The EUMETSAT Network of Satellite Application Facilities

NWC SAF

Support to Nowcasting and Very Short Range Forecasting

Algorithm Theoretical Basis Document for "Rapid Development Thunderstorms" (RDT-PGE11 v3.0)

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REPORT SIGNATURE TABLE

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2.0	01/10/2008		Chapter 3 – Algorithm description Discrimination algorithm change
2.1	01/10/2009		Update of the discrimination skill (statistical models)
2.2	22 October 2010		Use of NWP data, tuning of discrimination scheme over longer period
2.3	*15 February 2012*		Additional input (convective rain rate from PGE05, cloud phase from PGE02). New optional version of BUFR output, with additional attributes Cloud Type, Cloud Phase information, maximum rain rate, additional cells description when second level is relevant, or previous cells description when a cell become significant if output limited to significant cells.
3.0	*15th July 2013*	73	Detection of overshooting tops. New optional version of BUFR output, with additional attributes describing possible overshoots

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1. INTRODUCTION

1.1 SCOPE OF THE DOCUMENT

The ATBD document provides the scientific description of the PGE11 algorithm. It points out assumptions done on algorithms and limitations of RDT products. Lastly, this document summarizes RDT validation result and describes RDT outputs.

1.2 SCOPE OF OTHER DOCUMENTS

The PUM (Product User Manual) provides all useful information to user (forecaster or research).

The VR (Validation report) depicts the accuracy of RDT to classify the convective cloud object. The discrimination skills are based on lightning occurrences.

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/3 (Interface Control Document n°3) describes the input and output data formats of the SAFNWC/MSG software.

1.3 SOFTWARE VERSION IDENTIFICATION

This document is compliant with version v*2013*.of the SAFNWC software package.

1.4 IMPROVEMENT FROM PREVIOUS VERSION

1.5 IMPROVEMENT FROM PREVIOUS VERSION

PGE11 v*2013* main change concerns overshooting top detection (OTD) :

- PGE11 processes a detection of overshooting tops of cloud systems. In a first step Brightness temperatures of IR10.8 and WV6.2 channels are used to select candidates. Then in a second step, candidates are confirmed through combined analysis of VIS0.6 information (when available), NWP tropopause temperature (when available), and BTD WV6.2-IR10.8.
- A new version of BUFR output is available, allowing description of overshooting tops of a cloud system:
  - Depending on cloud morphology, a list of one or more overshoots is described for each concerned cloud system, with additional attributes
  - On user's request, it is still possible to limit the output to "significant" cells (convective, electric, high rain rates). Cloud cells associated with one or several overshoots are also diagnosed "significant".

    We remind that in that case, historical information is added for newly significant cells only, through the encoding of cells at previous slots.

  If PGE11 is run with initial default BUFR version 1, overshooting top information will be available in trajectory output only.

- Minor additional improvements or modifications

  The diagnostic of life-phases of the system is slightly improved (in very few cases), taking into account mainly temperature category, but also cooling/warming, expansion and activity of the cloud system (convective, electric …).

  The method to calculate the speed estimate has been modified, using weighted gravity centres of the cloud cell to estimate the displacement between two images. This approach tends to lower the impact of temperature threshold changes of a cloud cell from one image to the next one, and takes more into account the vertical morphology of the cell

- PGE11 execution log includes specific "Monitoring" lines summarizing configuration and output of the processing. The goal is to help users that would monitor the PGE execution.

1.6 Glossary, Acronyms and Abbreviations

1.6.1 Glossary

Cell	PGE11 "object" representation of a Cloud system in a satellite image
Convective mask	Identification of stable/ neutral/unstable/ areas from NWP data. Used by PGE11 to ignore stable areas
Detection	PGE11 algorithm that identifies cloud cells in IR10.8 image
Detection Mask	Mask derived from EUCLID data detection in order to define validation area and ignore trajectories out of these area
Discrimination	PGE11 diagnosis process to distinguish convective systems from the others
Flash proximity	Distance to nearest electric flash for non convective systems
Overshooting Top	Budding of a convective system rising above tropopause level, generally associated to a strong updraft activity
Precocity	Capacity of PGE11 to diagnose the convection before the first flash appears
Section	Period of a cloud cell trajectory defined from the lightning activity.
Time step	Elementary time-element of a given satellite image (15 minutes for FDSS).
Tracking	PGE11 process that associates cloud cells in two successive images
Trajectory	Ensemble of temporal-linked cloud cells representing the whole life cycle of a given cloud system

1.6.2 Acronyms and Abbreviations

BTD	Brightness Temperature Difference
BUFR	Binary Universal Form for the Representation for Meteorological data
CDOP	Continuous Development and Operation Phase
CMa	Cloud Mask (also PGE01)
ECMWF	European Centre for Medium-Range Weather Forecasts
EUCLID	European Cooperation for LIghtning Detection
EUMETSAT	European Meteorological Satellite Agency
FAR	False alarm rate
GOES	Geostationary Operational Environmental Satellite
GOES	Geostationary Operational Environmental Satellite
ICD	Interface Control Document
INM	Instituto Nacional de Meteorología

IOP Initial Operation Phase
MSG Meteosat Second Generation
MTR Mid Term Review
NMS National Meteorological Service
OT(D) Overshooting Top (Detection)
PGE Product Generation Element
POD Percentage of detection
POFD Percentage of false detection
RDT Rapid Development Thunderstorms
SAF Satellite Application Facility
SAF NWC SAF to support NoWCasting and VSRF
SEVIRI Spinning Enhanced Visible and InfraRed Imagery
TS Threat score

1.7 REFERENCES

1.7.1 Applicable documents

Reference	Title	Code	Vers
[AD.1.]	Product User Manual	SAF/NWC/CDOP/MFT/SCI/PUM/11	2011
[AD.2.]	Validation report	SAF/NWC/CDOP/MFT/SCI/VR/11	2011
[AD.3.]	Interface Control document for the External and Internal Interfaces	SAF/NWC/CDOP/INM/SW/ICD/1	2011
[AD.4.]	Interface Control Document for the input and output data formats	SAF/NWC/CDOP/INM/SW/ICD/3	2011
[AD.5.]	Software User Manual for the SAFNWC/MSG Application, Software Part	SAF/NWC/CDOP/INM/SW/SUM/2	2011

1.7.2 Reference documents

Reference	Title	Code	Vers
[RD 1]	Ruiz Gazen, A. Villa, N., (June 2007), RDT discrimination refining, intermediate report	Visiting scientist activities of the SAF NWC – http://nwcsaf.inm.es/VSA.html	2007
[RD 2]	Ruiz Gazen, A. Villa, N., (June 2008), RDT discrimination refining, final report	Visiting scientist activities of the SAF NWC – http://nwcsaf.inm.es/VSA.html	2008

1.8 Goal of the RDT product

The RDT, Rapid Development Thunderstorm, product has been developed by Meteo-France in the framework of the EUMETSAT SAF in support to Nowcasting. Using mainly geostationnary 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 numerical data stored in a BUFR format file. The objectives of RDT are twofold:

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

The object-oriented approach underlying the RDT product allows to add value to the satellite image by characterizing convective, spatially consistent, entities through various parameters of interest to the forecaster: 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 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/.

