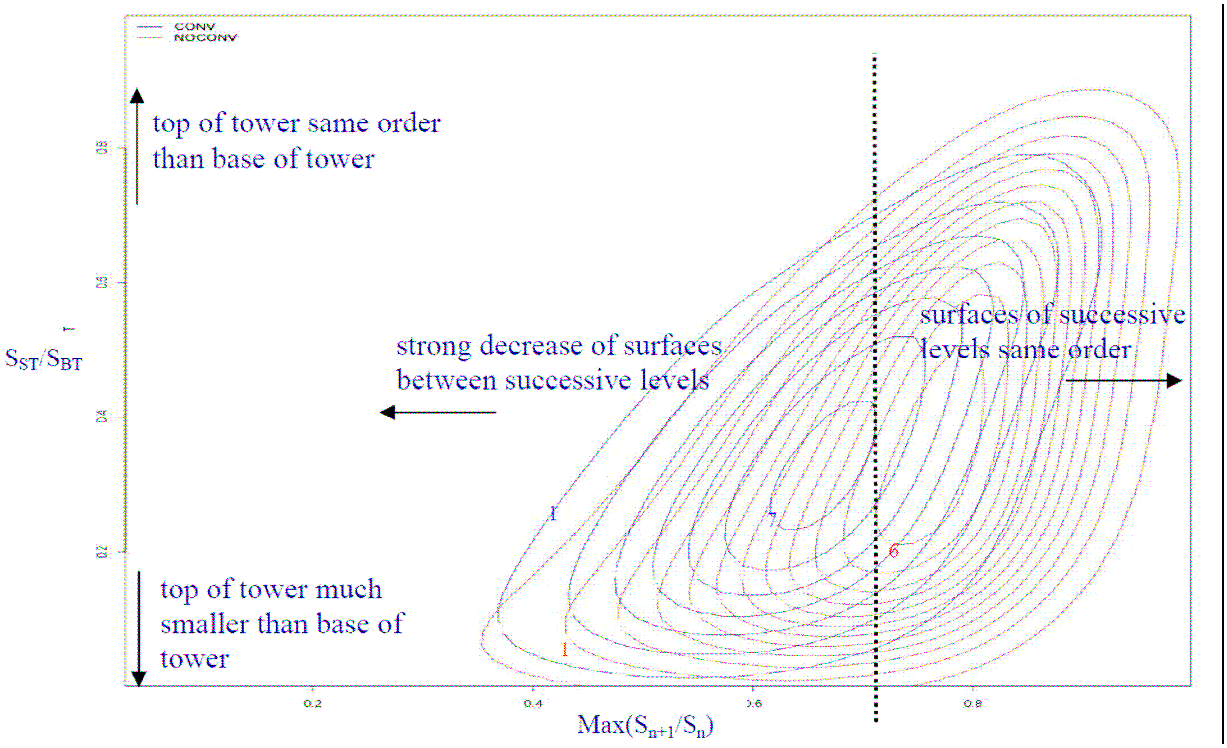


Figure 10: density contour plot. Arbitrary relative units. X-axis=Maximum of the surface ratio between 2 levels. Y-Axis= top/bottom surface ratio. Red=convective population. Blue=non convective population. One year database

In case of a “flat pyramidal” shape of single-tower cloud system, here again algorithm described in previous paragraph catches the bottom of the whole system, leading in some cases to an excessive difference between top and bottom horizontal extensions.

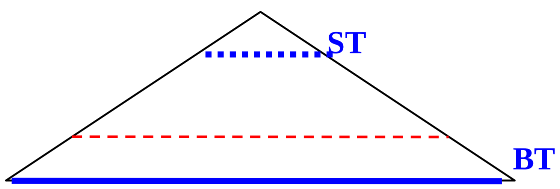


Figure 11: Pyramidal single tower. Base(BT) and Top (ST) level of Tower are represented

An upper threshold of the ratio between BT surface and ST surface is necessary. Most of the times, the threshold set the value of “3” is correct.

Figure 12 helps to analyse the impact of this threshold. Values close to 1 mean automatic BT level fulfil the desired limitation. An anomaly appears in this distribution (low values of $3*S_{ST}/S_{BT}$), especially for convective population, showing that in few cases (low densities of distribution) a new BT limit is useful. Limiting the plotted ratio to approximately 4/5 (black dotted horizontal line) could prevent a too large difference between top and bottom of the cloud tower, which can be expressed as $S_{BT} < S_{ST} *3*5/4$, rounded to $\mathbf{S_{BT} < 4*S_{ST}}$. Results are available for France. In tropical regions, there is a lack of ground truth to transpose theses conclusions. But one can expect that in these regions systems have below the tropopause a more cylindrical shape. Thus the impact of a new base of tower on the ratio is light.

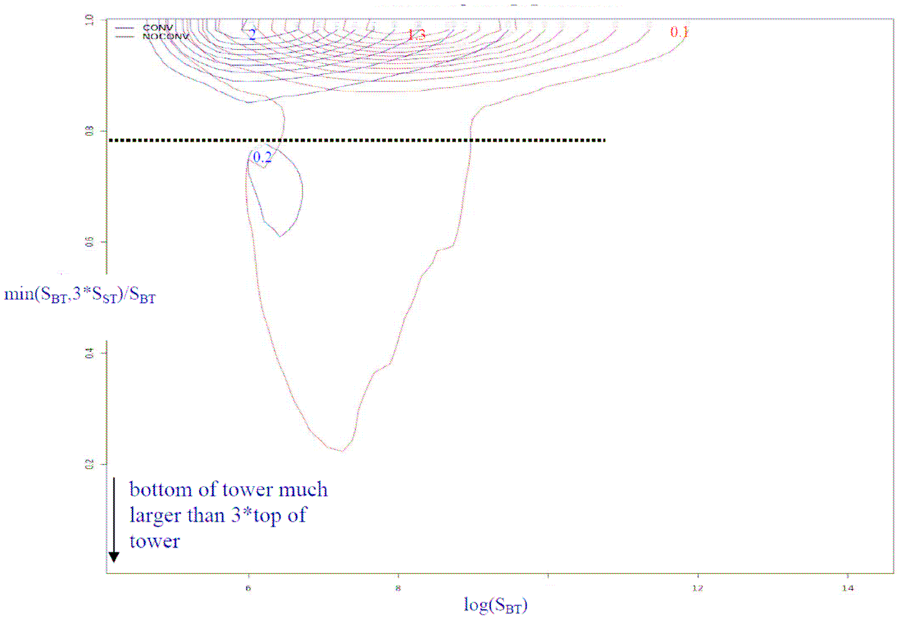


*Figure 12: Contour Density Plot. Arbitrary relative units. X-axis=log(S_{BT}) Y-axis= min(S_{BT},3*S_{ST})/S_{BT} . Red=convective population. Blue=non convective population. One year database, France domain*

Both modifications have been implemented in the algorithm, leading to

- Some visual improvements of RDT-CW cloud contours
- An increase of the homogeneity of the convective population.

3.2.1.2.2 The tracking of cloud systems

Once the detection of cloud systems is performed, the tracking module of the RDT-CW software is applied on the detected "cells" and allows building trajectories of cloud systems from a sequence of infrared images. The tracking algorithm is based on the geographical overlapping of "cells" between two successive infrared images (Figure 13). It also handles splits and merges of cloud systems.

One main input of the tracking of the cloud system is the previous moving speed estimation of cloud cells. One main result is the current moving speed estimation. For that reason RDT-CW software now pre –calculates a movement guess field from blending NWP data at mid-low levels (700hPa) and HRW winds from the current slot. This field allows:

- Initializing moving speed with "cold start" cases (first run), which will be usefull for the next runs
- Initializing moving speed for cells with no recovery and no neighbouring cells, used for a retro-advection and checking recovery again

The main difficulty is the tracking of small cloud systems (typically less than 5 pixels). In order to improve the tracking of such small cloud systems, the RDT-CW tracking algorithm takes into account an estimated velocity of "cells" to compute the overlapping between "cells".

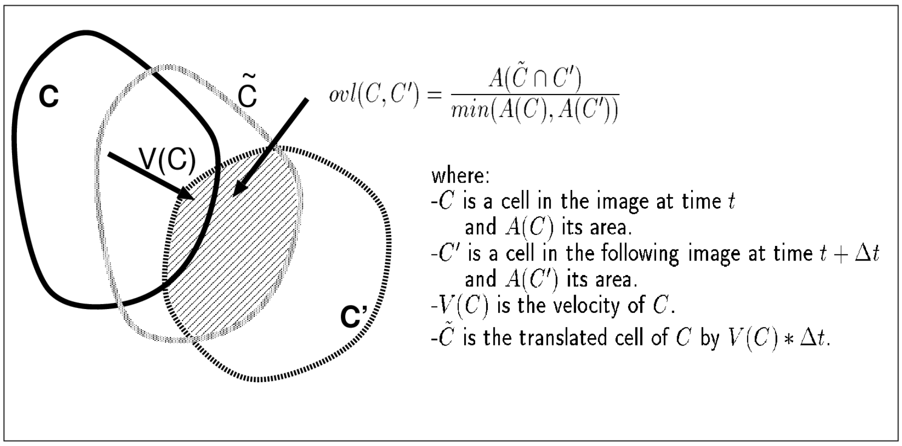


Figure 13: Definition of the overlapping between two cells

The search for an overlapping between a cloud system C' detected in the image at time t+Δt and cloud systems detected in the previous image at time t is described in Figure 14 and hereafter.

First, "cells" in the image at time *t* are advected using their estimated velocity. If at least one of these advected cells overlaps sufficiently with cloud system C' then a link is created between C' and this (these) cell(s).

Then, moving speed of cloud system C' is estimated from gravity centres displacement of all linked cloud cells. When no overlapping has been found for cloud system C', then its velocity is evaluated from cross-correlation technique, neighbouring speed, or pre-calculated movement guess field.

The cloud system C' is then backward-advected from this estimated velocity. If at least one of the cells detected at time t overlaps sufficiently with the backward-advected cloud system C' then a link is created between C' and this (these) cell(s).

If no overlapping is found, then the backward-advected cloud system C' is enlarged and a last search for overlapping between this enlarged backward-advected cloud system C' and cells detected at time t is done. If at least one of the cells detected at time t overlaps sufficiently with the enlarged backward-advected cloud system C' then a link is created between C' and this (these) cell(s).

If no overlapping is found then cloud system C' is identified as the beginning of a new trajectory.

Figure 15 illustrates how the steps 2 and 3 of the tracking algorithm could improve the tracking of small cloud systems. In the diagrams of this figure, the "cells" of a given cloud system in two consecutive images are showed: C is its "cell" in the image at time *t* and C' is its "cell" in the image at time $t+\Delta t$.

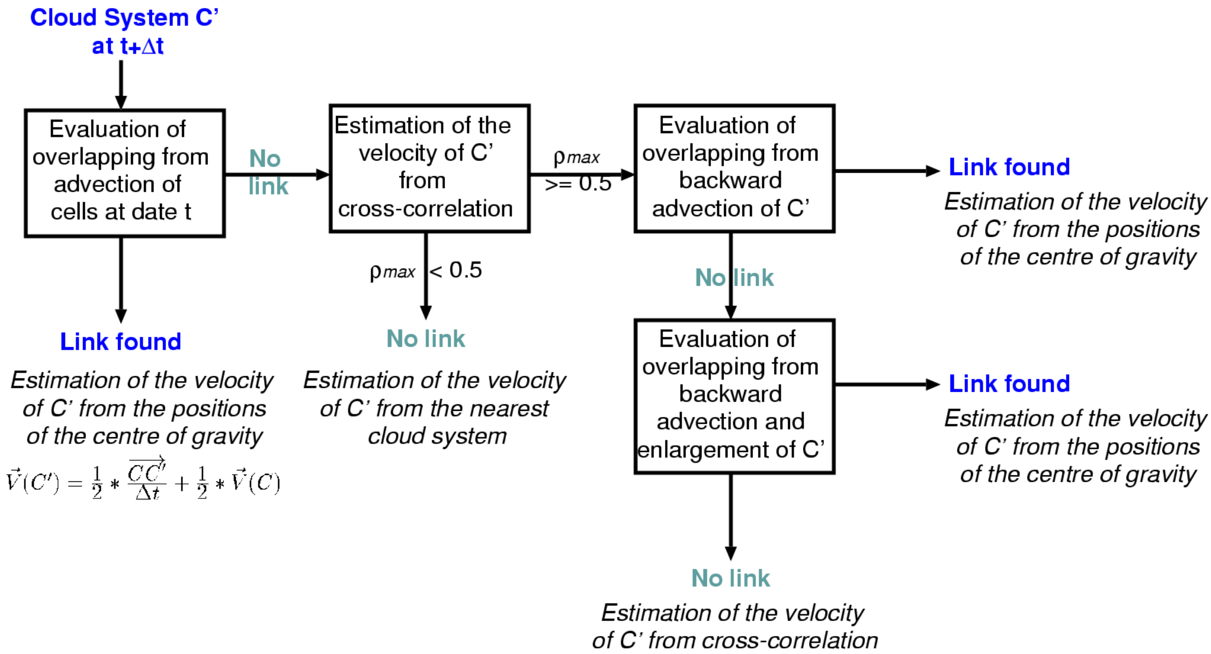


Figure 14: Main steps of the tracking algorithm

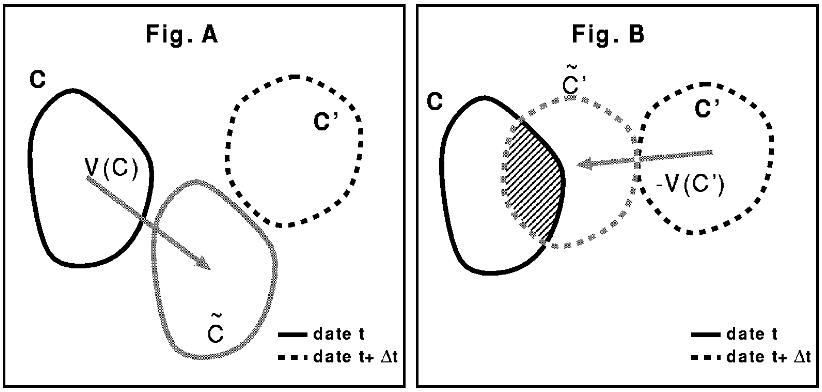


Figure 15: Principle of the tracking algorithm (steps 2 and 3)

In Figure 15 A, $\tilde{C}$ is the translated cell of C by $\vec{V}(C)\times\Delta t$ where $\vec{V}(C)$ is the estimated velocity of C, as computed in the previous tracking stage. In this case, the quality of the velocity was too low and lead to no overlapping between $\tilde{C}$ and C'. So, after step 1 of the tracking method, no link is created between "cells" C and C' and so, if steps 2 and 3 were not in the tracking algorithm, the tracking of this cloud system would have failed.

With the implemented RDT-CW tracking algorithm, the following analysis is done:

C' is a "cell" in the image at time $t+\Delta t$ which overlaps with no "cell" of the previous image, consequently its velocity $\vec{V}(C')$ is evaluated using a cross-correlation technique.

Figure 15 B displays the cell $\tilde{C}'$ which is the translated cell of C' by $-\vec{V}(C')\times\Delta t$, an overlapping is now existing between C and $\tilde{C}'$ and so, the tracking algorithm creates a link between "cells" C and C': the tracking is successful.

Step 4 of the tracking algorithm is an improvement for the tracking of very small cloud systems (less than 5 pixels). The enlargement of a cloud system consists of adding "pseudo-cloudy pixels" (see Figure 16) to the detected cells all along its edge in order to increase, artificially, the size of the cell and then to ease the occurrence of overlapping between consecutive cells corresponding to the same cloud system.

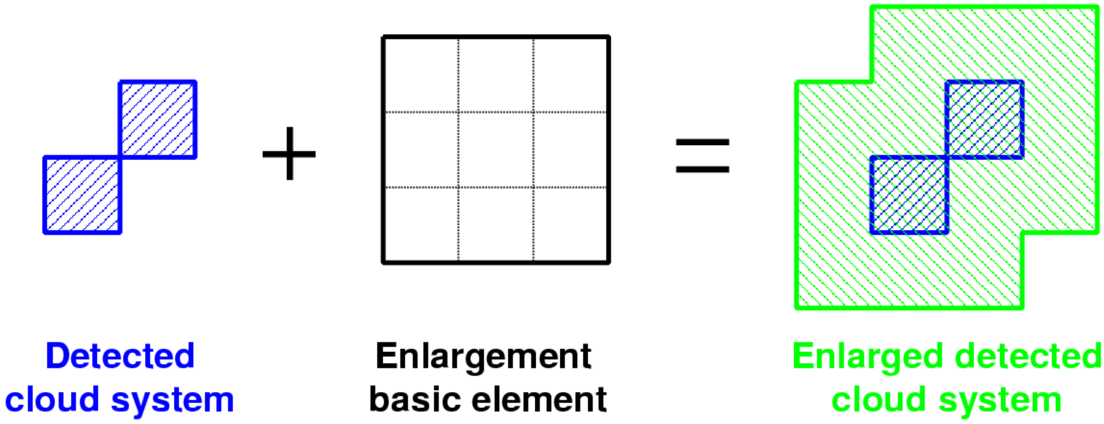


Figure 16: Principle of the enlargement of cloud systems (step 4)

3.2.1.2.2.1 Speed estimation from weighted gravity centres

As mentioned above, once links between cells in successive images have been identified, displacement is estimated from the successive positions of corresponding gravity centres. More precisely, displacement is processed taking into account all current and previous linked "group" of cells, weighted by the size of each cell. Thus, an estimation of "family" cell movement is done.