2. ALGORITHM OVERVIEW

2.1 Outline of the algorithm

The RDT algorithm could be divided into three parts:

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

2.1.1 The detection of cloud systems

The detection algorithm allows to define "cells" which represent the cloud systems. In the RDT 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.

The main idea is to adapt the threshold use to the topography of the cloud tops:

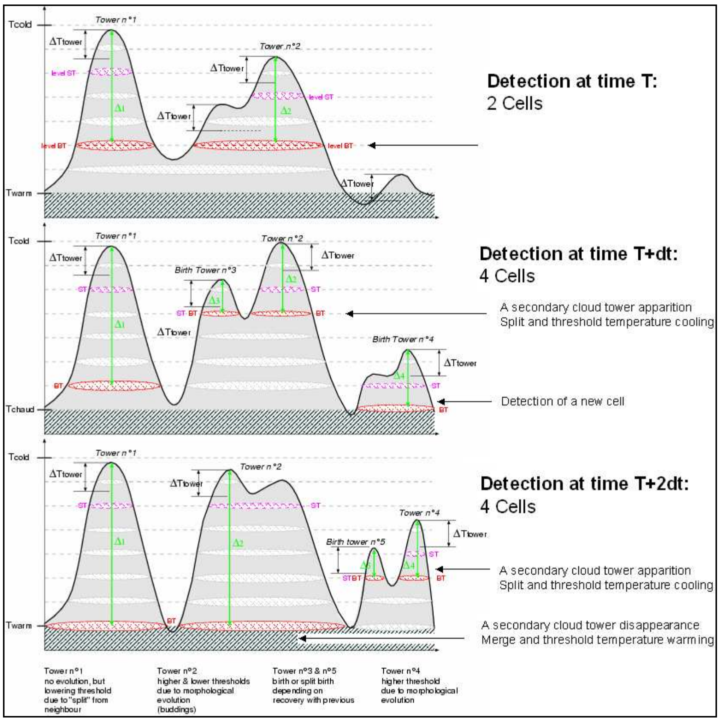


Figure 1: RDT cell definition

- 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)

Hence, the threshold use 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 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 (adaptative threshold) is to focus on convective parts of cloud systems, in order 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 60 squared kilometers (more or less 5 pixels with IR resolution over Europe) the minimum area of an object in order to improve quality of discriminating parameters processed. The minimum size of an object is defined into configuration file. On the other hand, a limitation to 200000 squared kilometers of the systems is enough to meet the objectives of RDT, and allow to avoid tracking huge non convective cloud systems.

2.1.2 The tracking of cloud systems

The adaptative threshold use makes complex the cell comparability due to various phenomena depicted. This method induces numerous merge and split 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 (formerly analyzed) move and speed. 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 adaptative 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 link allows to compute move, speed and trend of all cloud objects. The time series of cloud's characteristics (peripheral gradient, volume, cooling rate...) are key input for the discrimination algorithm.

2.1.3 The discrimination of convective objects

As it was mentioned previously, the RDT 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 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 software.

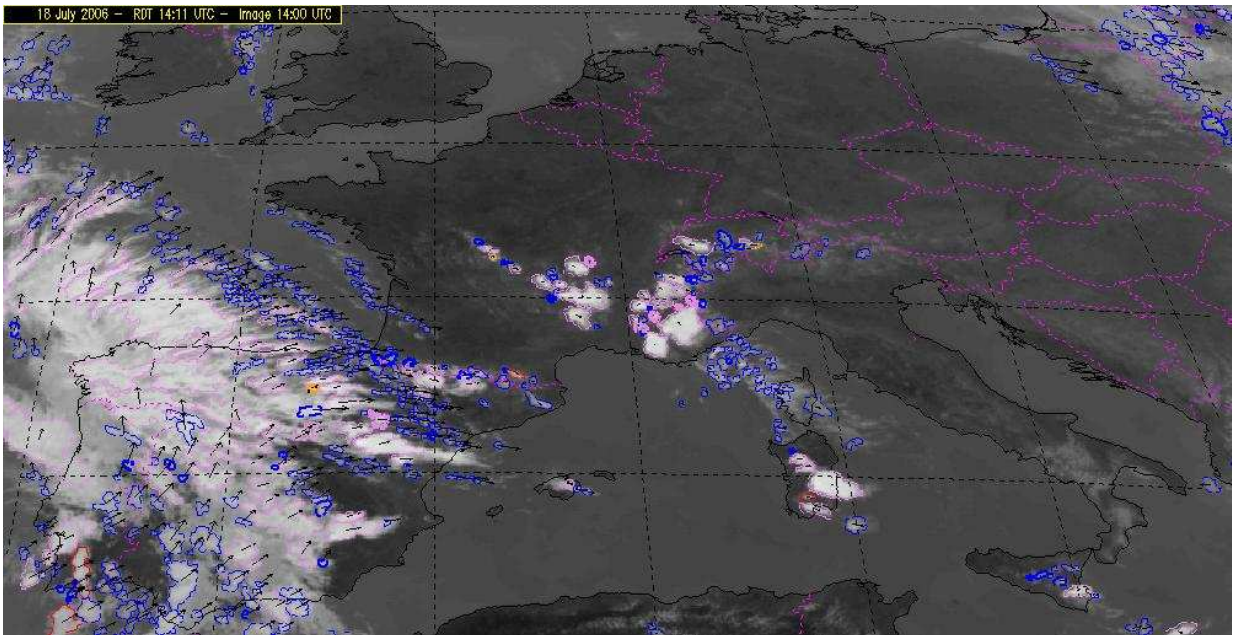


Figure 2: RDT objects before convective discrimination

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

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

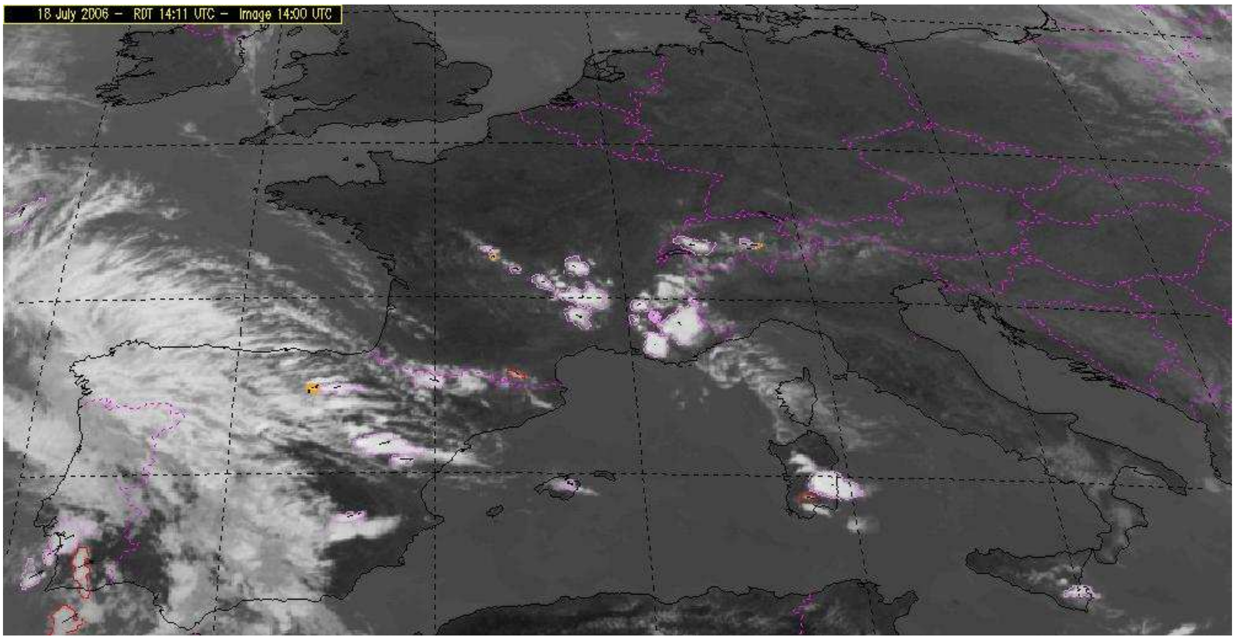


Figure 3: RDT objects after convective discrimination

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...)
- temporal characteristics (rate, extremes on various past period)

The discrimination scheme is a mix between empirical rules and statistical models tuned on a learning database.

The current learning data base is made over widened France. The ground truth used for building the data base is cloud to ground lightning occurrence.

Since v2011 release, PGE11 may use NWP data as a guidance for discrimination purpose.

3. ALGORITHM DESCRIPTION

3.1 THEORETICAL DESCRIPTION

3.1.1 Physics of the Problem

The thunderstorm detection by PGE11 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 data bases are then built on the most significant parts of the trajectories of the cloud systems, for a pre-conditional tuning.

3.1.2 Description of the Algorithm

3.1.2.1 The detection of cloud systems

3.1.2.1.1 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,…) 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 detection method is based upon an adaptative 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 Cells point out the bottom of cloud towers included inside cloud system. The temperature threshold used to define the bottom of an RDT object is the warmest one which allows to distinguish it from others nearby temperature extremes. As described in Figure 4, only strong enough temperature extremes are taken into account.

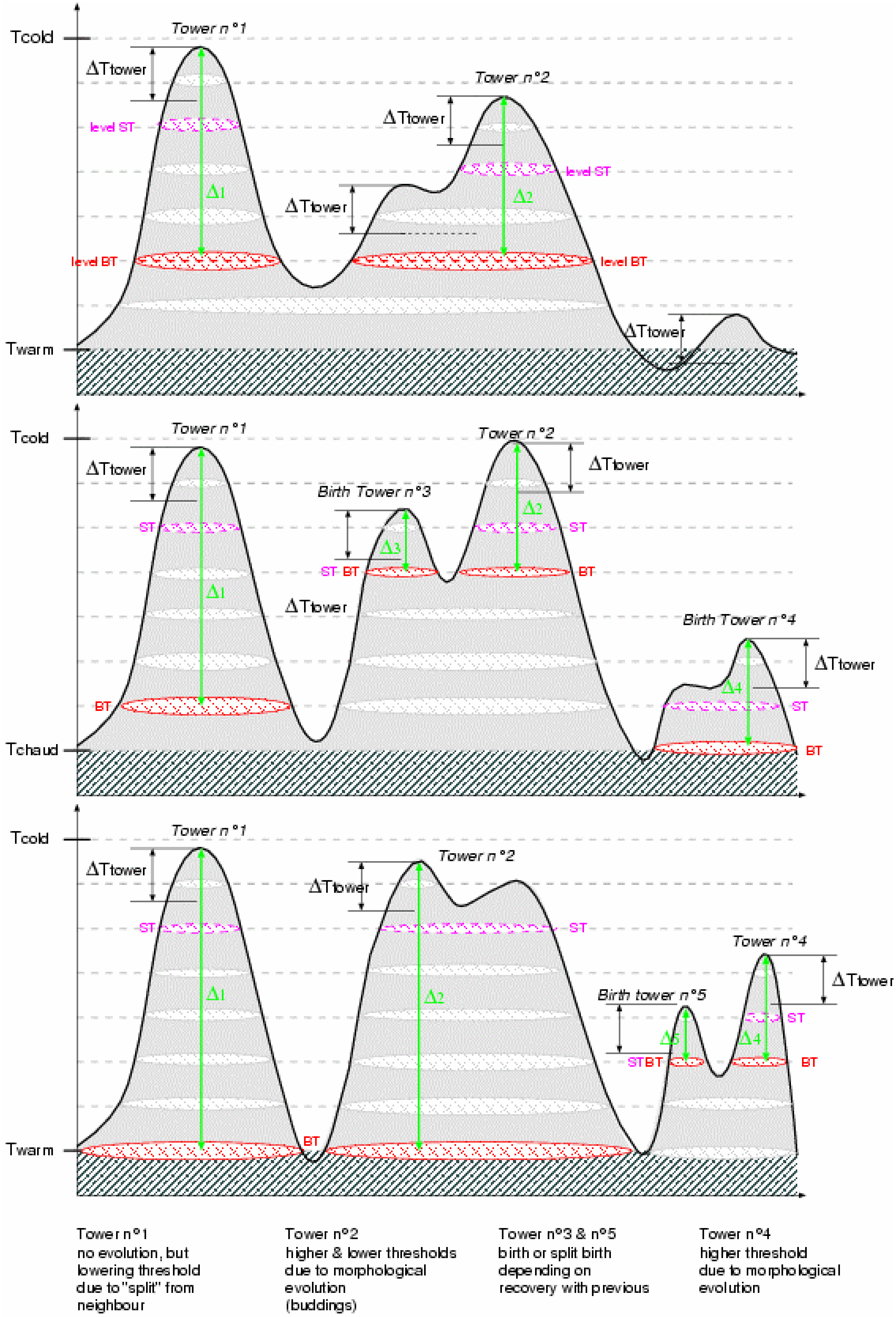
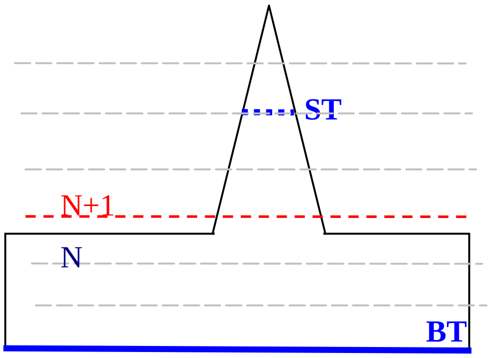


Figure 4: Diagram illustrating the principle of the detection algorithm

3.1.2.1.2 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 the vertical morphology of the cloud presents particular shapes, with cloud systems defined by only one tower
- when 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 5).