Previous chapter 3.2.1.2.1 has pointed the particularity of cloud cell identification with temperature threshold. This threshold defines the 2D geometric extension of cloud cell objects. Two kinds of gravity centres are calculated from this 2D representation during detection step:

Geometric gravity centre: mean of latitude and longitude of each pixel constituting the 2D horizontal extension at the temperature threshold defining the cloud cell

Weighted gravity centre: position of each pixel is weighted by its level (temperature), giving higher weight to higher levels (lower temperatures). The resultant localization is more representative of the 3D cloud morphology,.

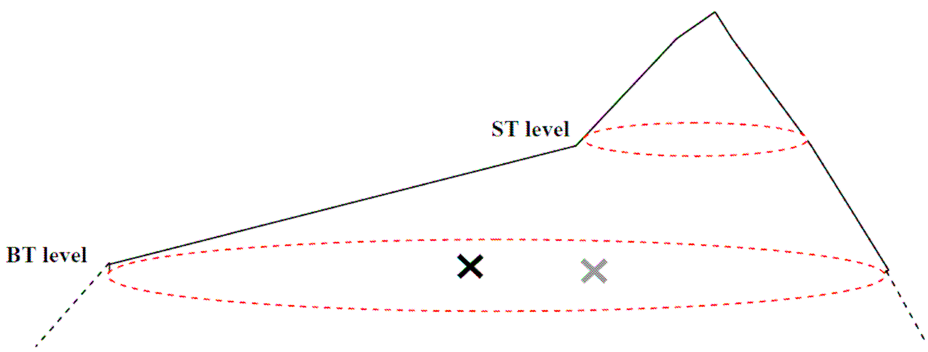


Figure 17: Positions of geometric and weighted gravity centres for a particular shape of cloud system

Motion vectors are now estimated by default using displacement of weighted gravity centres positions in successive images. This approach tends to lower the impact of temperature threshold changes of a cloud cell from one image to the next one. The figure below illustrates the kind of overestimation which can result of an estimation based on geometric gravity centres displacement in case of changes of cell's temperature threshold.

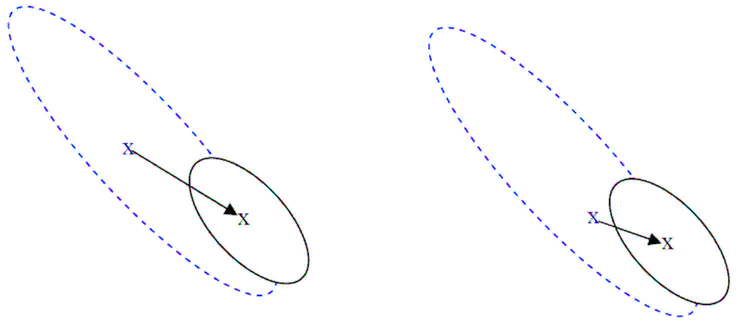


Figure 18: Synthetic example of speed estimation from geometric gravity centres (left) and weighted gravity centres (right). Previous cell dashed blue, current cell plain dark.

In a further step, a temporal coherence of moving speed is undertaken, to eliminate erratic estimation due to split/merge cases or due to different temperature thresholds and thus too large distance between gravity centres.

3.2.1.2.3 The discrimination scheme

3.2.1.2.3.1 Main principles

The methodology and the statistical model choice have been defined with the support of Statistical Laboratory of Toulouse (R.D. 1)

On statistical approach, the two populations, convective and no convective, are unbalanced. We can notice a ratio of one convective for more than one hundred non convective over Europe.

Moreover, a convective object has not homogeneous characteristics during its life time. Thus, it is necessary to define several statistical bodies in order to take care of various stages of convective phenomena: triggering, development, mature and decaying phases.

At last, the ground truth used, cloud to ground occurrence, doesn’t allow to diagnose the time of convection triggering or to depict the decaying period.

Therefore, the discrimination scheme is a mix between statistical decisions and empirical rules. The statistical decisions are only processed for a short period centred on several times of interest. They are only applied on no convective object to check their convective status. The empirical rules are defined to declassify convective object (convection decaying or false alarm diagnosis). They are based on cooling parameters for triggering and development phase and based on cooling and global convection index for mature phase.

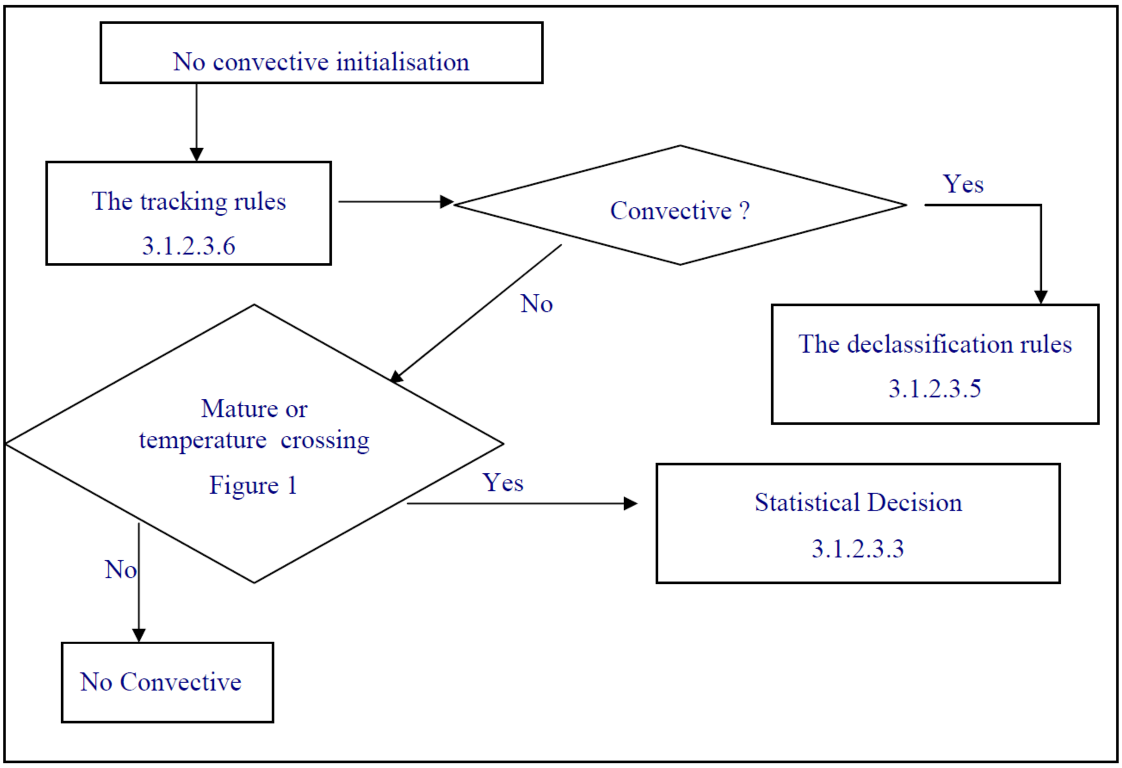


Figure 19: The discrimination schedule

3.2.1.2.3.2 NWP convective mask

PGE19 takes benefit from a NWP guidance before attempting a diagnostic.

NWP data are used to produce a convective mask through availability or computation of several convective indexes: K index, Showalter index and Lifted index. The union of these indexes allow to identify stable areas where probability of convection will be very low.

Indices used for convection mask can reflect unstable, unclear or stable meteorological situations. Values of the mask are 0 if all indexes are stable, 2 if at least one index is unstable, 1 in other cases:

- Full stable case: Pixel value of NWP_Mask =0 (if pixel value of LI index stable (>0) and pixel value of SHW index stable (>3) and pixel value of KI index stable (< 20))
- Unstable case: Pixel value of NWP_Mask =2 (if pixel value of LI index unstable (<-3) or pixel value of SHW index unstable (<-3) or pixel value of KI index unstable (>30))
- Unclear case: pixel value of NWP mask=1 (for other cases than above)

Regions with null (0) values are ignored by discrimination step.
Thus, PGE19 discrimination scheme focuses on convective regions, and avoid eventual false alarms, especially in winter or intermediate (autumn and spring) seasons.

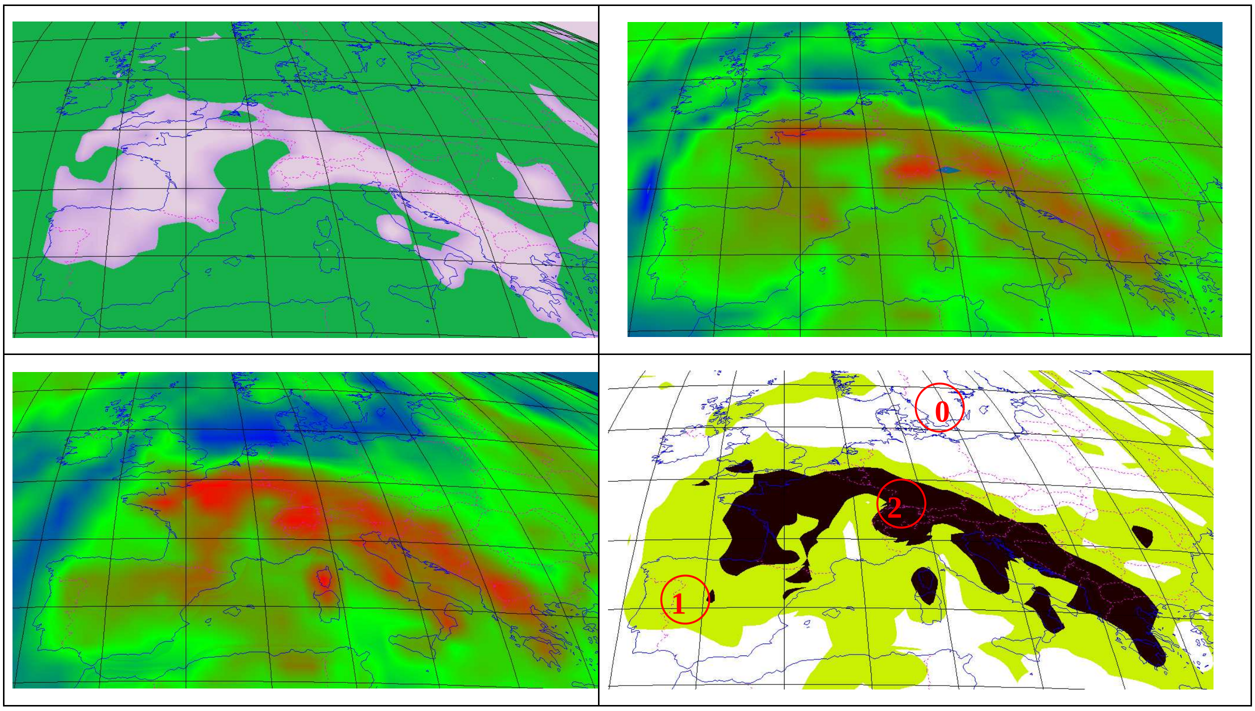


Figure 20: 25 May 2009, 12h15. Convective mask (bottom right), as a union of K index (top left), Showalter index (top right) and Lifted index (bottom left), from NWP data. Regions 1 and 2 are region of interest for PGE19 discrimination

Moreover, this approach has been applied during the tuning of PGE19 discrimination scheme, to exclude from the tuning areas and cloud systems without interest from a convective point of view.

Thus, this lead to a major improvement thanks to a strong decrease of the imbalance between convective and non-convective populations, especially in the in warmest categories. The consequence is a better tuning in these categories, leading to a strong improvement concerning precocity.

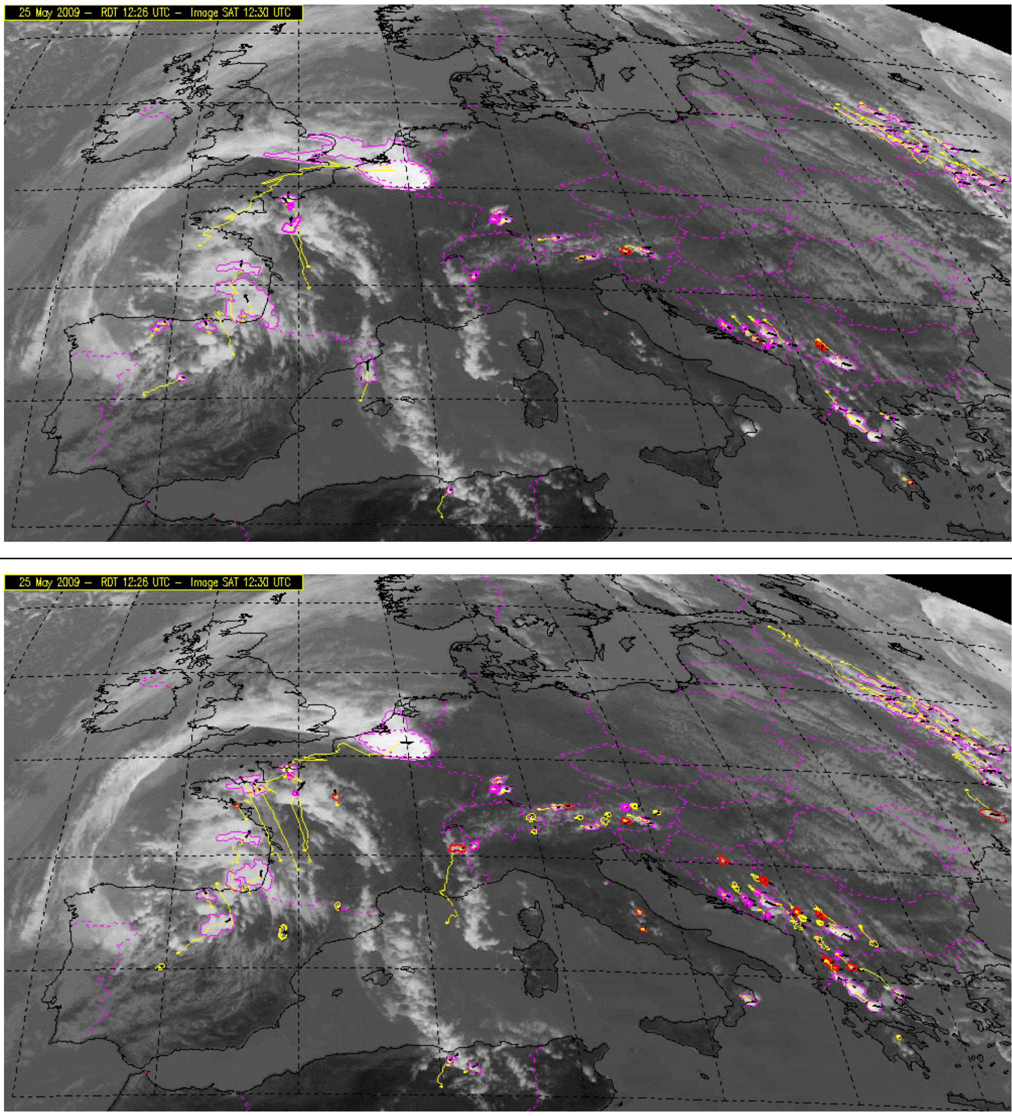


Figure 21: 25 May 2009, 12h30 UTC. PGE19 without NWP tuning (top) and with NWP tuning (bottom). NWP obviously brings benefit to the tuning in warmer categories, with higher precocity (cells over Italy diagnosed 30 min previously)

3.2.1.2.3.3 The statistical decision (logistic regressions)

The statistical decision relies on an ensemble of logistic regressions, here named statistical models, tuned and applied for various steps of cloud development, and various PGE19 configurations. The objective is to distinguish the convective cells from the other one's.

The discriminating parameters associated to a cloud object are processed on five MSG channels (IR 10.8µm, IR8.7µm, IR12µm, WV 6.2µm and WV 7.3µm). Moreover, the cloud tracker allows to estimate rates and extremes on various past period.

Discriminating parameters are extreme values over the considered period (15, 30, 45 or 60 minutes depth):

- Main 10.8 µm channel:
  - Values: the minimum value (of all the pixel at each step), maximum value of the following parameter defined at each step “average minus minimum”
  - Morphology: maximum value of following parameters defined at each step: average and extreme spatial gradients at the outline of the cell, volume, surfaces, ratio aspect

- Other channels
  - BT: minimum values of the cell are estimated and then extreme values and trends are used as predictor
  - BTD representative values are estimated and then values and trends are used as predictor
- Other:
  - Maximum LI (issued from NWP) over the period
  - Maximum gap to tropopause (issued from NWP) over the period

The statistical decision operates like a sieve with several level of accuracy. It combines several times of interest defined on temperature threshold crossing, a final step focused on mature stage, and a beginning step for initial developing stage

- Mature: top temperature < -40°C since at least 45min
- Mature transition: crossing top temperature –40°C
- Cold transition: crossing top temperature –35°C **or** base of cloud tower –25°C
- Warm2 transition: crossing top temperature –25°C **or** base of cloud tower –15°C
- Warm1 transition: crossing top temperature –15°C **or** base of cloud tower –5°C
- Warm: top temperature > -15° **and** base of cloud tower > –5°C, preceding Warm1 crossing

The statistical models, defined on temperature threshold crossing are named transition models. The models defined on mature population are named mature models, and those defined on warm population warm models

The warm and transition models are defined for four depth, depending on available past historic: 15, 30 , 45 and 60 minutes. The mature ones are defined on period of at least 45 minutes, i.e. for 45 and 60 minutes depth.