Figure 5: Single tower from cloud layer. Bottom (BT) and Top (ST) level of Tower are represented

Figure 6 plots the maximum surface ratio between two successive temperature levels (max S_{n+1}/S_n, horizontal axis) against surface ratio between bottom and top levels (S_{ST}/S_{BT}, vertical axis), for convective and non-convective populations.
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.

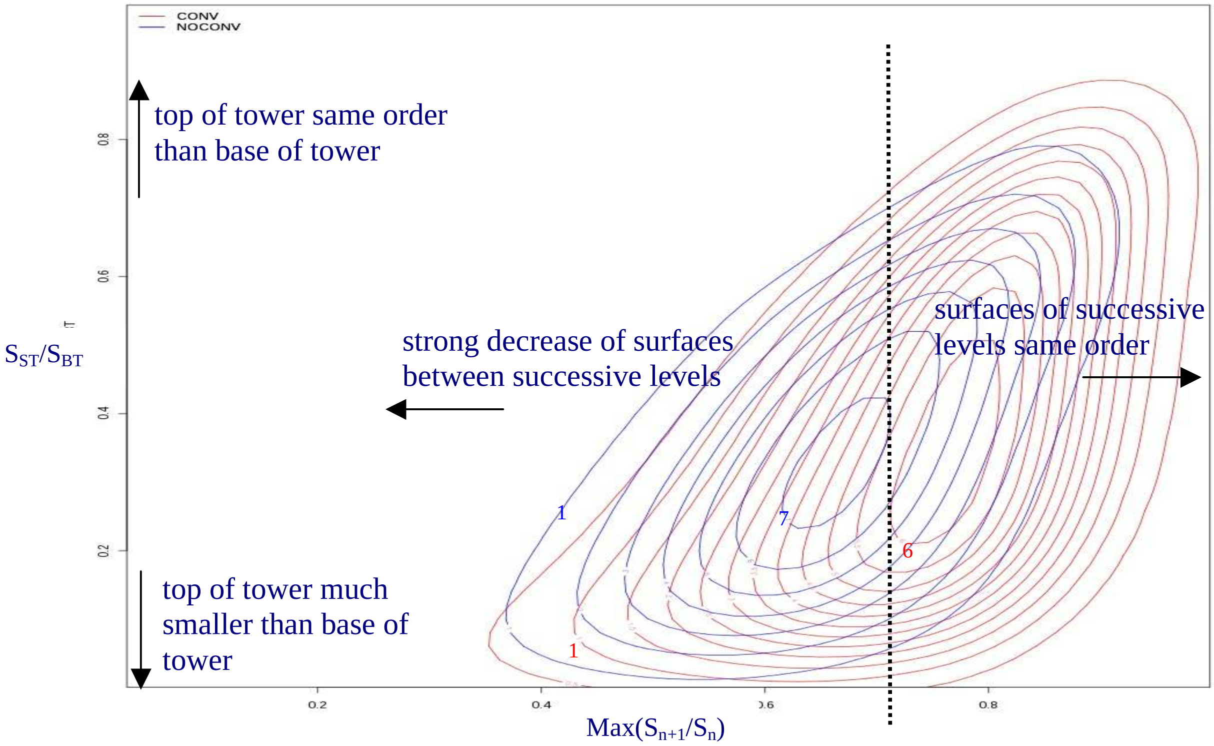
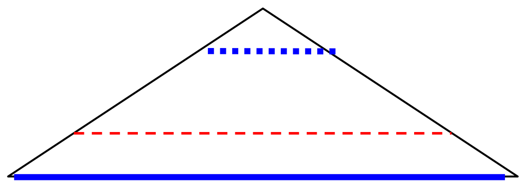


Figure 6: density contour plot. Arbitrary relative units. X-axis=Maximum of the surface ratio between 2 levels. Y-Axis= top/bottom surface ratio. Red=convective population. Blue=non convective population. One year database



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 7: 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 8 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 $\mathbf{S_{BT} < 4*S_{ST}}$

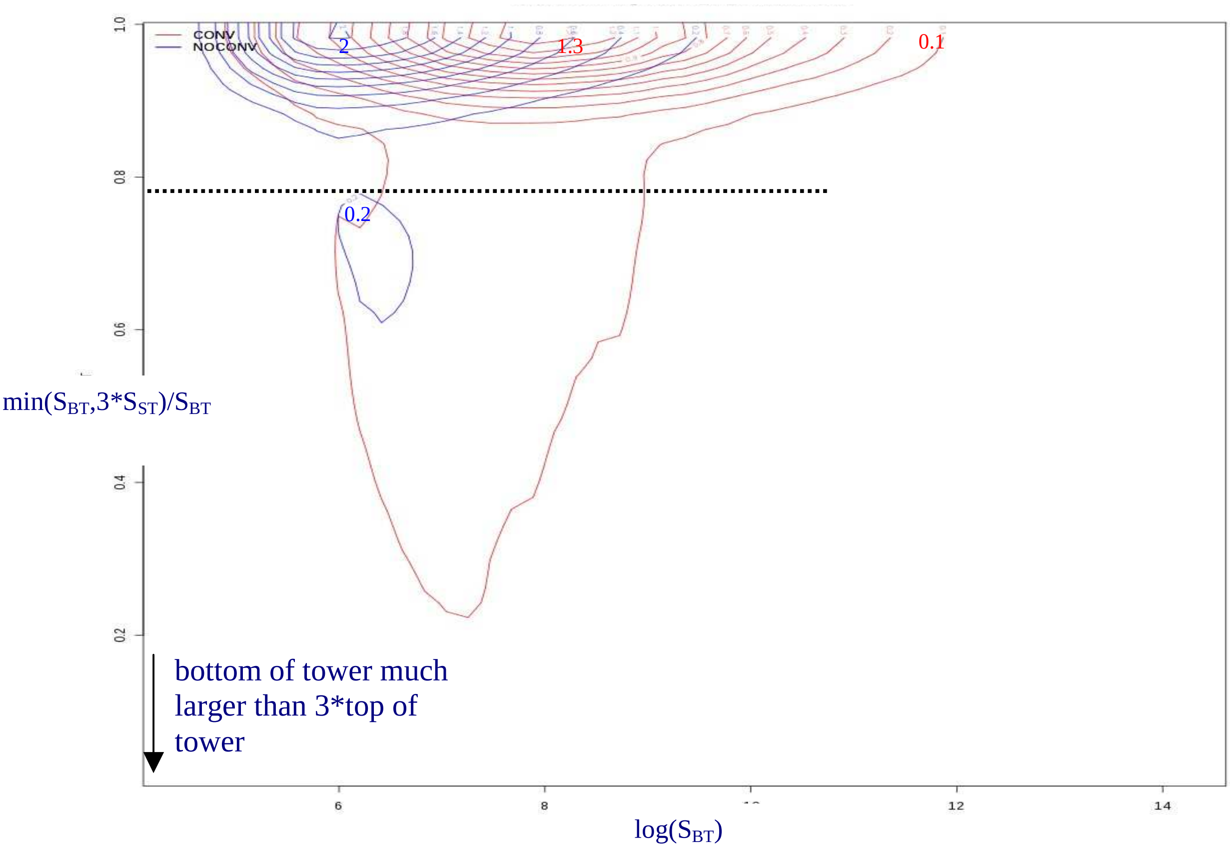


*Figure 8: Contour Density Plot. Arbitrary relative units. X-axis=log(S_{BT}) Y-axis= min(S_{BT},3*S_{ST})/S_{BT} . Red=convective population. Blue=non convective population. One year database*

Both modifications have been implemented in the algorithm, leading to

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

3.1.2.2 The tracking of cloud systems

Once the detection of cloud systems is performed, the tracking module of the RDT software is applied on the detected "cells" and allows to build 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. It also handles splits and merges of cloud systems.

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 tracking algorithm takes into account an estimated velocity of "cells" to compute the overlapping between "cells".

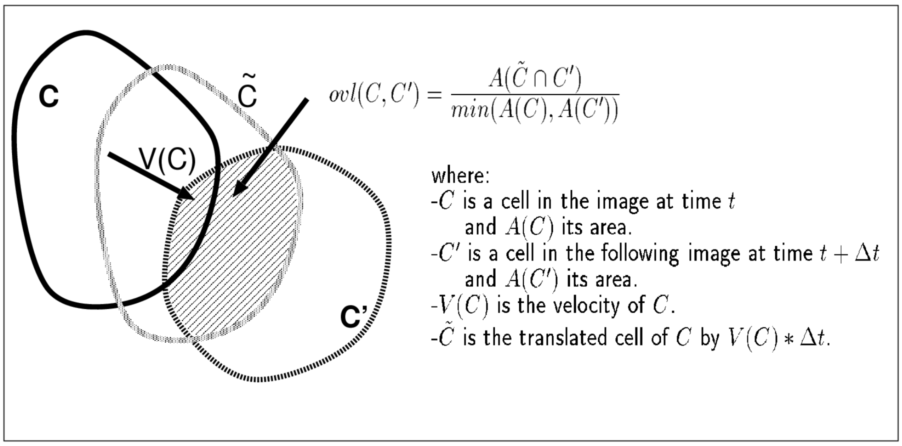


Figure 9: Definition of the overlapping between two cells

Briefly, 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 made as follows:

1. 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).
2. If no overlapping is found, then the velocity of the cloud system C' is evaluated from cross-correlation technique.
3. 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).
4. 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).
5. If no overlapping is found then cloud system C' is identified as the beginning of a new trajectory.

Figure 11 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 $t+\Delta t$.

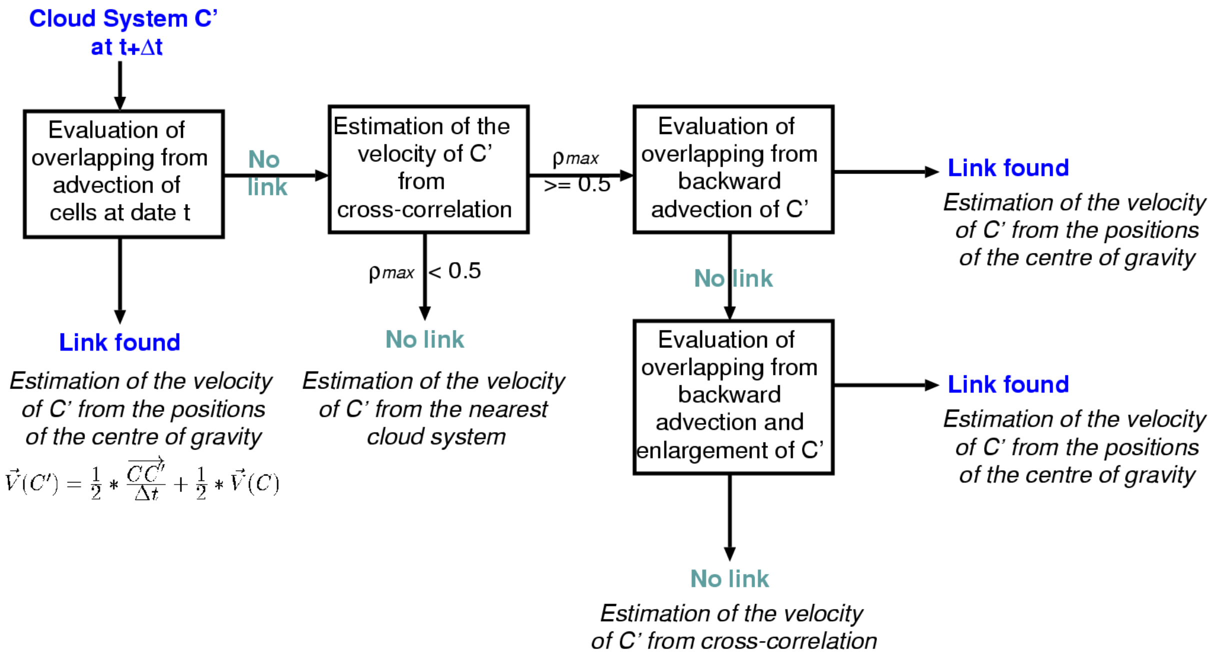


Figure 10: Main steps of the tracking algorithm

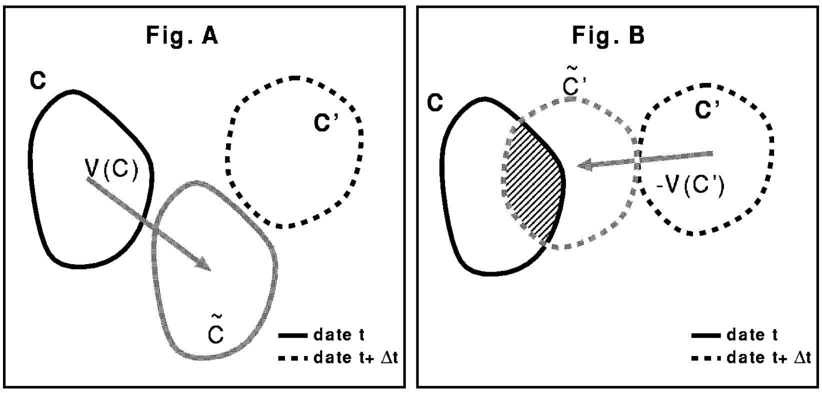


Figure 11: Principle of the tracking algorithm (steps 2 and 3)

In Figure 11 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 tracking algorithm, the following analysis is done:

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

- Figure 11 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 12) 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.