In order to provide a classification for several configurations, statistical models are defined for six available data hypothesis:

- IR10.8µm, IR8.7µm, IR12µm, WV6.2µm, WV7.3µm + NWP data
- IR10.8µm, WV6.2µm + NWP data (designed for GOES)
- IR10.8µm + NWP data (designed for METEOSAT-7)
- IR10.8µm, IR8.7µm, IR12µm, WV6.2µm, WV7.3µm
- IR10.8µm, WV6.2µm (designed for GOES)
- IR10.8µm (designed for METEOSAT-7)

It is to note that even if the user’s configuration file does not correspond to the real time availability of data, PGE19 is able to adapt and detect automatically the best usable configuration among the ones listed above. For that reason, each mode has benefit from a specific tuning

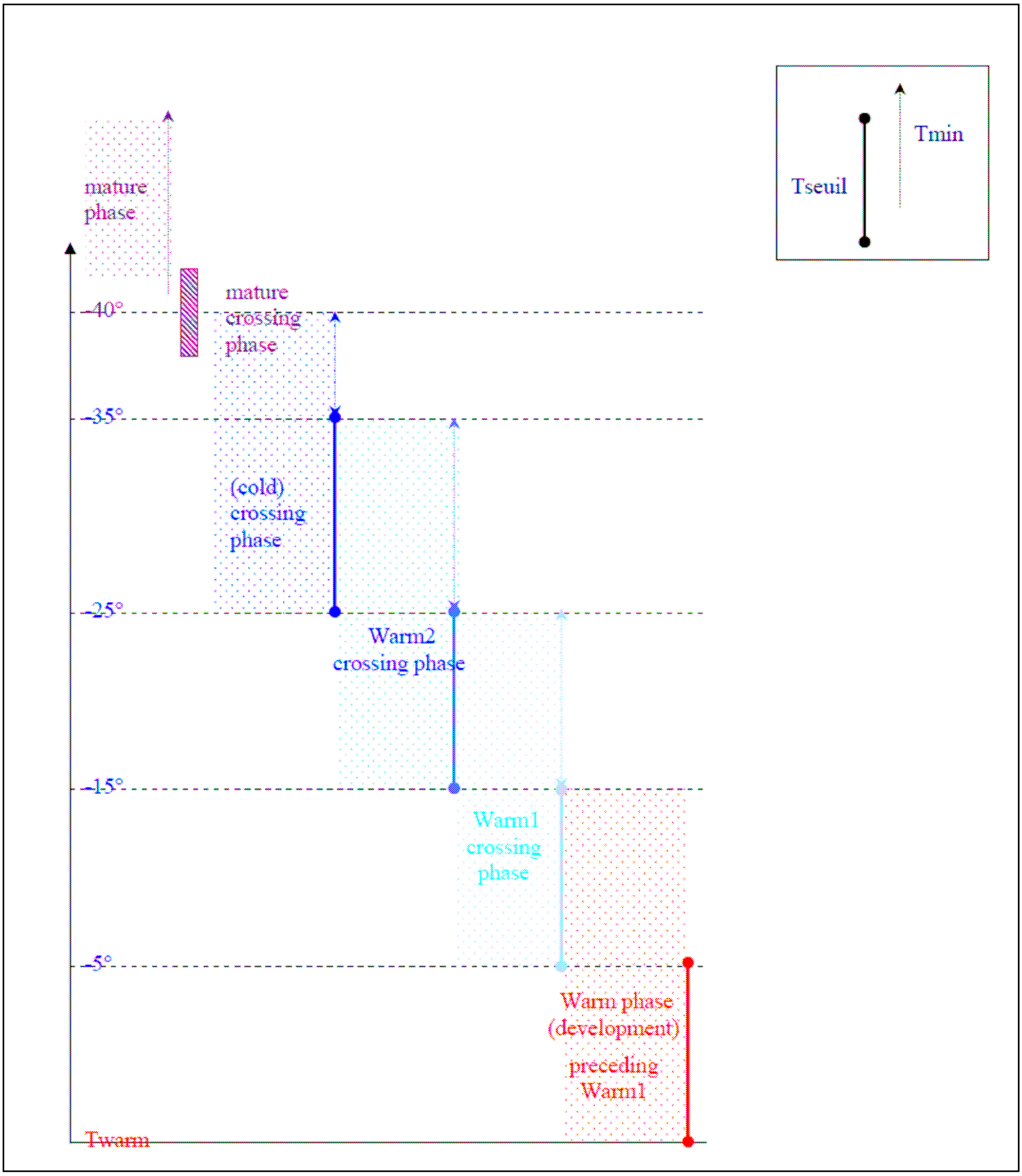


Figure 22: Vertical view: Categories of discrimination scheme and corresponding discrimination models

During the discrimination tuning for transition categories, 60 minutes sections centred on transition time are extracted from cloud system trajectories, and models (logistic regressions) are defined on various depth, respecting the way those models are planned to be used in real time: the choice of a model correspond to a choice of depth, based on age in the category, age of first detection, and past historic in the warmer category.

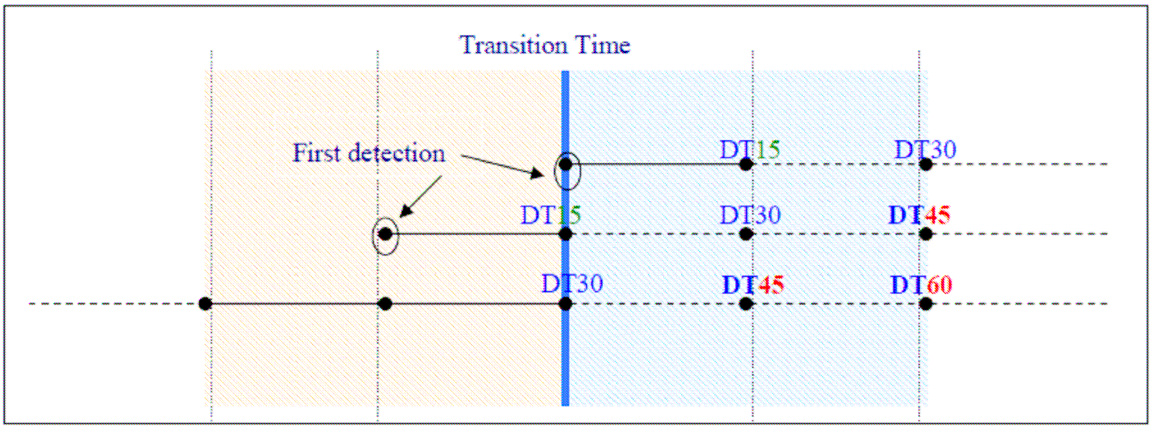


Figure 23: Temporal view: Transition model applicability depending on available historic. 3 cases depending on time of first detection. Transition time may be Tmin or temperature of Base of Tower crossing their respective thresholds.

Warm category benefits from a specific approach, taking into account that the 60min section are extracted from cloud trajectories ahead a time of reference which is the Warm2 transition time, respecting the figure below.

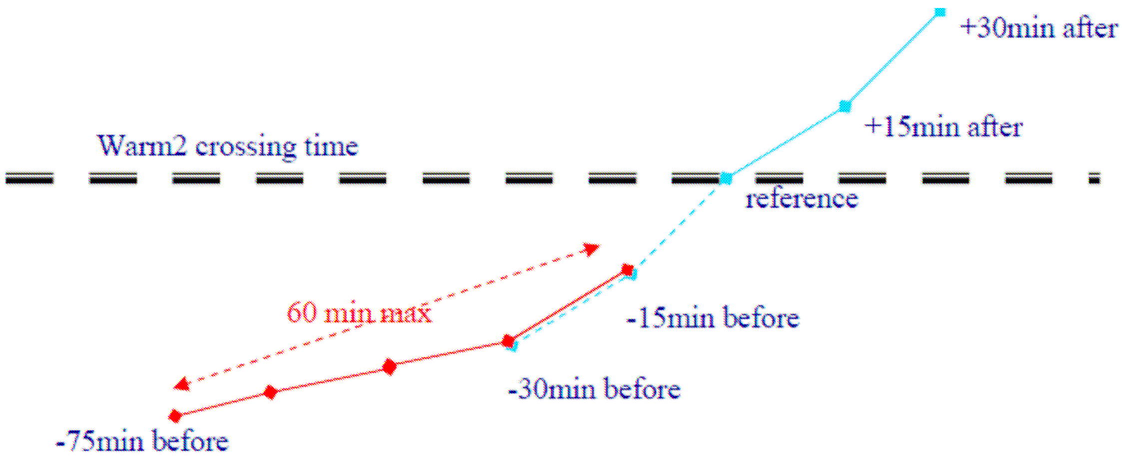


Figure 24: Spatial and temporal view for Warm category.

To summarize, the discrimination scheme is based on four discriminations defined on crossing times and one discrimination for each mature and warm case. Each discrimination is defined for various time depths, depending on available historic data (15, 30, 45 and 60min), except mature case defined for 45 and 60min only. Thus, the discrimination scheme rests on (5 categories x 4 depth + 1 category x 2 depth) x 6 configurations = 132 models (logistic regressions). Each model has to be specifically tuned on learning databases. For that reason, the description of discrimination tuning in this document will give only a quick overview of the results obtained.

Preliminary studies had been led to assess convective discriminating skill of linear and no linear models (see R.D. 1) to be incorporate into the discrimination scheme. The best results were obtained with random forest method (with 600 trees) and simple Logistic Regression method. The logistic regression had been implemented into operational version from v2009 release. This model is simple and fast, and provide some information one discriminating parameters. More details are given in Annex.

3.2.1.2.3.4 The statistical model tuning

The data used for discrimination were June-August 2008 and June-September 2009, for both MSG02 and MSG01-RapidScan, and corresponding NWP data from Meteo-France ARPEGE model, for 12h and 18h ranges (as for real time use).

The domain used for the tuning has been a little bit widened, to take into account last 2008 statistics of lightning data (provided by Météo-France Observation Department and concerning Météorage and partners network). An accuracy of 2-4km of detection has been taken into account.

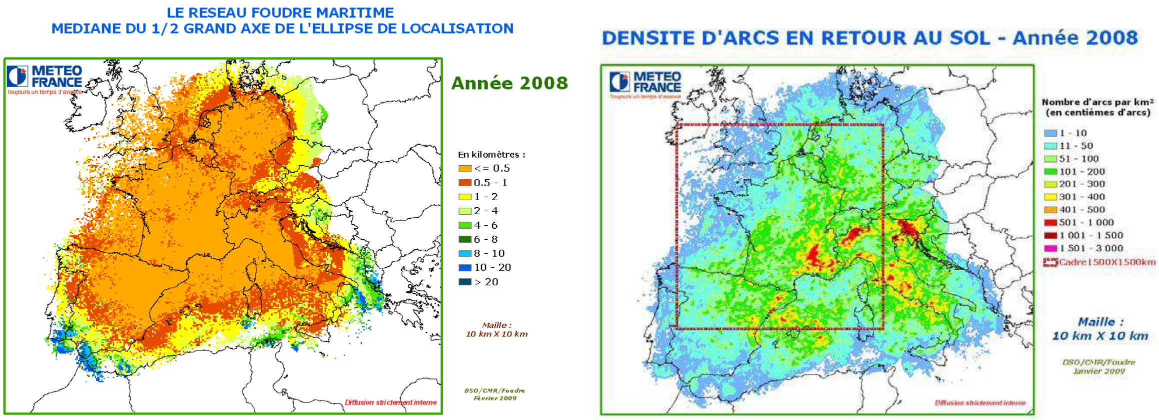


Figure 25: Extension and quality (precision left, density right) of Meteorage+partners network. Meteorage network coverage appears in red on right image

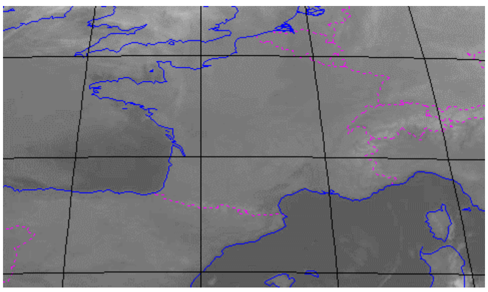


Figure 26:Domain used for RDT v2011 discrimination tuning

With numerous 2008 and 2009 data, the discrimination tuning statistical method is more stable, with an increase of the stability (robustness) of statistical models.

The use of NWP data to exclude cloud systems in stable areas has allowed to reduce in the database the imbalance between electric and non electric systems. For that reason, the method has evolved in respect to “data mining” techniques: a large learning data set without modifications of the initial proportion of population.

The ground truth used rests on a moderate lightning data activity, even for mature and transition mature categories. But the proximity to lightnings has been taken into account to built a non polluted non-convective population, still decreasing the imbalance (non convective when 50 pixels far from flashes, i.e. about 150-200 km).

Cross validation method has been implemented to reduce the dependency to the learning data set. For each statistical model, the whole data base has been taken into account for a first tuning (except 4 weeks for a further independent and coherent validation) in order to obtain a selection of relevant parameters (predictors). The coefficients of these parameters have been then “adjusted” through the processing of fifty learning-validation steps, where learning and validation dataset where randomly chosen (with respect to a proportion 80%-20%). Thus, linear model will be less dependent on learning data set.

Finally, a validation step is undertaken on a independent data set: 4 weeks distributed among 2008 and 2009, 20080713-20, 20080901-08, 20090617-24 and 20090821-28.

2008 and 2009 summers, except non electric days	4 distributed weeks
Learning dataset	Validation dataset

Table 4: learning dataset and test dataset

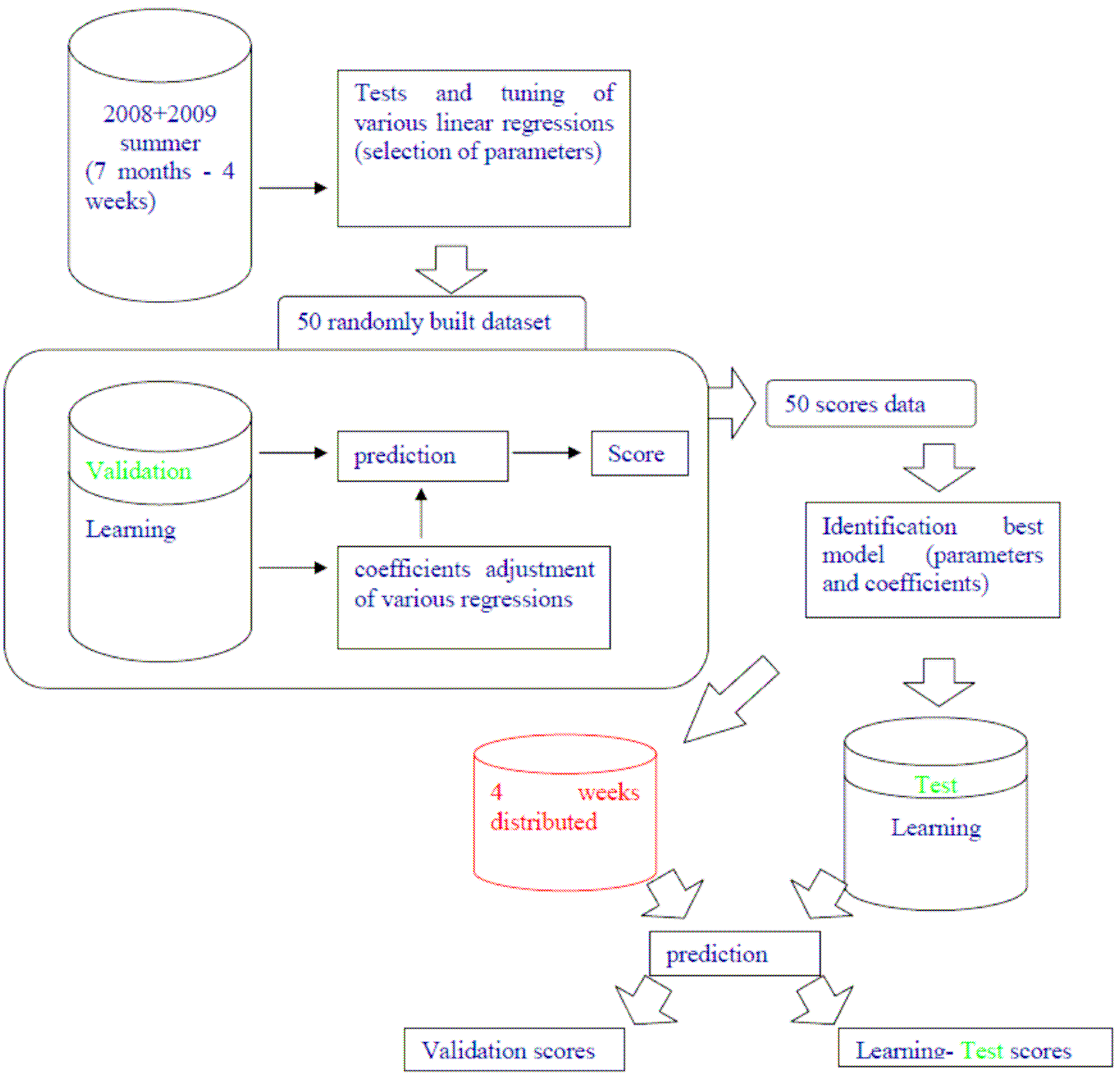


Figure 27: Discrimination tuning methodology.

The discrimination skill is depicted from threat score -false alarm distributions. This depicting allows to point out the inflexion point where the false alarm increase more than no detection decreasing, with respect to a maximum acceptable false alarm ratio (varying from 5% to 15% depending on distributions).

The threat score /false alarm distributions are displayed in graphs like figure below, where learning data set appears in black (80% of learning data set), random test data set in green (remaining 20%), and validation data set in red. Minimum value of (TS-FAR) is marked as a cross. The automatic choice of decision threshold is made from red distribution, taking into account this marked point and a maximum value of FAR.

It has to be noted that tuning scores and graph will be dependent on several parameters:

- The use or not of a NWP convective mask as a first filter of clouds
- The tuning methodology, with the parameters used for cross-validation process (different manner to consider learning dataset, test dataset and validation dataset).
- The period of tuning: the larger it is, the more reliable tuning is
- The ground truth and flashes proximity, to define non convective population
- The area of tuning

The comparison with successive versions has to be undertaken on a subjective basis, using case studies and analyzing real time situations, for a larger domain than the tuning-domain.

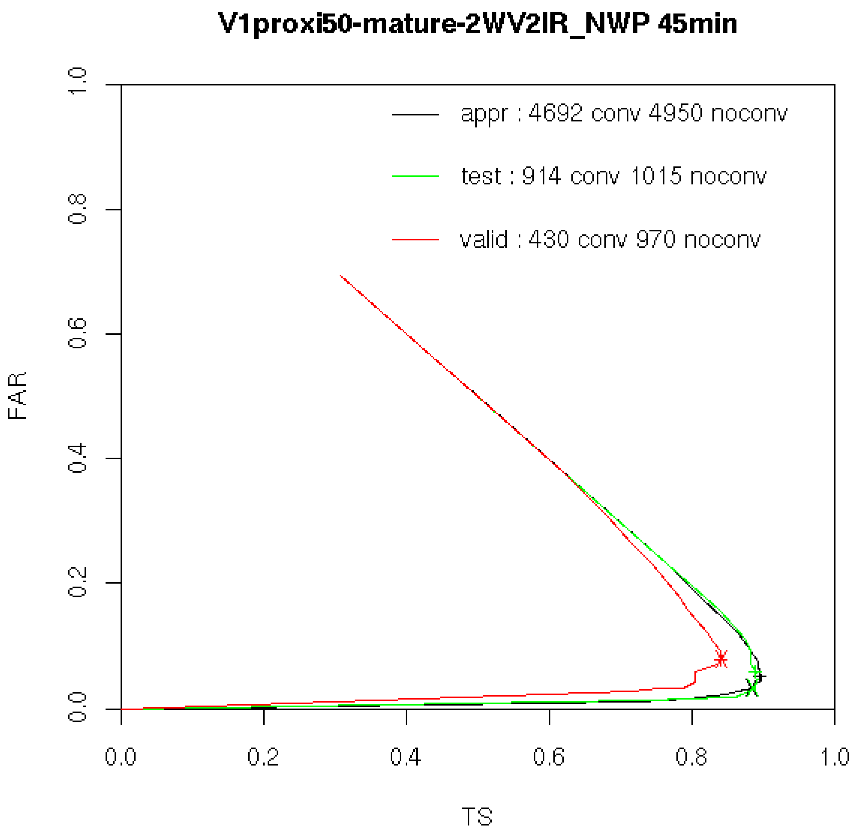


Figure 28: MSG v2011 tuning. TS/FAR curves for mature discrimination (DM), full configuration 6.2µm+7.3µm +8.7µm +10.8µm +12.0µm +NWP, 45 min depth, for a moderate ground truth with proximity to flashes taken into account Learning database (black), random test database (green), Validation database(red)

The results issued from discrimination tuning (see graphs in next sections) allow to rank the configurations of PGE19 upon scores, whatever the categories:

- “Full” configuration IR10.8µm+all additional channels (6.2µm+7.3µm +8.7µm +12.0µm) +NWP data

- "All channels" configuration IR10.8µm+all additional channels (6.2µm+7.3µm +8.7µm +12.0µm)
- "Limited with NWP" configuration IR10.8µm+WV6.2µm +NWP data
- "Limited" configuration IR10.8µm+WV6.2µm
- "Mono channel with NWP" configuration IR10.8µm+ NWP data
- "Mono channel with NWP" configuration IR10.8µm

The automatic choice of configuration mode by PGE19 in the discrimination step, depending on available data (additional channels or not, NWP data or not), will respect this ranking.

Considering categories, the ranking upon scores is similar to the vertical ranking, as expected: cold categories offer better tuning and scores than warmest ones.

Considering past historic depth, larger depth most often get better scores than shorter ones, except for warmest categories, where significant signal is found and exploited even in shorter depth (15 and 30min), with systems is ascending phase remaining few time in these categories.

Synthesizing all the results leads to invalidate some models, when they present higher false alarms.

All invalidated models are listed in a specific file in $SAFNWC/import/Aux_data/RDT-CW/files_for_discri/ConvCoeffRegr_mask (ConvCoeffRegr_5_mask for rapid-scan tuning) , sorted by configuration/category/depth. This file is read as guidance in real time at the discrimination step of PGE19.

This is for example the case for warm category, for other configurations than the "full" configuration 2WV2IR+NWP: The use of NWP configuration allow lowering the false alarms, making those models usable for 15 and 30min depth essentially (Threat scores approaching 60% for False alarms less than 10%).

3.2.1.2.3.5 The inheritance and tracking rules

The previous paragraphs depict convective and no convective decision depending on object attributes. This paragraph depicts empirical rules defined on convective management associated to tracking algorithm.

At first, a new detection is always classified like no convective.

Then, from the tracking algorithm, current and previous objects may be temporally linked. A main link (named "father" link) is then identified (often based on the higher surface at a common temperature) to represent the cloud system evolution and process discriminating parameters. But in the discrimination scheme, a convective link is also searched among all temporal links, to allow inheritance of convective diagnosis from one step to the other. In most cases, main father and convective father are the same.

If an object has a convective father, the inheritance makes this object also convective. In the case of decreasing temperature category change (continuous growing), the convective time is initialised to zero for the new class. In the other cases, the convective time and category are incremented.

Then, declassification conditions may be checked.

3.2.1.2.3.6 The declassification rules

The declassification is only applied on convective object in order to diagnose the false alarms or decaying phase. The declassification rules have been empirically defined on some case studies due to lack of ground truth to tune statistical models on these problematic.

To manage change of RDT-CW objects into discrimination scheme (Figure 22), the objects are characterized by temperature classes:

- Category 1: Top Temperature < -40°C
- Category 3: Top Temperature < -35°C or Base temperature < -25°C
- Category 4: Top Temperature < -25°C or Base temperature < -15°C
- Category 5: Top temperature < -15°C or Base temperature < -5°C
- Category 6: Top temperature > -15°C and Base temperature > -5°C

As shown in Figure 14, Category 2 is associated to discrimination of mature transition. Nevertheless, these object are assumed mature (category1) for declassification rules.

The convective classification is supposed to be valid at least 45min for cloud systems, from the moment they do not present a strong warming. Due to a higher probability of false alamr, this validity is only 30 min for the warmest category for cooling systems only.

Beyond this validity time, except category 1, a convective object is declassified if it stays into the same category. This schedule allows improving the stability of diagnosis, and focusing on cloud systems in ascending phase.

The category 1 is associated to mature phase. The declassification rules cannot be defined on development criteria or cooling rate. As previous cases, the convective classification is assumed 45 minutes at least.

After this period, the convective object is declassified if at least one the following conditions is satisfied

Temperature category of the object changes (that means that its top temperature becomes warmer than –40°C)

The BTD WV6.2-IR10.8 is inferior to –1°C and its trend is negative over the last 45 minutes

A criteria base on the sum of all BTDs is satisfied

3.2.1.2.3.7 The discrimination skill option

The statistical available by default are depicted on the graphs in annex. Nevertheless, the user could reduce the false alarm ratio with option “precocite” of configuration file.

This option set to 0 deactivates the warmest discrimination of transition and all statistical models defined on a past historic shorter than 30 minutes.

3.2.1.2.3.8 The non-optional use of overshoot information for convection diagnosis

If the algorithm detects one or more overshooting tops in a given cell, it is likely linked to intense updraft, corresponding to an active convective system (see below Overshooting Top Detection attribute). This information concerning the presence of overshoot is used to set convection diagnosis to “yes”. There’s only one possibility of change of convection diagnosis: from “no” to “yes”. No option is offered to skip this possibility.

A cloud cell not classified as convective by the discrimination scheme will be convective if the cell is associated with one or several overshoots.

3.2.1.2.3.9 The conditional use of lightning data to for convection diagnosis

Lightning data, if available in real time, may greatly contribute to the diagnosis of convection. The object approach allows the data fusion with auxiliary data. The LGH argument of configuration file defines the way to use lightning data. Set to N>0, lightning data are used to eventually change the convective diagnosis of an object. Using this option, there's only one possibility of change of convection diagnosis: from "no" to "yes".

An object not classified as convective by the discrimination scheme can be convective if more than N flashes strokes are paired with the cloud system.

3.2.1.2.3.10 The conditional use of Convective Rain Rate data for convection diagnosis

Same approach is offered with auxiliary CRR data (see below Convective Rain Rate attribute). The CRRDISCRI argument of configuration file defines the way to use this approach. Set to N>=1, CRR is used to eventually change the convective diagnosis of an object. Using this option, there's only one possibility of change of convection diagnosis: from "no" to "yes".

An object not classified as convective by the discrimination scheme can be convective if CRR attribute becomes greater than N mm/h (default 50mm/h if N = 1).

3.2.1.2.3.11 The conditional minimum temperature of tropical systems for convection diagnosis

Particular approach can be applied in tropical regions. When detected and tracked by RDT-CW software, coldest cloud systems may easily be considered as convective beyond a given temperature. The TROPICALDISCRI argument of configuration file defines the minimum temperature threshold for this approach. Using this option, there's only one possibility of change of convection diagnosis: from "no" to "yes".

An object not classified as convective by the discrimination scheme can be convective if located between 30°N and 30°S and minimum temperature attribute below specified threshold.

3.2.1.2.4 The forecast scheme

3.2.1.2.4.1 Main principles

Convective cells have their own dynamic and can have a trajectory that does not always follow the environmental displacement fields. The object mode of RDT-CW analyses the motion of each cell, and compute the speed. The forecast scheme uses this speed estimate to forecast the successive position of each cell.

The Lagrangian method is proved to be quite efficient up to 1 hour range. Thus the RDT forecast is proposed up to this limit.

3.2.1.2.4.2 Specific limitations

Please note that

- If there is not speed estimate for a given cell at a given slot, there should be no forecast of this cell (case of a new cell). Thanks to initialization through guess of movement field, this case should be rare.
- EXIM product is not used
- Overlap of forecast cells is not managed: motion vectors for neighbouring cloud cells may vary in direction and/or intensity, in particular when split/merge processes occur. In those cases, Lagrangian advection may lead to overlapping of forecast cells. Ideally, one should merge forecast cells, or produce probabilistic forecasts.
- Most of attributes are unchanged for forecast cells. Nevertheless, during first lead ranges up to 30min, trends are taken into account for corresponding attributes. Activity/severity of the cell may be incremented when high cooling or expansion rates, or high lightning trends.

- Default configuration lead to no change in cell geometry. Smoothing advected contours and dilatation/contraction vs expansion rate and lead range may be activated through SMOOTHPTS and DILAT arguments.

3.2.1.2.5 Processing additional and synthesis attributes

A lot of cloud cell's attributes are directly determined during the detection step: extreme and average temperatures, gradients, BTDs, morphology parameters (areas, ellipses axis).

Other attributes are provided using external sources, like lightning data, other PGEs, NWP data, or are determined at the end of the process before output encoding, when the maximum of information is available.

3.2.1.2.5.1 Lightning

Lightning data are associated with cloud cells when it is possible. A first check takes into account the temporal tolerance for this pairing, as provided through "LGHDTANT" and "LGHDTPOST" arguments of the model configuration file. A second check considers the region over which PGE19 is processed.

Then, each pixel of a window centred over a lightning is explored in order to associate the impact with the collocated cell or the closest cell. In this latter case the minimum distance is evaluated against the spatial tolerance as provided in the model configuration file ("LGHTLR" argument).

Negative, positive and intra-cloud lightning data are ***counted*** for each cloud cell. Moreover, the total lightning activity is checked from previous cloud cell, to evaluate a ***lightning trend*** (number/sec) useful for activity/severity purpose.

3.2.1.2.5.2 Cloud type and phase

Cloud type value extracted from CT product is examined for each pixel of cloud object. The ***most frequent value*** is attributed to the cloud cell when enough values are available.

The quality of CT products is directly taken into account to assess the quality of this attribute.

3.2.1.2.5.3 Cloud microphysics

Cloud microphysics parameters and value are extracted from CMIC product, and are examined for each pixel of cloud object.

The ***most frequent value*** for the "phase" parameter is considered. The value is set to "ice" if the proportion of ice is above 60%. The value is set to "water" if the proportion of liquid water is above 60%. The value is set to "mixed" in other cases.

The ***maximum*** values of Cloud Optical Thickness (day only), Radius Effective, Ice Water Path and Liquid Water Path are determined over the horizontal cloud cell extension.

A basic synthetic index for high altitude icing hazard, designed to be linked to significant values of high ice water content, is then evaluated. When cloud cell's "phase" attribute corresponds to ice and Cloud top height is above 5000m, cloud cell's values of Cloud Optical Thickness (day only) and total Cloud water Path are taken into account to increment an intensity index when above corresponding thresholds (COT above 40, CWP above 0.2kg/m2).

Cloud cell's phase = ice AND Cloud cell's Top Height above 5000m

Cloud cell's COT value above 40 => index incremented

Cloud cell's CWP value above 0.2 g/m^2 => index incremented

At a first stage, only 0 (no severity) 1 (light severity) and 2 (moderate severity) are possible. This attribute will later take benefit from external research about this topic.

3.2.1.2.5.4 Cloud Top Pressure

PGE19 uses mainly Cloud Top Pressure value of CTTH product. This approach can fulfil aeronautical user's needs (through FL conversion with International Standard Atmosphere).

The ***minimum*** value of pressure is considered among the pixels of the cloud-cell, to surround the vertical extension of the cloud. The quality of PGE03 product is directly taken into account to assess the quality of the attribute.

3.2.1.2.5.5 Convective Rain Rate

Convective Rain Rate intensity values are issued from PGE05. Values are analyzed for the cloud-cell horizontal extension and the ***99% percentile is calculated*** and associated to the RDT-CW object.

3.2.1.2.5.6 NWP attribute

Lifted Index and Tropopause temperature and pressure are as the NWP attributes of cloud cells. Those parameters can be used in the discrimination scheme

Tropopause parameters correspond to the ***median value*** of the pixels of the cloud-cell, whereas representative convection index is seen as the ***10% percentile*** of Lifted Index values of pixel of the cloud-cell.

3.2.1.2.5.7 Overshooting Top Detection

Overshooting top (OT) detection is facilitated by the availability of a multi-parametrical description of a cloud cell.

A first pre-selection of "candidates" overshoot is undertaken during the detection step. Once all input data have been managed and analyzed, a final confirmation of relevant overshoots is done for each cloud cell.

The first step consists in a detailed morphological analysis of the cloud top, combining static and morphological criteria:

The minimum temperature of the cloud cell, defining the first pixel of interest, has to be colder than a given value to be considered as OT (called "COLD_Threshold" and set to –50°C in mid-latitude regions and –70°C in tropical regions)

The maximum BTD=WV6.3-IR10.8 of the cloud cell has to be above a given value (called "BTD condition" and set to 0°C)

Then, the vicinity of the pixel of interest is analysed inside the cloud cell in order to

Confirm that the colder spot is above at least two surrounding warmer pixels, identified as following:

- Exploration of 16 pixels towards height directions and up to two characteristic distances. Only pixels belonging to the cell are then considered. Those distances are multiple values (twice and four times) of typical OT-size of 20km (50km in tropical latitudes)
- Warmer surrounding pixels are identified if the temperature difference with OT is above a given value (called "minimum vertical extension threshold" and set to 6°C)

Define the horizontal extension of the OT. Neighbour pixels belonging to OT are identified as following:

- Exploration of all cell's pixels inside a twice "OT-size"-window centred on the pixel of interest

- Temperature difference with OT lower than a given value (called "maximum threshold" and set to 3°C)

Other pixels of interest may be taken into account giving relevant BTD, WBTD (WV6.2-WV7.3) and VIS06 maximum values over cloud cell extension, if the corresponding pixels are not close to a previously identified OT candidate ("distance threshold" set to 50km in mid-latitude regions and 200km in tropical regions).

This step identifies a cloud cell's list of so-called "OT candidates"

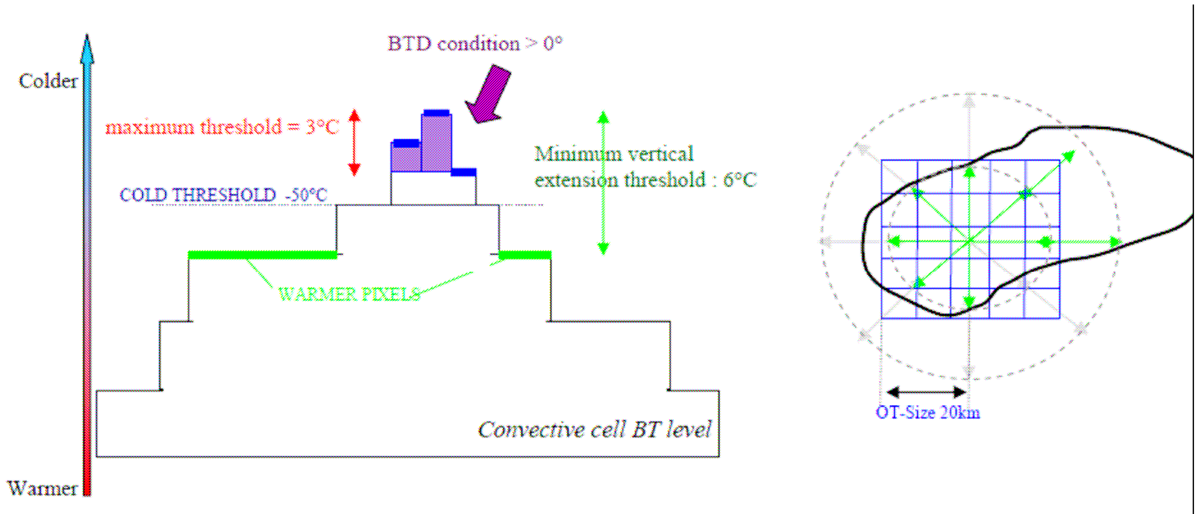


Figure 29: First step of OT detection: Values of criteria for vertical morphological analysis (left), illustration of a horizontal analysis (right). Arrows point surrounding pixels to check (green when belonging to the cloud cell), blue grid represent the research window for OT extension.