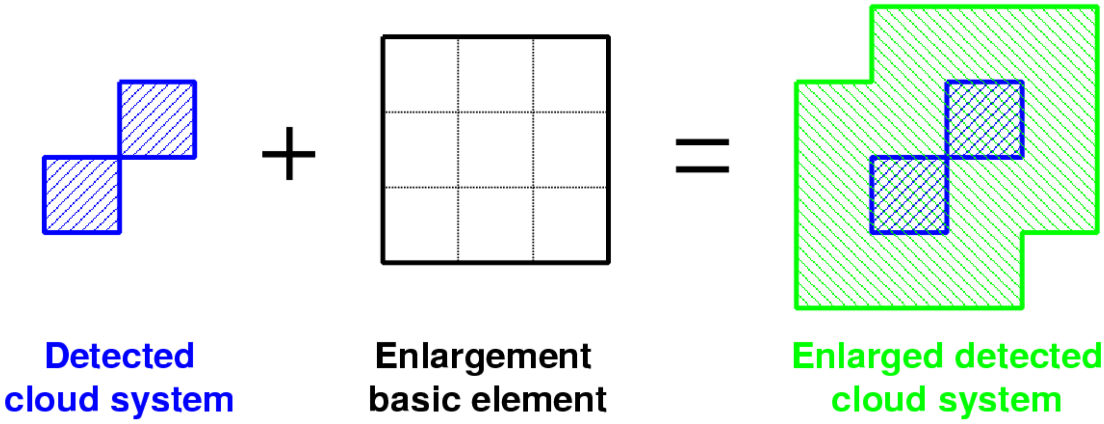


Figure 12: Principle of the enlargement of cloud systems (step 4)

3.1.2.2.1 Speed estimation from 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.

Previous chapter 3.1.2.1 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,.

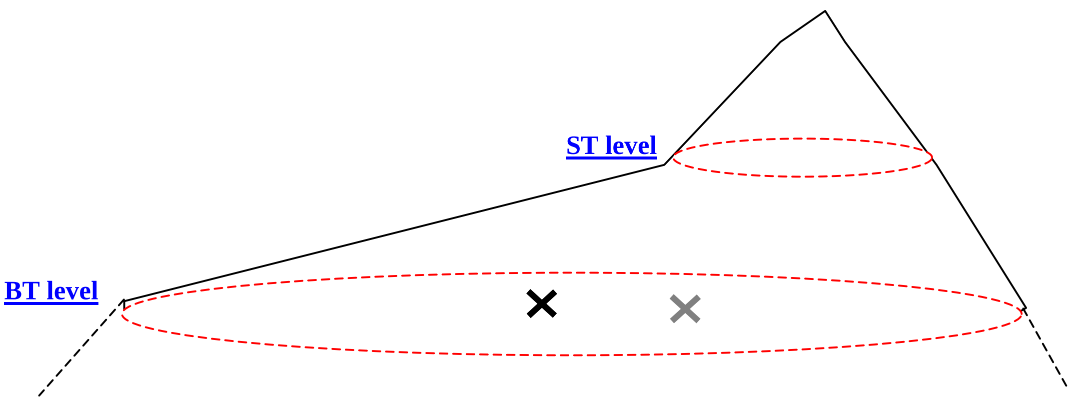


Figure 13: Positions of geometric and weighted gravity centres for a particular shape of cloud system

From v*2013*, PGE11 will base its moving estimation by default from 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.

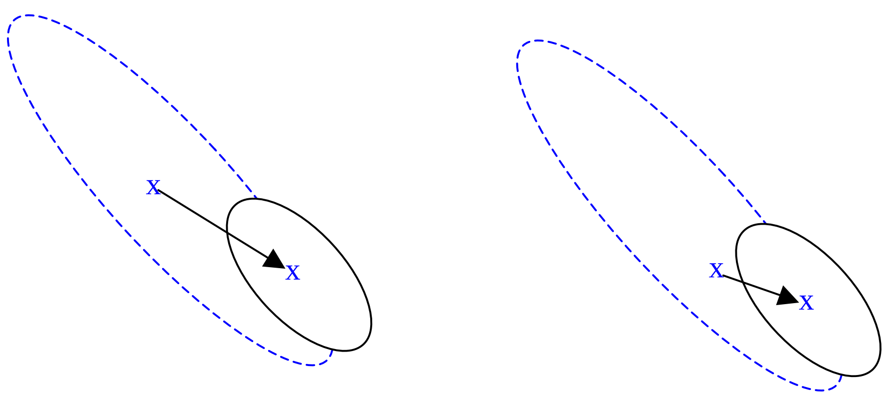


Figure 14: Synthetic example of speed estimation from geometric gravity centres (left) and weighted gravity centres (right).Previous cell dashed blue, current cell plain dark.

3.1.2.3 The discrimination scheme

3.1.2.3.1 Main principles

The methodology and the statistical model choice have been defined with the support of Statistical Laboratory of Toulouse ([RD 1], [RD 2])

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 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.