The second step takes benefit from NWP tropopause data. Tropopause data are a direct input of PGE or can be re-processed from other NWP parameters. The conditions to confirm a candidate as overshoot are described below:

- OT at least 5°C colder than NWP tropopause. This represents the main characteristic of the relevancy of OT extension

<u>or</u>

- OT colder than NWP tropopause or no NWP tropopause and 2 of 3 following conditions:
  - BTD=WV6.3-IR10.8 of the pixel has to be above 1.5°. This criteria highlights a relevant intensity of OT
  - VIS06 reflectance above 70%. This criteria available only during day-time, offers an alternative signature of cloud morphology
  - OT temperature 6°C colder than average temperature of cloud cell. This represents an alternative criteria for budding above surrounding

It is to note that without NWP tropopause data or VIS0.6 channel information, PGE19 OTD will be less reliable.

3.2.1.2.5.8 <u>The "phase of development" attribute</u>

RDT-CW output product includes a specific attribute named "phase of life" or "phase of development", ranging from "triggering" (or "split") to "growing", "mature" then "decaying" values. This attribute is an attempt to diagnose the stage of development of the tracked cloud system.

The true development stage of a convective system is difficult to diagnose: conceptual models do not always spread over the same period of time, and depend on the way the convection is organized.

- This attribute was initially (IOP) exclusively based on cooling and expansion rates, but was very variable for a given cloud system from one slot to the other
- The following versions of RDT (v2009=>v2012) made this attribute rather correspond to vertical "categories", the "mature" label corresponding to the coldest one. The diagnosis was simpler, but stable.
- However, some developed cloud systems may reveal signs of variable and strong activity. It lead us to take again into account additional parameters linked to the activity of the system (expansion rate, cooling rate, lightning activity, overshoots) and get a more relevant and realistic diagnosis, which becomes a short mix of history, vertical extension and activity.

The tables below synthesize the modifications.

History	*Vertical category (based on Tmin)*	*Type*	*Encoded phase*
birth			***0 = Triggering***
Split			***4 = Triggering from a Split***
continued	***Warm***	***Conv***	***0 = Triggering***
		not Conv	*3 = decaying*
	Warm Transition	***Conv***	***0 = Triggering***
		not Conv	*3 = decaying*
	Warm transition2	***Conv***	***1 = growing***
		not Conv	*3 = decaying*
	Cold Transition	***Conv***	***1 = growing***
		not Conv	*3 = decaying*
	Mature		***2 = mature***

Table 1 - diagnostic of phase of development - V2009 => V2012

History	*Cooling*	*Vertical category (based on Tmin)*	*Expansion*	*Activity : Type, lightning, OTD*	***Encoded phase***
birth					***0 = Triggering***
Split					***4 = Triggering from a Split***
continued	*Cooling*	***Warm***			***1 = growing***
		Warm Transition			***1 = growing***
		Warm transition2			***1 = growing***
		Cold Transition			***1 = growing***
		Mature	*no expansion*		***2 = mature***
			expansion		***1 = growing***
	~same T°	***Warm***	*expansion*	*or **Conv** or Light.*	***1 = growing***
			no expansion +	*not Conv + no Light.*	*3 = decaying*
		Warm Transition	*expansion*	*or **Conv** or Light.*	***1 = growing***
			no expansion +	*not Conv + no Light.*	*3 = decaying*
		Warm transition2	*expansion*	*or **Conv** or Light.*	***1 = growing***
			no expansion +	*not Conv + no Light.*	*3 = decaying*
		Cold Transition	*expansion*	*or **Conv** or Light.*	***1 = growing***
			no expansion +	*not Conv + no Light.*	*3 = decaying*
		Mature			***2 = mature***
	Warming	***Warm***		*Lightning or (**Conv** and low warming)*	***1 = growing***
				else	*3 = decaying*
		Warm Transition		*Lightning or (**Conv** and low warming)*	***1 = growing***
				else	*3 = decaying*
		Warm transition2		*Lightning or (**Conv** and low warming)*	***1 = growing***
				else	*3 = decaying*
		Cold Transition		*Lightning or (**Conv** and low warming)*	***1 = growing***
				else	*3 = decaying*
		Mature		*Lightning or (**Conv** and low warming) or OTD*	***2 = mature***
				else	*3 = decaying*

Table 2 - Diagnostic of phase of development from V2013

Default configuration of RDT-CW handles those improvements. Nevertheless, if the user prefers the previous diagnosis based on vertical categories, it is possible to de-activate the modifications and return to the previous diagnostic, by changing one argument in the configuration file.

3.2.1.2.5.9 The “severity” attributes

RDT-CW is a result of cloud cell morphological analysis, tracking, convective diagnosis and data blending with external data sources. For that reason, there is a possibility to undertake a kind of synthesis of parameters which are supposed to be linked to a strong activity or severity of a thunderstorm.

- Presence of overshoot
- High Cooling rate (thresholds -20, -50, -100°/h)

- Strong horizontal expansion rate
- High lightning activity (thresholds 20, then 50 strokes per 15min)
- High values of convective rain rate

Those elements increment level on a 4-scale index, and give a global estimation of the activity of the convective cloud system.

Then, an attempt to characterize most relevant phenomena is undertaken from available information: TURBulence when presence of overshoot, if not High Ice Water Content when high corresponding index, if not HeaVY Rain when high values of Convective Rain Rate. This attribute should later be completed from external research on this topic.

3.2.2 Practical Considerations

3.2.2.1 Calibration and Validation

3.2.2.1.1 Objective validation

3.2.2.1.1.1 Analysis part

Concerning the analysis part (without the forecast), the validation of RDT-CW v2016 has been limited on study cases. No modification has been brought to the discrimination scheme. Thus, the discrimination skill processed on the v2013 version of RDT remains valid.

An objective validation of RDT v2011 has been lead over Europe for an extended period (April to October). The lightning activity issued from EUCLID database has been used as ground truth.

This extended validation confirms and improves the previous validation lead with v2009 version over France and summer season.

Considering a moderate electrical activity, the overall probability of detection is 74%, and reaches 77% on convective periods. The start of a convective period is defined on the first lightning occurrence on the convective section. When considering convective cells at single moments, the probability of detection is smaller (65%) but still satisfying with about 20% of false alarms. Nevertheless, 25% of good detections are detected before the first lightning occurrence, and more than 80% within following 30 minutes.

The RDT-CW has also been validated on several cases study, and in real time configuration. More than objective score, PGE19 provides a convective classification stable in time. The discrimination algorithm is focused on convective period. The convective systems are de-classified in time during decaying phase, avoided the tracking of un-interest objects. The false alarms are well diagnosed after a small track (45 minutes).

Thus, the RDT-CW provides a right depicting of convective phenomena, from triggering phase to mature stage. The RDT-CW object allows to point out the interest area of a satellite image. It provides interest information on triggering and development clouds and on mature systems. Even if the precocity on the first lightning occurrence remains weak, the subjective evaluation confirms the precocity usefulness on moderate lightning activity.

3.2.2.1.1.2 Forecast part

The objective validation of the forecast part will be carried out once the algorithm stabilized, the forecast performances will be analysed with case studies.

3.2.2.1.2 Subjective validation

3.2.2.1.2.1 Analysis part

The subjective evaluation of RDT-CW had pointed out some performance characteristics:

- False alarm reduced by the use of NWP data as a guidance (convective mask)
- Detection improvement by the use of NWP data for the tuning, improving the scores of statistical models in all categories.
- Early detection improvement due to score increasing on Warm1 and Warm statistical models.

PGE19 discrimination tuning focuses on early diagnosis of detection in warmest categories, by the use of a NWP convective mask to decrease the imbalance between convective and non-convective systems, but also by the use of a convective index as additional parameter.

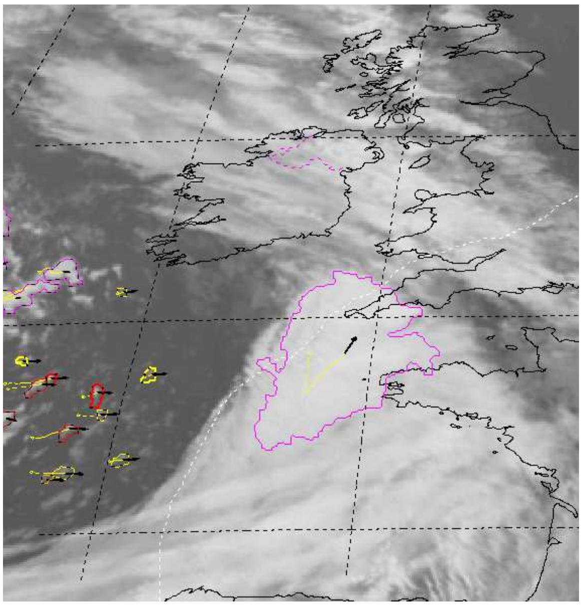


Figure 30: RDT with NWP data.6 September 2010, 07h30

On the figure above, numerous small and warm convective systems are diagnosed in the cold convective air mass behind cold front thanks to NWP tuning and guidance. All these systems are cooling convective clouds, even if not always leading to an electrical activity. On this picture, the only electric system is embedded in the cloud mass of the perturbation.

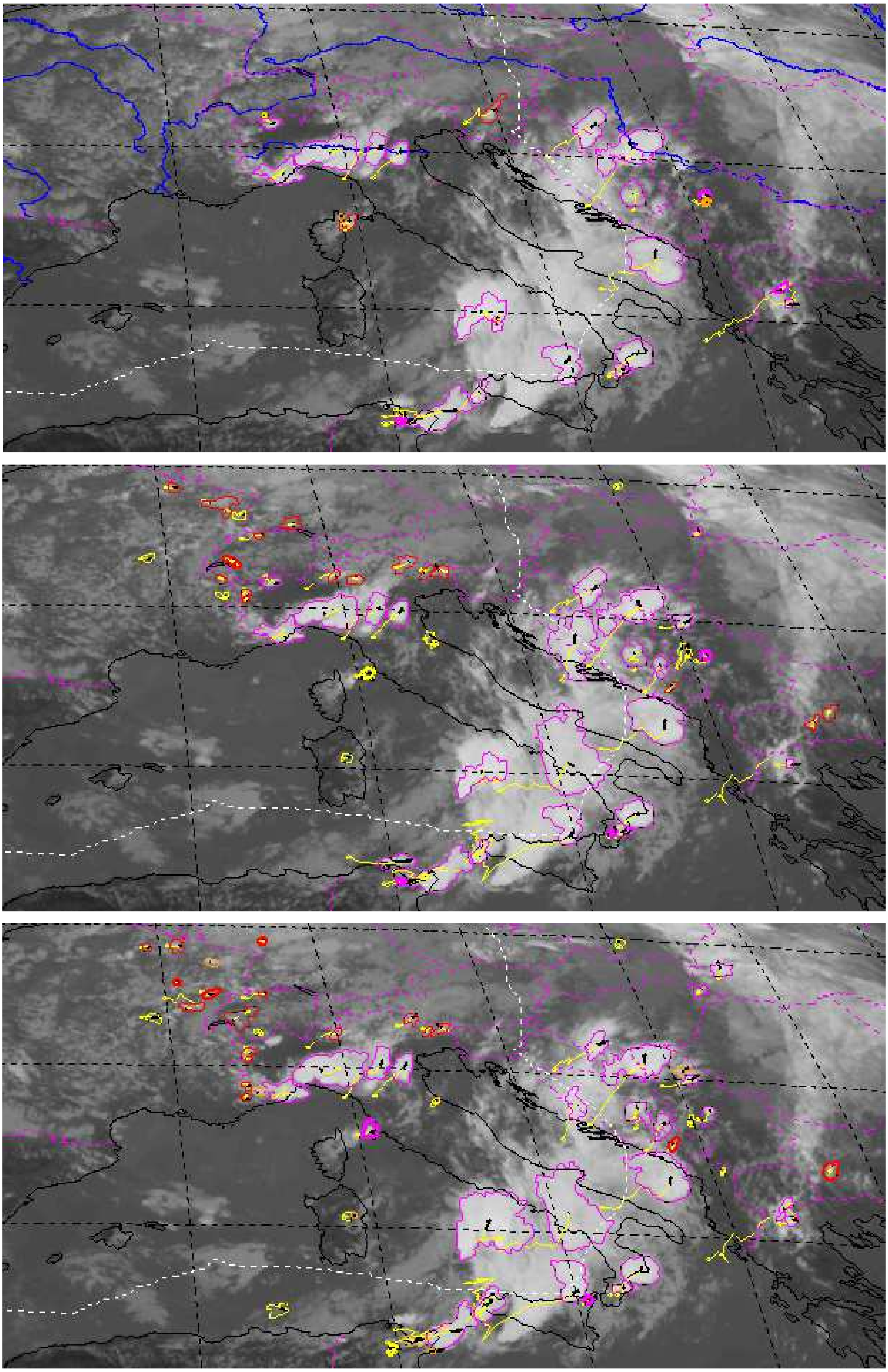


Figure 31: Impact of NWP data: Top: RDT without NWP data. Middle: RDT with NWP data, 9 September 2010, 13h15. Bottom: same as middle but for 13h30 . Yellow contours for Warm and Warm1 categories, red for Warm2 and Cold, violet for mature and transition mature.

The situation above not only displays the improvement with warm categories discrimination, but also higher detection of mature ones.

Small systems on the eastern French frontier are all convective cooling systems, most of them associated with lightning flashes, and diagnosed only with NWP data. Other warm systems (yellow contours) are relevant (good precocity east of Corsica at 13h15), some others are not confirmed (French Alps).

Finally, NWP data allow decreasing false alarms and increasing precocity of detection, thanks to a better tuning in all categories. Probability of detection is higher than previous version, especially in the warmest categories. Convective systems are thus more numerous, but it must kept in mind that the attempt to classify cloud systems in the warmest categories may lead to an increase of false alarms compensate the gain in the colder categories.

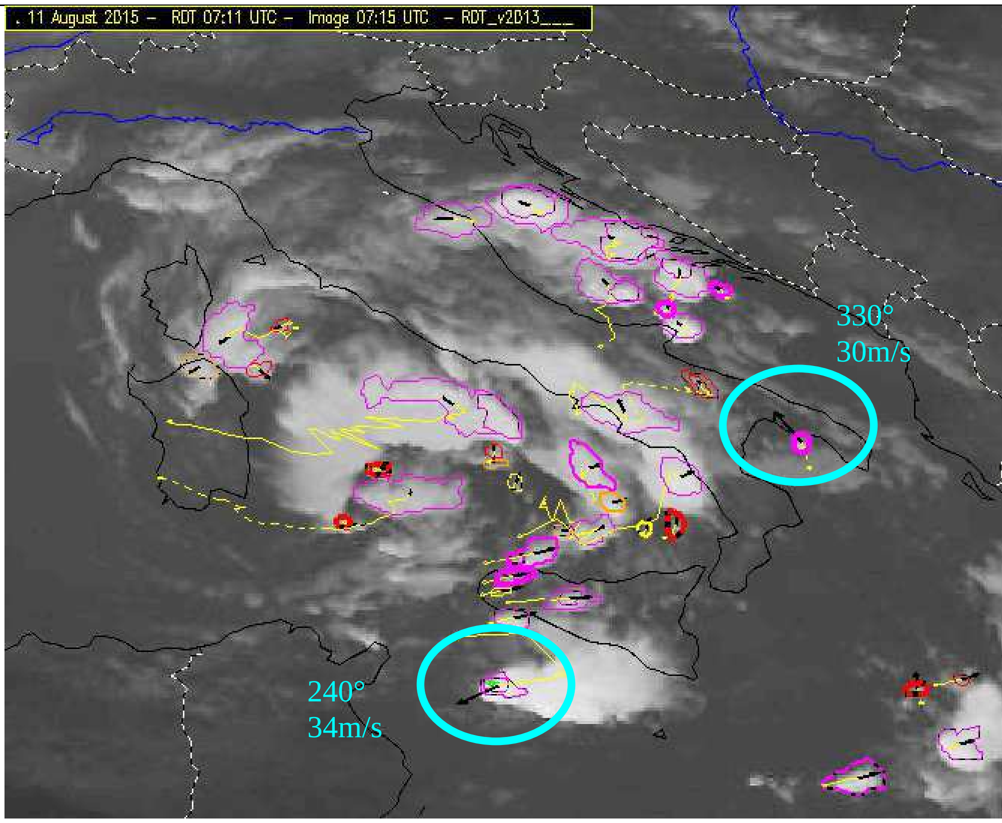
3.2.2.1.2.2 Forecast part

Evaluation of the forecast part of RDT-CW is highly linked to and dependent of quality of cell's motion estimate. Improvements of movement analysis in v2016 RDT-CW software are reminded here:

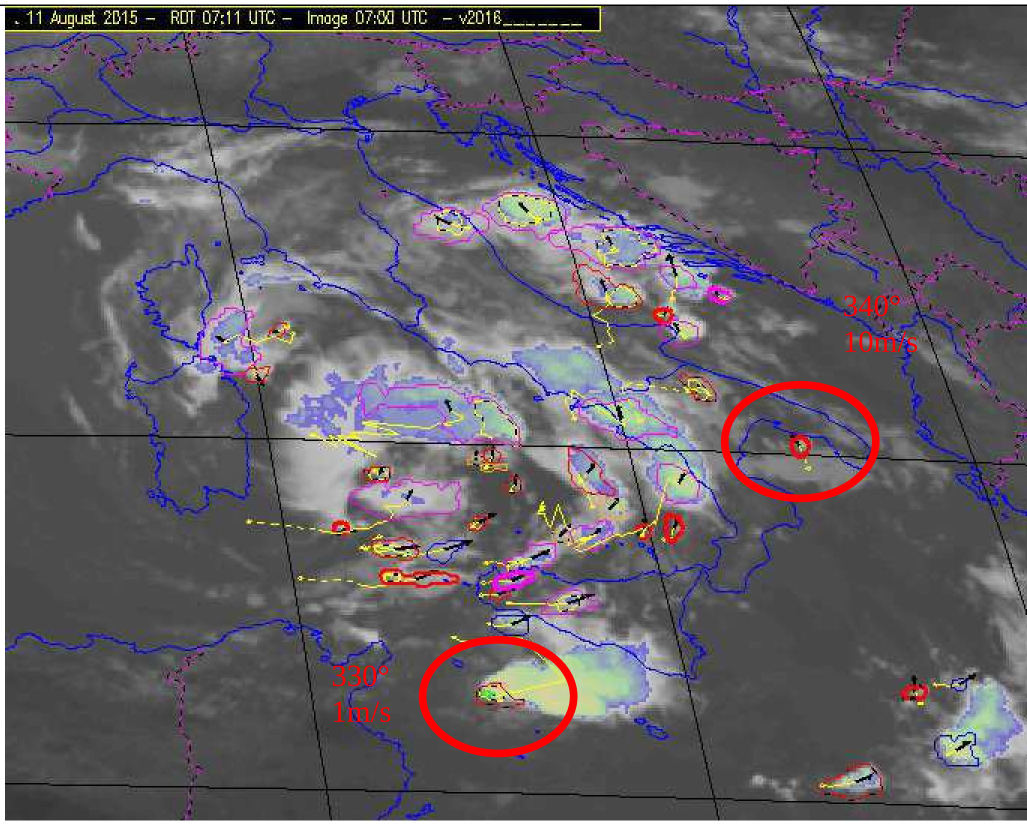
- Use of NWP low level wind field and HRW observations to process a guess of movement field
- Use of this movement field in case of initialization: cold start cases, birth of cell, orphan cells after recovery process
- Temporal Coherence analysis along cell's trajectory and smoothing step

Subjective validation of those improvements is illustrated in Figure 32. One can note that improvements lead to suppress erratic values of speed or direction of motion due merges or splits along cloud system trajectory/life. They also allow increasing horizontal coherence with neighbouring cloud systems.

The advection scheme takes benefit from an improving quality of cell's motion. It is illustrated in Figure 33, where smoothing and dilatation options have been activated. Even if those latter options may obviously insert a touch of uncertainty, they also can sometimes lead to excessive dilated contours when large cells are associated with high expansion rates. That's why RDT-CW default configuration file keeps those options non active.

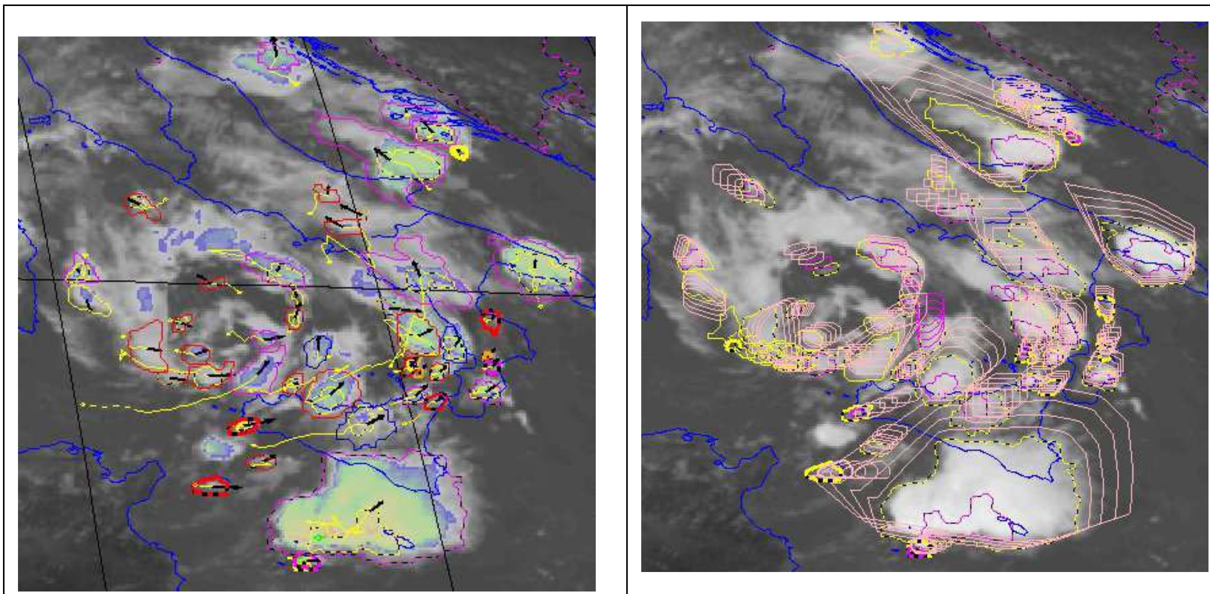


RDT v2013 visualization. One excessive speed (30m/s) southern Italy, one excessive speed and opposite direction south of Sicilia



RDT-CW v2016 illustration, run with NWP and HRW, and temporal coherence of cell's motion.

Figure 32: 11th August 2015 07h00 UTC slot – v2013 vs v2016 illustration of RDT motion vectors



Analyzed RDT-CW cells with motion vectors

RDT-CW +15, +30, +45 and +60 smoothed and dilated forecast cells

Figure 33: 11th August 2015 09h00 UTC slot –illustration of RDT advection scheme

3.2.2.2 Quality Control and Diagnostics

PGE19 doesn't process real time quality control on tracking or diagnosis result. Sanity check are in place to make, for example, the speeds realistic. But it is not used to create a quality control diagnosis

3.2.2.3 Exception Handling

In case of missing satellite images, some error messages inform the user and CI fully recovers its quality few images later. . Nevertheless, RDT-CW manages the flag quality of some optional input products like CT, CTTH and CRR.

Moreover, the RDT-CW software produces some error messages in exception cases.

3.2.2.4 Output

The final product is numerical data which depict satellite characteristics and move information associated to RDT-CW cells, and provides a full spatial description (3D-like) of each cell. Numerical data are provided as a list of current cells and characteristics valid for the current slot.

The output NetCDF default format is described in the Output Format Document of SAFNWC (see A.D. 4). Previous CDOP BUFR format has been however kept possible for non-regression purposes onto some user's display. It is fully detailed in A.D. 6.

The output file lists a large number of variables/attributes, taking into account horizontal, vertical and temporal description of each cloud cells. But this output may also (NCMAPINCLD argument of configuration file set to 1) include an image part.

- The bulletin-like part of the product relies on several dimensions: number of cells, number of contour points for horizontal description, number of levels, slices and overshoots for vertical description, number of trajectory points for a temporal description.

- The *overview part* of the output lists some characteristics of cloud cell population. It may also include an additional optional *map of type and phase* of cloud cells (default mode). It is possible to de-activate the encoding of this map, and keep bulletin-like structure only (user configuration)
- The *cell part* details the spatial and temporal description of the cloud system
  - The *main description part* lists for each cloud system identity characteristics, date type and other characteristics (type, movement, cooling rate, severity …) which concern the whole cloud system
  - The *level and contour description part* lists for each cloud system and each “bottom” and “top” threshold level the localization parameters (contour and gravity centre), satellite characteristics, morphological characteristics and data fusion parameters (lightning, other PGEs …).
  - The *vertical surface description part* lists for each cloud system pairs of threshold brightness temperature / surface allowing vertical morphological description
  - The *historical description part* lists for each cloud system a limited set of characteristics of its recent past (maximum 12 time steps corresponding to satellite refresh rate): localization of gravity centre, satellite and morphology characteristics, movement and trends. This part makes the RDT-CW output independent of previous outputs, when users want to manage trajectory of the cloud system and main temporal characteristics. A more complete temporal description will imply to manage previous outputs.
- The *overshooting top description part* lists all detected overshoots , their localization, characteristics and reference to the corresponding cloud system
- Forecast products
  - Forecast products are only bulletin-like product, without map container. Moreover, the set of variables/attributes is more restricted: only main and bottom level description.
  - There is one forecast products for each given lead range. The maximum lead range may be configurable, but cannot exceed 1h. Forecast products are available each 15min. So there can be up to 5 output files produced, one for the analysis, and 4 for +15, +30, +45 and +60min lead ranges.

3.2.2.5 Access to cloud system history

With previous CDOP BUFR , optimal use of RDT-CW product needed to rebuilt temporal links between successive could cells of a given cloud system (at least to identify successive locations of gravity centres and re contruct cloud track).

The recent main characteristics of a cloud system are now described inside the NetCDF product, with a corresponding dimension describing trajectory steps.
Thus, user may benefit (or not) from the last steps of a current cell, without accessing previous products. Past localization parameters as well as important characteristics (brightness temperatures, surfaces, trends …) are now available in each current product.

3.2.3 Assumptions and Limitations

The tuning of discrimination scheme relies on the availability of an efficient lightning data network used as ground truth for constituting learning and validation data sets. It had been carried out on a summer period over a domain centred over France using French Meteorage lightning data network. It may also use data from extended network (like EUCLID data for extended validation).

Nevertheless, the discrimination scores during winter period could remain weak since the lack of convective situations impacts the quality of learning data set for tuning purposes.

3.3 CTRAJ INTERMEDIATE PRODUCT

3.3.1 Goal of the CTRAJ intermediate product

CTRAJ is a technical intermediate product issued from PGE19. When RDT-CW represents a full spatial (3D like) description of cloud cells, CTRAJ represents a full temporal description of terminated cloud systems.

CTRAJ product represents the difference between current internal backup file and previous one, storing characteristics of achieved cloud system trajectories. Thus, a trace of past convective activity can be made available.

Depending on the use, thus on user's choice and configuration, CTRAJ file may content full or brief information of cloud systems.

The following main uses of CTRAJ intermediate product can be identified:

- Discrimination Tuning (full description – backup-like)
  Trajectories produced on a specific area with all kinds of data constitute a basis for convective discrimination tuning of RDT. This facility is needed for managing new input data or new releases of RDT.
- Monitoring (synthetic description)
  Real-time trajectory production allow to have the first step of convection validation. For example to provide forecasters or end-users some element about the quality of the product. Real time validation depends on available data. It also helps have an overview of a complete trajectory
- Climatological studies (statistical description)
  Real-time trajectory production can allow to undertake studies to define hazardous areas with high probability of RDT, to define for a given place the beginning and the end of the convective season, etc.

3.3.2 Optional production outline

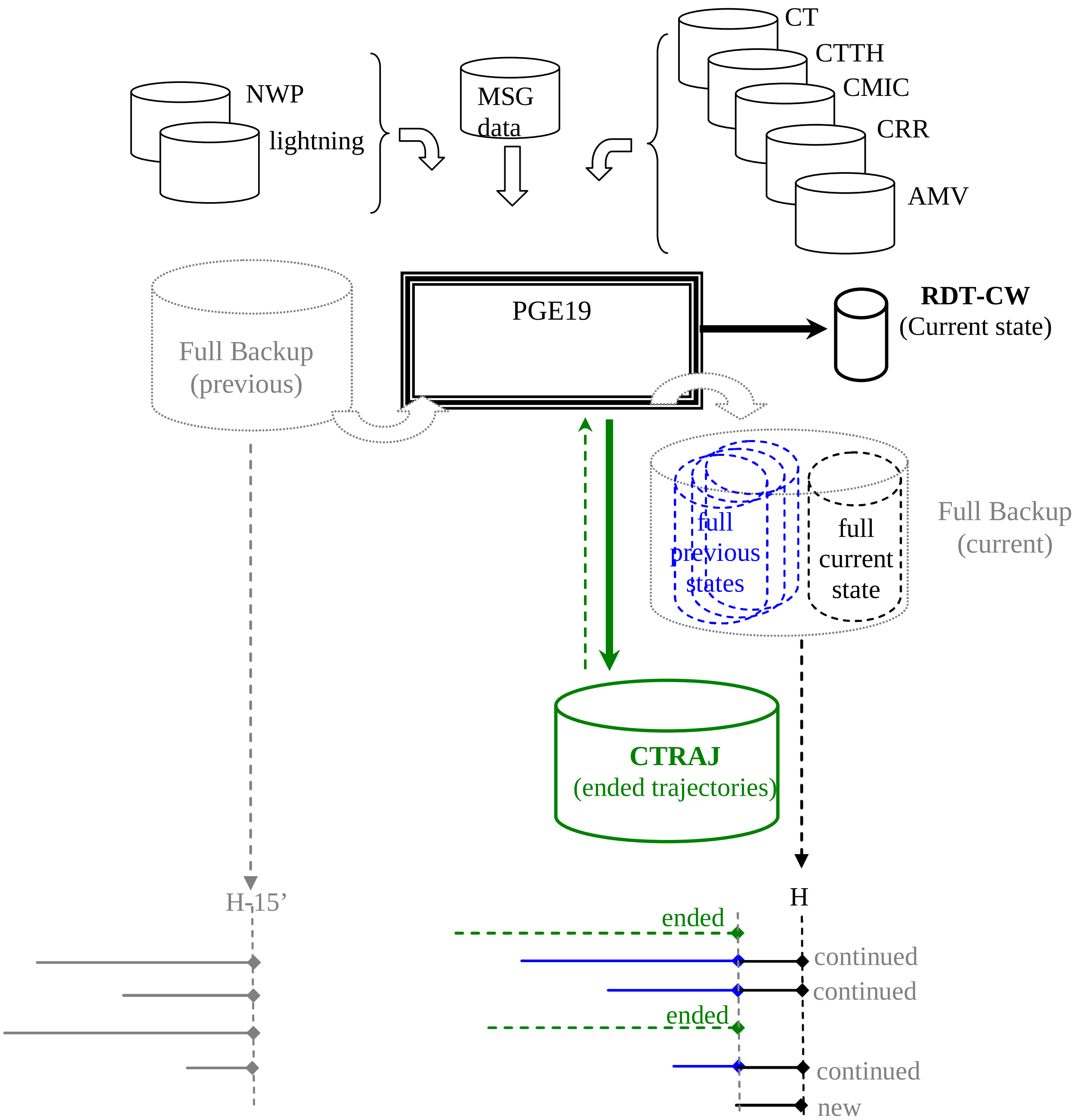


Figure 34: Production of RDT-CW and the associated intermediate product CTRAJ by two different processes during CDOP2 phase

The production of CTRAJ file is fully optional.

The advantage of this intermediate product is the possibility to define the characteristics of trajectories that will be kept and eventually to get specific attributes related to the whole trajectory: maximum of activity, area swept by the convective cell, length of trajectory, etc. Options help the user to configure the level of description of the convective cells trajectories.

For an optimal production of CTRAJ intermediate product, an optimal production of RDT-CW is mandatory, i.e. with all possible external or internal input data (NWP, lightning data, CMa, CT, CTTH, CRR, CMIC, AMV, etc.).

3.3.3 Practical Considerations

Output product will remain in ASCII format (at least in a first stage).

It describes some of the selected characteristics of the previous cloud system trajectories that ended at the current slot, i.e. whose tracking was interrupted or finished on the current image.

Three output modes are available, upon user's request:

- Distinct output at each slot (default mode)
- Daily output updated at each slot (input/output file)
- Monthly output updated at each slot (input/output file)

Note: For the two latter options, previous output file is updated with the latest trajectories. Thus, in case of temporarily no update (continued cloud systems, or no cloud activity during a short period), user has to take care that output file is not removed by Task Manager monitoring cleaning tasks.

3.3.4 CTRAJ content

At the end of the processing, RDT-CW may provide (depending on user's configuration) a consolidated record of all achieved trajectories during the time slot. The trajectory file is coded in ascii format. The name of the file depends on the frequency of production (driven by TRAJPROD argument of model configuration file):

- Monthly (0) S_NWC_CTRAJ_*satelliteId_regionName_YYYYMM*
- Daily (1) S_NWC_CTRAJ_*satelliteId_regionName_YYYYMMDD*
- Each slot (2 - ***default***) S_NWC_CTRAJ_*satelliteId_regionName_YYYYMMDDHHmm*

The missing value is –9999

This file is organized in rows. The first character differentiates different kinds of lines:

- A line beginning with '***T***' indicates the beginning of the description of a whole trajectory. The description begins from the first detected cell to the last one, sequentially.
- Each cell is described by a group of different lines (***I, S, S2, X, H, O, L***) each documenting a particular aspect of the concerned cell
    - Lines beginning with 'I' = full identification of the cell
    - Lines beginning with 'S' = satellite morphology and radiative characteristics of tracked cell ('S2' = characteristics of corresponding tower top cell)
    - Lines beginning with 'X' = radiative and temporal characteristics of additional satellite channels, information from other PGEs or from NWP data
    - Lines beginning with 'O' = description of overshooting top detected in cell
    - Lines beginning with 'H' = Vertical description of cell
    - Lines beginning with 'L' = association with lightning activity

1. <u>Line "T" (Trajectory)</u>

The T line describes a trajectory. The cells that compose it are outlined in the following lines.