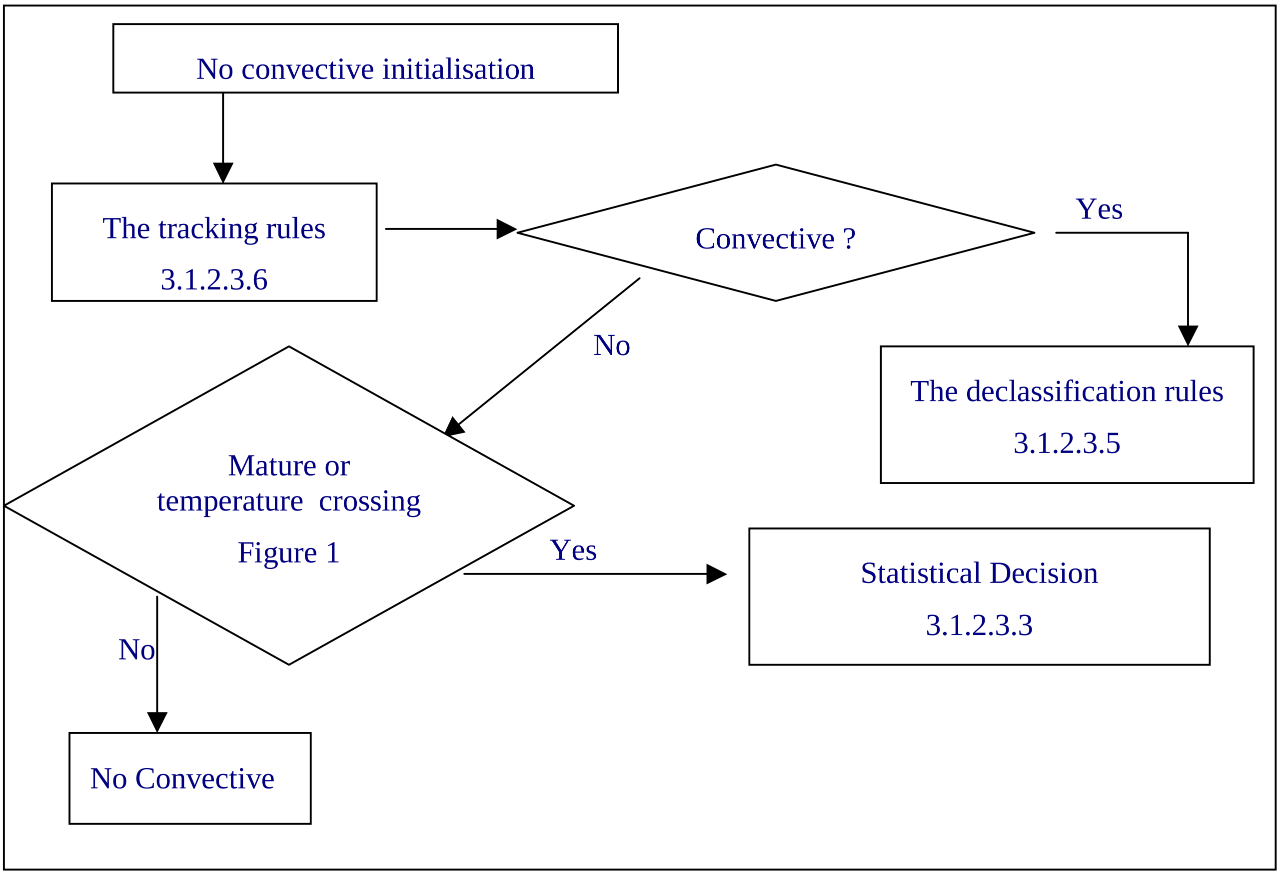


Figure 15: The discrimination schedule

3.1.2.3.2 NWP convective mask

PGE11 takes benefit from a NWP guidance before attempting a diagnostic.

NWP data are used to produce a convective mask through 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, PGE11 discrimination scheme focuses on convective regions, and avoid eventual false alarms, especially in winter or intermediate seasons.

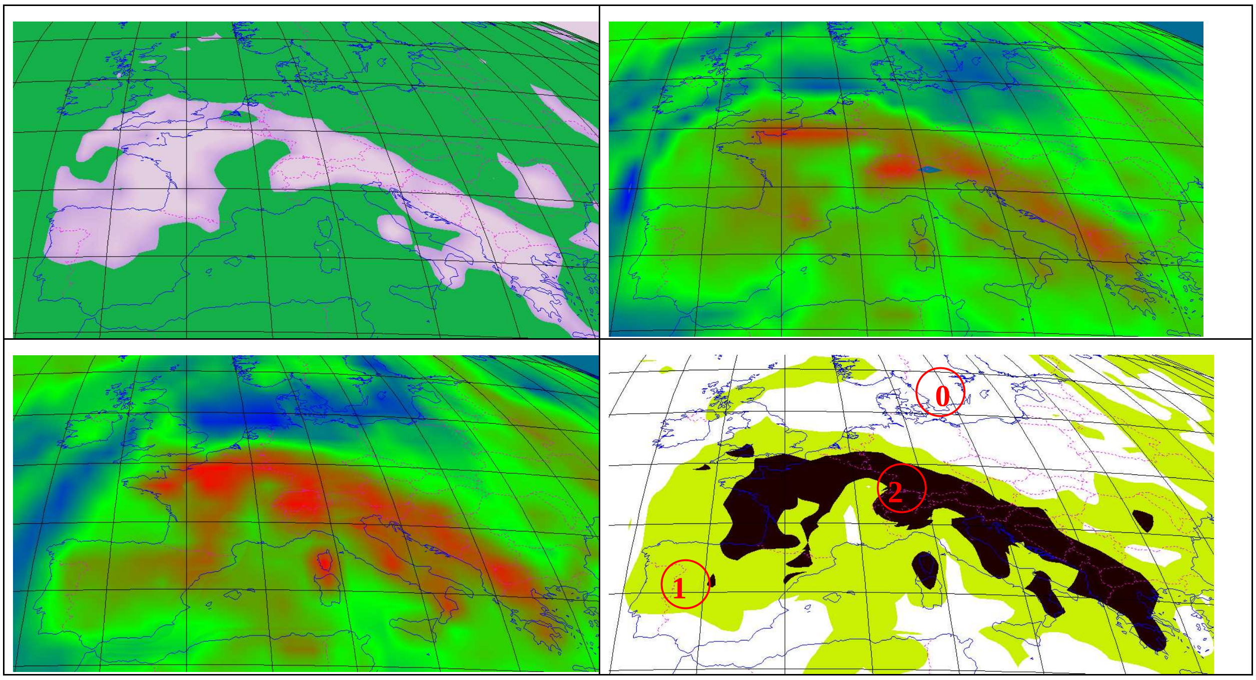


Figure 16: 25 May 2009, 12h15. Convective mask(bottom right), as a union of K index (top left), Showalter index (top right) and Lifted index (bottom left), from NWP data. Regions 1 and 2 are region of interest for PGE11 discrimination

Moreover, this approach has been applied during the tuning of PGE11 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.