Format:

T ch2 ch3 ch4 … ch14 ch15 ch16

ch2: The type of trajectory:
- 0: Path not convective
- 1: Trajectory convective
- 2: *internal use*

ch3: Flag test cutoff temporal trajectory
- 0: No break
- 1: The system has been detected just after a missing image
- 2:Trajectory with missing time step
- 3: The cutoff spatial index is not zero for at least one cell of the trajectory
- 4: 1 & 2
- 5: 1 & 3
- 6: 2 & 3
- 7: 1, 2 & 3
- 14: End of episode (edge of domain)

ch4: Flag test cut-off spatial trajectory
- 0: No break
- 1: Cell touching the edge of the domain
- 2: Pixel (s) of incalculable value to the cell
- 3: 1 & 2

ch5: The duration in minutes
ch6: The number of the first cell of the trajectory
ch7: The start date (Format YYYYMMDDhhmm)
ch8: The end date (Format YYYYMMDDhhmm)
ch9: Characteristic of trajectory start
- Normal: 'No'
- After a split 's'
- After a merge: 'g'
- After a complex case (undefined: merge + split) 'c'
- Error code: '.'

ch10: Number of cells integrated over the trajectory
ch11: Number of cells expelled during the course (cell split)
ch12: Characteristic of closure
- Normal: 'No'
- Termination in split case: 's'
- Termination in merge case: 'g'
- Termination in complex case: 'c'
- Error code: '.'

ch13: *internal use*
ch14: *internal use*
ch15: *internal use*
ch16: The probability of error of the method of discrimination (in%)

2. Line "I" (Identity)

The "I" line identifies a cell.

Format:

I ch2 ch3 ch4 ch5 ch6 ch7 ….. ch20 ch21

ch2: The ***date*** of the cell (Format YYYYMMDDhhmm)
ch3: His ***number*** (internal functioning of PGE)
ch4: The cell ***identifier*** (Format YYYYMMDDhhmm_ <temperature of threshold> _ <latitude gravity center> _ <longitude gravity center >)
ch5: convective ***type*** (0 to 15)

- 0: diagnosis not convective (static model results)
- 1: diagnosis convective (static model results)
- 2: *internal use*
- 3: cell previously convective and declassified
- 4 & 5: convective nature of inherited primary link (5 if under development stage)
- 6 & 7: convective nature inherited a secondary link (7 if under development stage)
- 8 & 9 & 10: undefined
- 11 & 12 & 13 & 14: forced diagnosis (LGH, OTD, CRR, TROP)
- 15: inherited forced diagnosis

ch6: the likelihood of ***error*** diagnostics above (%) (-9999 if no diagnostic)
ch7: ***class/category*** of cell

- 0: mature Tmin <= -40 °C
- 1: mature transition Tmin <= -40 °C or Threshold temperature <=- 35 °C
- 2: Cold transition Tmin <= -35 °C or Threshold temperature <=- 25 °C
- 3: Warm transition Tmin <= -25 °C or Threshold temperature <=- 15 °C
- 4: Warm transition Tmin <= -15 °C or Threshold temperature <=- 5 °C
- 5: Hot cell (no active discrimination): Threshold temperature > -5 °C

ch8: the cell ***class/category of convective*** diagnosis (-9999 otherwise)
ch9: ***age*** (minutes) in the class
ch10: ***convective age*** (minutes) convective (-99999 otherwise)
ch11: ***history*** (minutes) available with 5 channels
ch12: ***history*** (minutes) available with 3 channels IR10.8, WV6.2, IR12.0
ch13: ***history*** (minutes) available with 3 channels IR10.8, WV6.2, WV7.3
ch14: ***history*** (minutes) available with 2 channels IR10.8, WV6.2
ch15: ***history*** (minutes) available with channel IR10.8 only
ch16: ***history*** (minutes) with the maximum available channel IR10.8 without time interruption
ch17: ***history*** (minutes) with available NWP data
ch18: ***significant*** characteristic of the cell (0 or 1)
ch19: ***severity*** index of the cell (0=NIL, 1=light,2=moderate,3=high,4=very high, 5=unknown)
ch20: type of hazard of cell (0=NIL, 1=turbulence, 2=lightning, *3=icing*, *4=high ice water content*, *5=hail*, 6=heavy rain rate, 7=unknown)
ch21: cell ***number at birth***

3. Line “S” or “S2” (Satellite)

The S line gives the satellite characteristics of the cell previously defined in line “I”.

Format:

S ch2 ch3 ch4 ch5 ch6 ch7 … ch33 ch34

ch2: ***Date*** of the cell (Format YYYYMMDDhhmm)
ch3: His ***number*** (internal functioning of PGE)
ch4: ***Threshold*** temperature at which the cell is defined
ch5: ***internal number*** of the cell into the threshold process

ch6: Position of gravity centre: ***Latitude***
ch7: Position of gravity centre: ***Longitude***
ch8: Position of weighted gravity centre: ***Latitude***
ch9: Position of weighted gravity centre: ***Longitude***
ch10: ***Average*** temperature of the cell
ch11: ***Standard deviation*** of cell temperature
ch12: ***Minimum*** temperature of the cell
ch13: ***Area*** (km2)
ch14: ***Minor axis*** of the ellipse approaching the cell (in km)
ch15: ***Major axis*** of the ellipse approaching the cell (in km)
ch16: ***Orientation*** of the ellipse approaching the cell (angle in degrees from north)
ch17: Internal use
ch18: Internal use
ch19: Internal use
ch20: Average temperature ***gradient*** on the cell
ch21: Average of ***peripheral gradient*** of temperature on the cell
ch22: ***Percentile 95%*** of peripheral gradient
ch23: ***Number of pixels*** on the periphery of the cell
ch24: X axis (horizontal) ***Speed*** of movement in the (pixels / hour)
ch25: Y axis (vertical) ***Speed*** of movement in the (pixels / hour)
ch26: ***cooling rate*** of the cell based on the minimum temperature (° C / h and positive when Tmin decreases)
ch27: ***minimum pressure*** of top of the cloud (CTTH)
ch28: height of cloud base (missing)
ch29: Pixel location of the minimum temperature: ***Latitude***
ch30: Pixel location of the minimum temperature: ***Longitude***
ch31: ***Closest lightning*** = pixel distance of the nearest impact
ch32: moving ***speed*** (m/s) of the cell
ch33: moving towards ***direction*** of the cell
ch34: Cloud Top Pressure ***trend*** (Pa/sec)

4. Line “X” (eXtra data)

The X line describes the characteristics of additional channels, additional PGEs or NWP data of the cell previously defined in line “I”.

Format:

X ch2 ch3 ch4 ch5 ch6 ch7 ……. ch54 ch55 ch56

ch2: ***Date*** of the cell (Format YYYYMMDDhhmm)
ch3: His ***number*** (internal functioning of PGE)
ch4: Attribute external Classification Cloud = predominant ***cloud type*** (CT)
ch5: Cloud Field Classification = surface corresponding ***proportion***
ch6: Cloud Field Classification = cumuliform or stratiform ***type*** (CT)
ch7: Attribute = channel WV6.2 ***Minimum*** temperature
ch8: Attribute = channel WV6.2 ***trend***
ch9: Attribute = channel WV7.3 ***Minimum*** temperature
ch10: Attribute = channel WV7.3 ***trend***
ch11: Attribute = WV-IR Brightness Temperature Difference ***maximum*** value on cell
ch12: Attribute = WV-IR Brightness Temperature Difference ***75% percentile***

ch13: Attribute = WV-IR Brightness Temperature Difference ***90% percentile***
ch14: Attribute = WV-IR Brightness Temperature Difference ***ratio***
(nb relevant pixels surrounded by relevant pixels SIG) / (nb relevant pixels)
ch15: Attribute = WV62-WV73 Brightness Temperature Difference ***maximum*** value
ch16: Attribute = WV62-WV73 Brightness Temperature Difference ***75% percentile***
ch17: Attribute = WV62-WV73 Brightness Temperature Difference ***90% percentile***
ch18: Attribute = WV62-WV73 Brightness Temperature Difference ***ratio***
(nb relevant pixels surrounded by relevant pixels SIG) / (nb relevant pixels)
ch19: Attribute = channel VIS0.6 ***Maximum*** reflectance
ch20: Attribute = channel VIS0.6 ***trend***
ch21: Attribute = channel IR1.6 ***Maximum*** reflectance
ch22: Attribute = channel IR1.6 ***trend***
ch23: Attribute = IR1.6-VIS0.6 Reflectance Difference ***maximum*** value
ch24: Attribute = IR1.6-VIS0.6 Reflectance Difference ***percentile 75%***
ch25: Attribute = IR1.6-VIS0.6 Reflectance Difference ***percentile 90%***
ch26: Attribute = IR1.6-VIS0.6 Reflectance Difference ***ratio***
(nb relevant pixels surrounded by relevant pixels SIG) / (nb relevant pixels)
ch27: Attribute = channel IR3.9 ***Minimum*** temperature
ch28: Attribute = channel IR3.9 ***trend***
ch29: Attribute = channel IR8.7 ***Minimum*** temperature
ch30: Attribute = channel IR8.7 ***trend***
ch31: Attribute = channel IR12.0 ***Minimum*** temperature
ch32: Attribute = channel IR12.***trend***
ch33: Attribute = IR3.9-IR10.8 IR Brightness Temperature Difference ***maximum*** value
ch34: Attribute = IR3.9-IR10.8 Brightness Temperature Difference ***percentile 75%***
ch35: Attribute = IR3.9-IR10.8 Brightness Temperature Difference ***percentile 90%***
ch36: Attribute = IR3.9-IR10.8Brightness Temperature Difference ***ratio***
(nb relevant pixels surrounded by relevant pixels SIG) / (nb relevant pixels)
ch37: Attribute = IR8.7-IR10.8 Brightness Temperature Difference ***maximum*** value
ch38: Attribute = IR8.7-IR10.8 Brightness Temperature Difference ***percentile 75%***
ch39: Attribute = IR8.7-IR10.8 Brightness Temperature Difference ***percentile 90%***
ch40: Attribute = IR8.7-IR10.8Brightness Temperature Difference ***ratio***
(nb relevant pixels surrounded by relevant pixels SIG) / (nb relevant pixels)
ch41: Attribute = IR12.0-IR10.8Brightness Temperature Difference ***maximum*** value
ch42: Attribute = IR12.0-IR10.8 Brightness Temperature Difference ***percentile 75%***
ch43: Attribute = IR12.0-IR10.8 Brightness Temperature Difference ***percentile 90%***
ch44: Attribute = IR12.0-IR10.8 Brightness Temperature Difference ***ratio***
(nb relevant pixels surrounded by relevant pixels SIG) / (nb relevant pixels)
ch45: Attribute NWP= predominant value over cell of ***convective mask***
0=NOCONV, 1=NEUTRAL, 2=CONV
ch46: Attribute NWP= convective index ***type*** : 0=K index, 1=Lifted index, 2=Showalter index
ch47: Attribute NWP= convective index ***value*** of (10% or 90%percentile depending on index)
ch48: Attribute NWP= ***Tropopause Temperature*** median value over cell
ch49: Attribute NWP= ***Tropopause Pressure*** median value over cell
ch50: Attribute = Cloud ***Phase*** - water (1) or ice (2) or mixed (3) (CMIC)
ch51: Attribute = maximum ***convective rain rate*** (mm/h) (CRR)
ch52: Attribute =
ch53: Attribute = maximum ***radius effective*** (m) (CMIC)
ch54: Attribute = maximum ***cloud optical thickness*** (unitless) (CMIC)
ch55: Attribute = maximum ***liquid water path*** (kg/m2) (CMIC)
ch56: Attribute = maximum ***ice water path*** (kg/m2) (CMIC)

5. Line "O" (Overshooting top)

The "O" line documents overshoot characteristics associated with the cell defined in line "I". There are as many "O" lines as overshoots in the cell. In practice cells with more than one overshoot are not frequent.

Each overshoot is described by at least one point, corresponding to the main characteristic (minimum temperature and/or maximum BTD, etc …).

O ch2 ch3 ... ch 23 ch24 ....

ch2: ***Date*** of the cell (Format YYYYMMDDhhmm)
ch3: its ***number*** (internal functioning of PGE)
ch4: main ***characteristics*** of overshoot : "IRMin", "BTDMax", "ReflMax"
ch5: ***temperature*** (°C) of overshoot (IR10.8)
ch6: ***horizontal gradient*** (°C/km)
ch7: maximum ***temperature difference*** (°C) betwwen OT and surrounding pixels (always >= 0)
ch8: number of warmer ***surrounding pixels***
ch9: ***BTD***=WV6.2-IR10.8 (always >= 0)
ch10: number of ***pixels*** with BTD >=0
ch11: ***WBTD***=WV6.2-WV7.3 (when available)
ch12: ***BTD3***= IR3.9-IR10.8 (when available)
ch13: ***BTD4***=IR10.8-IR8.7 (when available)
ch14: ***BTD5***=IR12.0-IR10.8 (when available)
ch15: ***reflectance*** (VIS06) (when available)
ch16: horizontal ***gradient*** of reflectance (VIS06) (when available)
ch17: ***Reflectance Difference*** IR1.6-VIS0.6 (when available)
ch18: ***reflectance*** (HRV) (missing)
ch19: horizontal ***gradient*** of reflectance (HRV) (missing)
ch20: ***pressure gap*** to tropopause (hPa)
ch21: ***temperature gap*** to tropopause (°C)
ch22: ***number of points*** belonging to overshoot (always >=1)
ch23: ***latitude*** of main point of overshoot
ch24: ***longitude*** of main point of overshoot
ch25: (latitude of next point)
ch26: (longitude of next point)

.../...

6. Line "H" (morpHology)

The "H" line documents the vertical structure associated to the cell defined in line "I"

Format:

H ch2 ch3 ch4 ch5 ch6 ch7 …

ch2: ***Date*** of the cell (Format YYYYMMDDhhmm)
ch3: His ***number*** (internal functioning of PGE)
ch4: The threshold temperature of the ***hottest temperature*** for which the surface of the system is processed
ch5: The temperature ***increment*** between two consecutive surfaces
ch6: The ***number*** N of surfaces evaluated

ch7 to ch X (X = 6 + N): The ordered ***surfaces*** as follows: S (ch4), S (ch4 + ch5), S (ch4 +2*ch5), ..., S (ch4 + (N-1)*ch5)

7. Line “L” (Lightning)

The L line documents the electrical activity of the cell (identified with the line 'I' preceding the line)

Format:

L ch2 ch3 ch4 ch5 ch6 ch7 ch8 ch9 ch10 ch11 ch12

ch2: ***Date*** of the cell (Format YYYYMMDDhhmm)
ch3: His ***number*** (internal functioning of PGE)
ch4: Number impact ***intra-cloud*** lightning in the cell in the]date-date_before; date+date_after]
ch5: Number of ***negative impacts*** lightning in the cell in the]date-date_before; date+date_after]
ch6: Number of ***positive impacts*** lightning in the cell the]date-date_before; date+date_after]
ch7: ***Average intensity*** of ***negative*** impacts in the the]date-date_before; date+date_after]
ch8: ***Standard deviation*** of intensity of ***negative*** impacts in the the]date-date_before; date+date_after]
ch9: ***Average intensity*** of ***positive*** impacts in the the]date-date_before; date+date_after]
ch10: ***Standard deviation*** of intensity of ***positive*** impacts in the the]date-date_before; date+date_after]
ch11 total ***lightning trend*** expressed in number / second
ch12: Date of ***first impact*** of lightning associated with that cell (YYYYMMDDHHMMSS)

ANNEX – SOME STATISTICAL MODEL SCORES FOR RDT-CW FOR MSG FULL DISK SCAN SERVICE (FDSS) AND RAPID SCAN SERVICE (RSS)

1. FDSS: MATURE (DM), VARIOUS CONFIGURATIONS

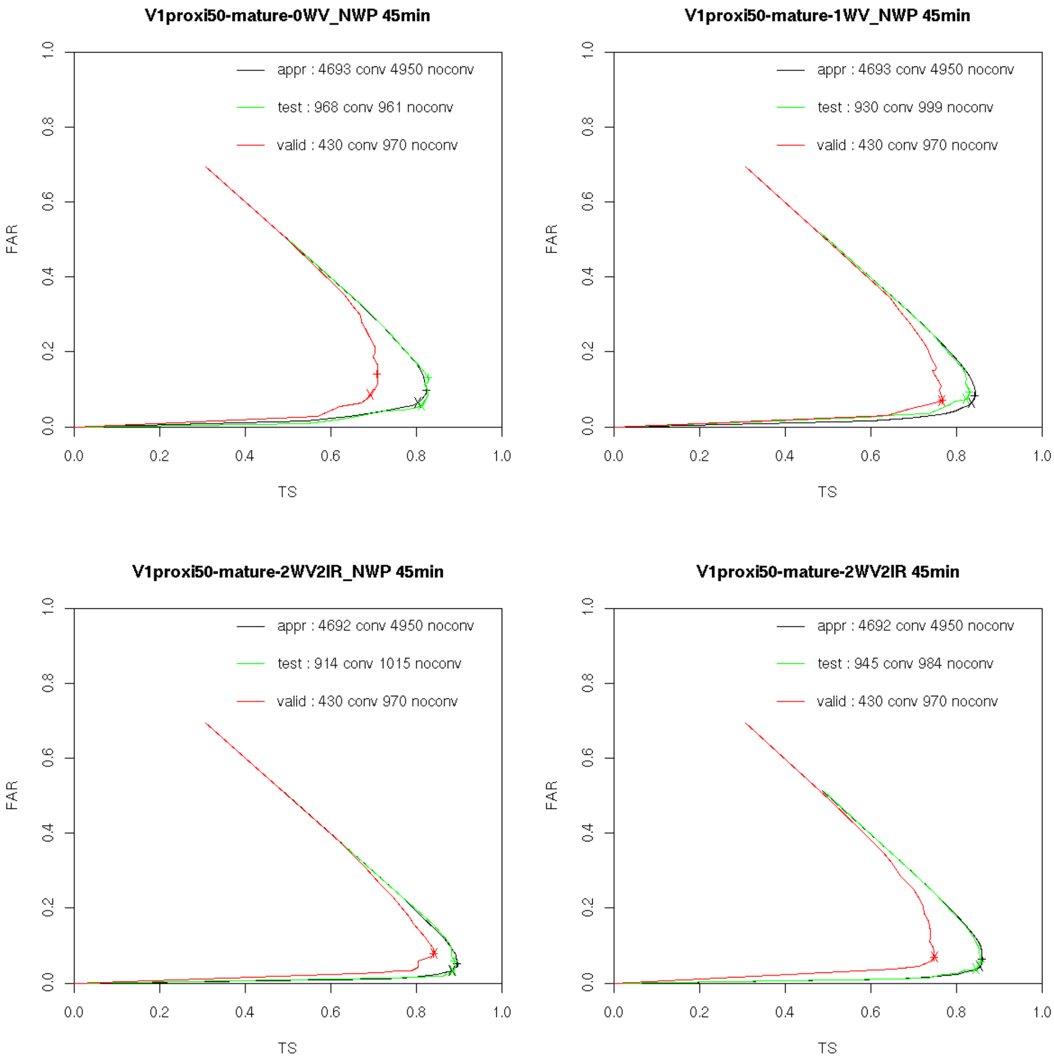


Figure 35: MSG v2011 tuning for mature category, 45 min depth, for 4 configurations: With NWP (top) with IR10.8 only (top left), IR10.8 and WV6.2 (top right), with 2 WV et 2 IR (bottom left) and with 2 WV et 2 IR without NWP (bottom right)

2. FDSS: MATURE TRANSITION (DTM), VARIOUS DEPTHS

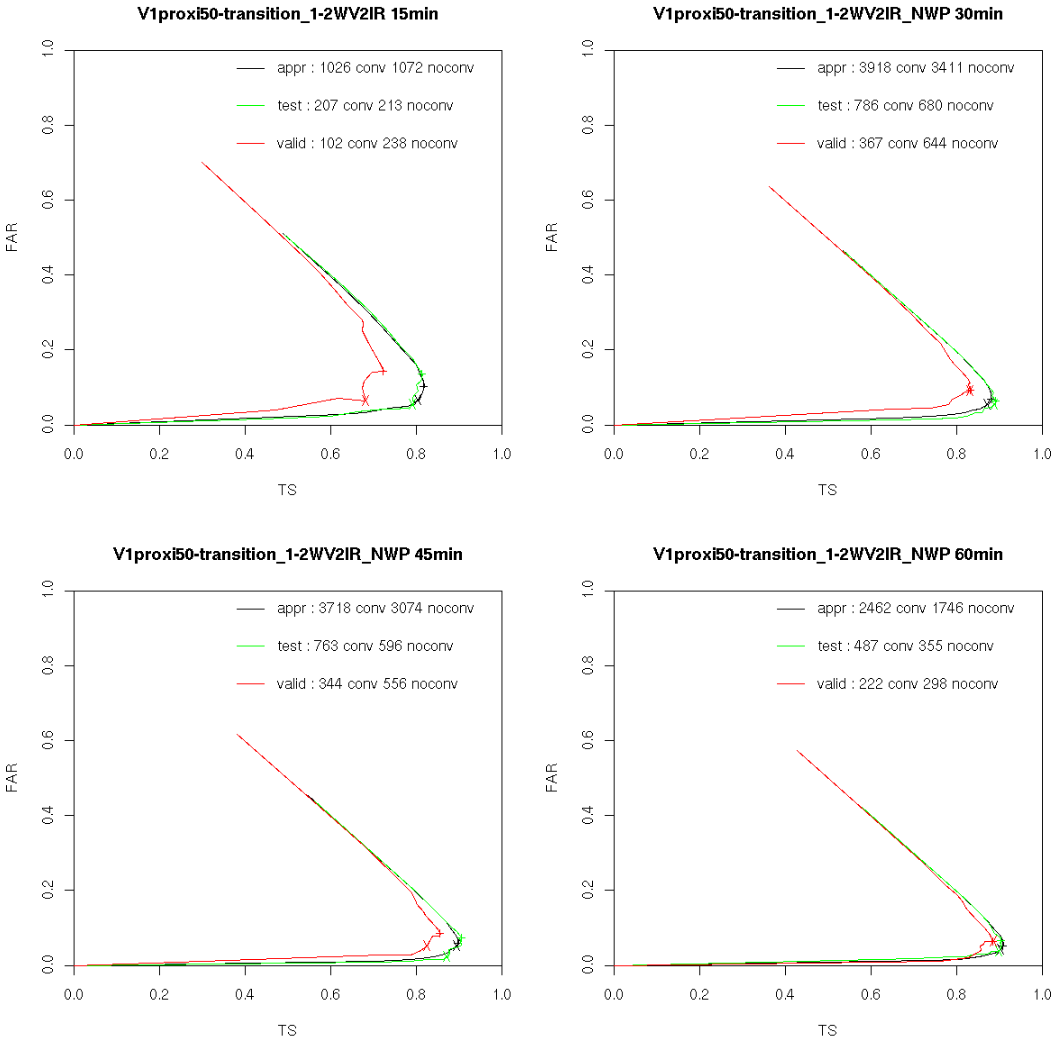


Figure 36: MSG v2011 tuning for transition mature category, full configuration, various depths

3. FDSS: FIXED 45 MIN DEPTH , VARIOUS CATEGORIES,

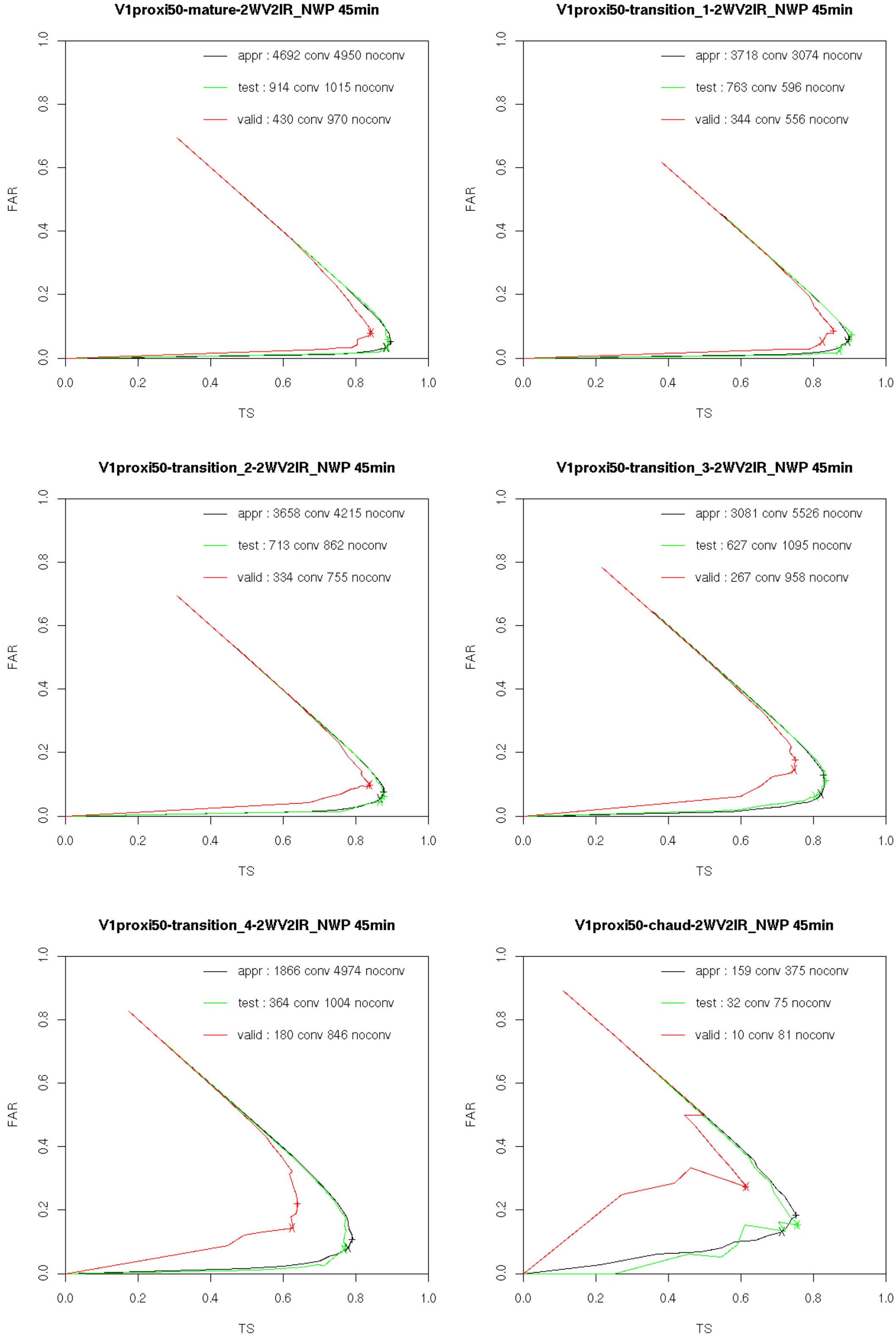


Figure 37: MSG v2011 tuning for various categories, full configuration, 45min depth

4. FDSS: VARIOUS CATEGORIES, VARIOUS DEPTHS

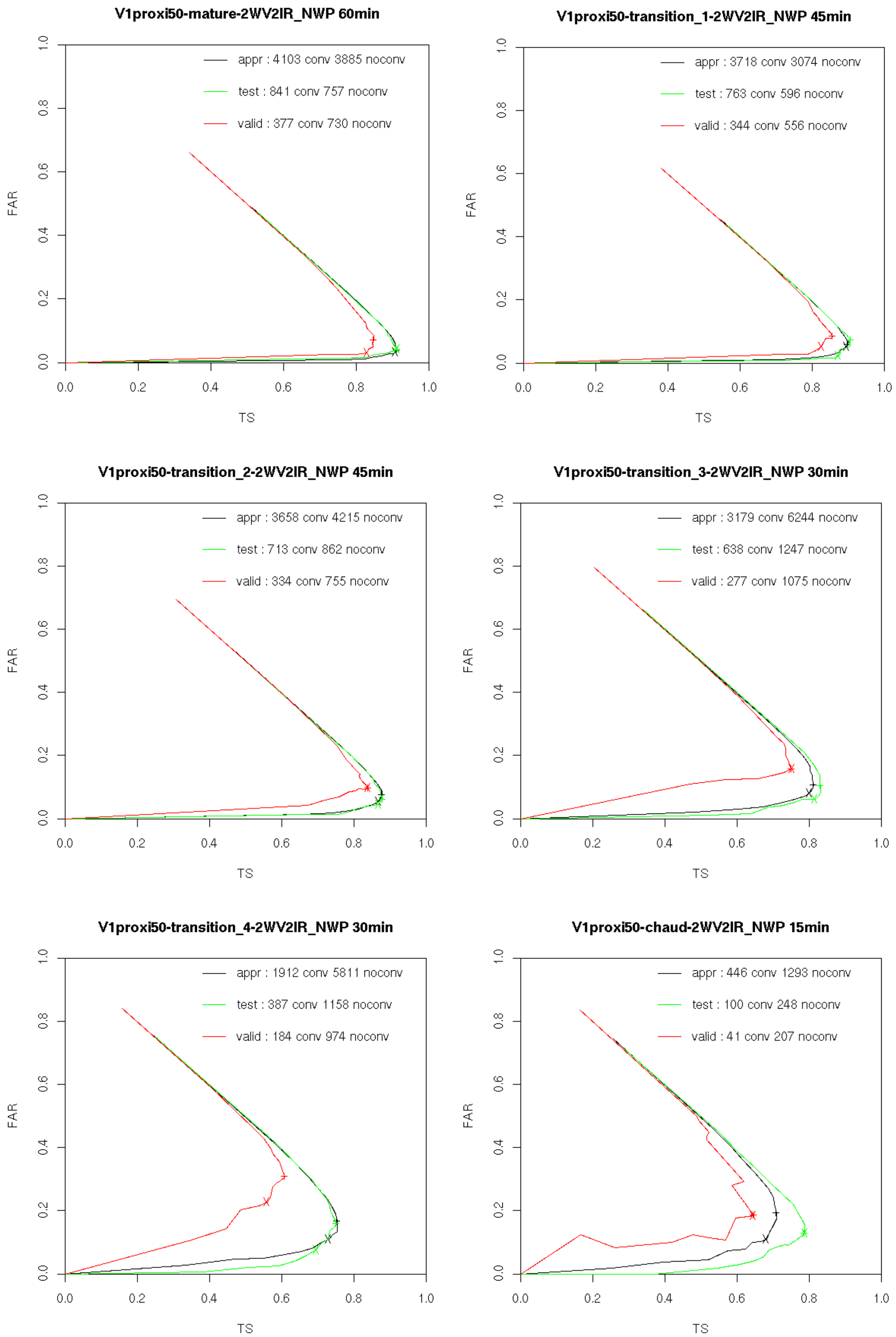


Figure 38: MSG v2011 tuning for various categories, full configuration, various depths

5. RSS: VARIOUS CATEGORIES, VARIOUS DEPTHS

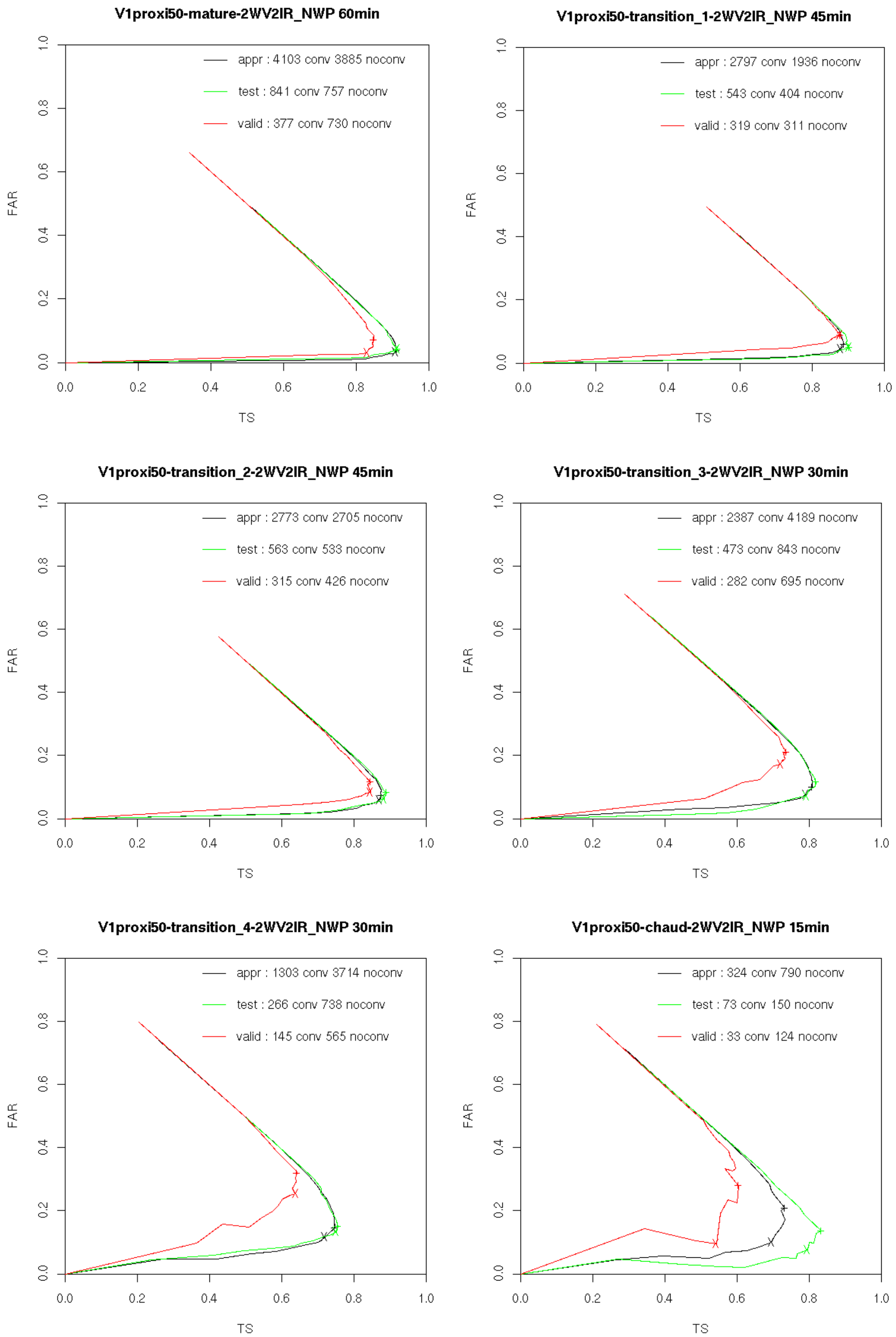


Figure 39: RSS v2011 tuning for various categories, full configuration, various depths