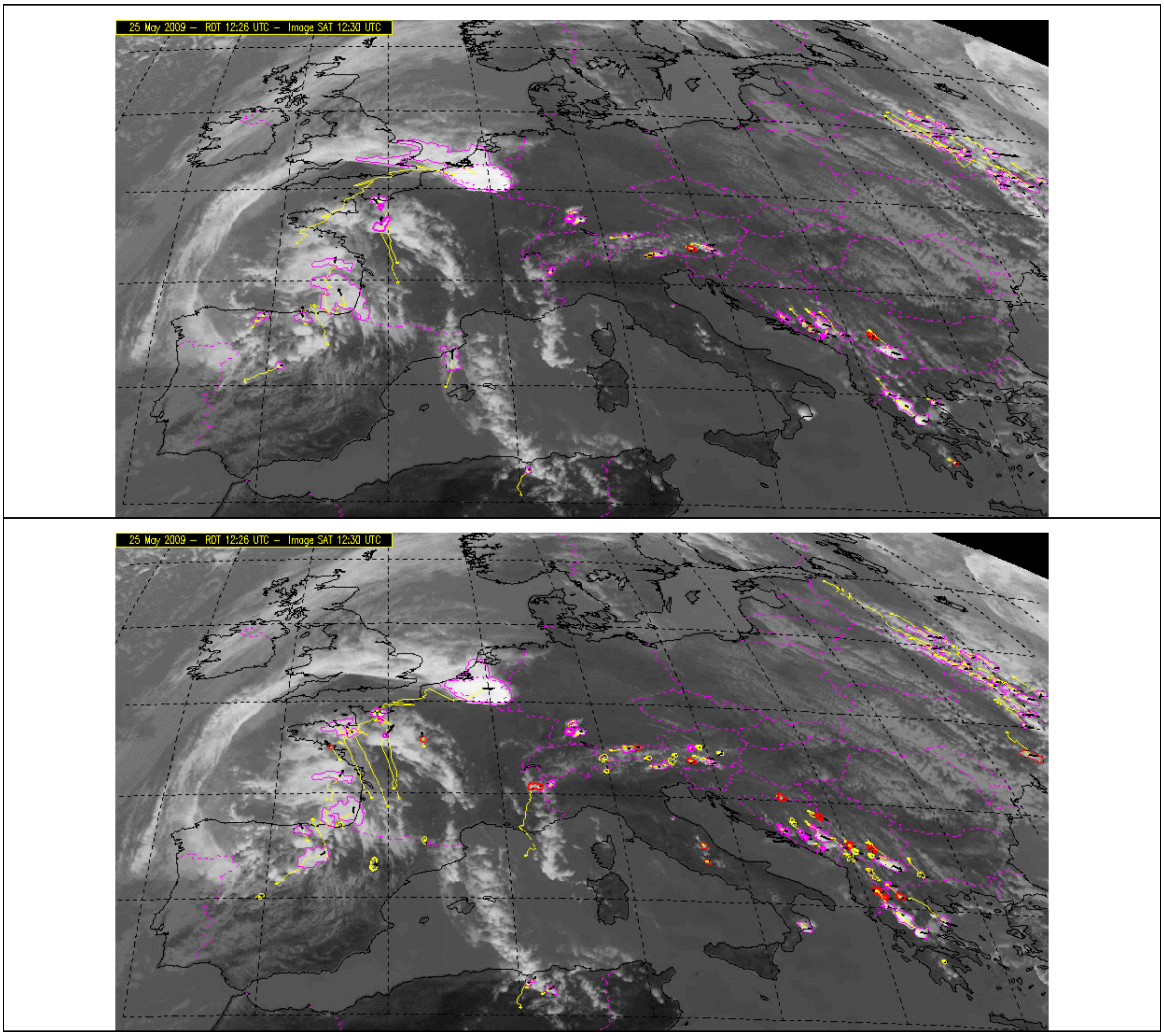


Figure 17 : 25 May 2009, 12h30 UTC. PGE11 without NWP tuning (top) and with NWP tuning (bottom). NWP obviously brings benefit to the tuning in warmer categories, with higher precocity (cells over Italy diagnosed 30 min previously)

3.1.2.3.3 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 PGE11 configurations.

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. The list of discriminating parameters is provided in annex.

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-12)
- IR10.8µm + NWP data (designed for METEOSAT-7)
- IR10.8µm, IR8.7µm, IR12µm, WV6.2µm, WV7.3µm
- IR10.8µm, WV6.2µm (designed for GOES-12)
- 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, PGE11 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

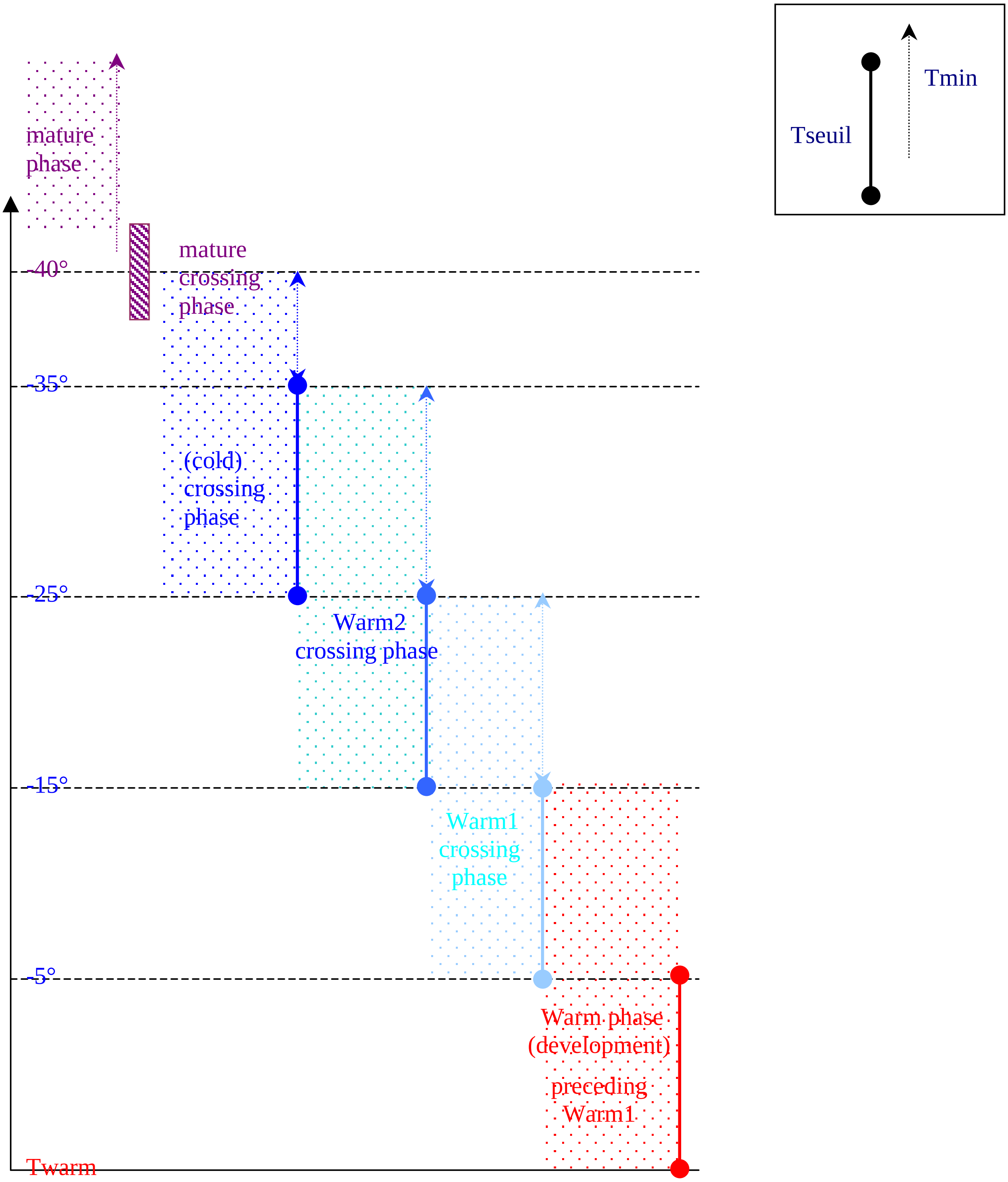


Figure 18: Vertical view : Categories of discrimination scheme and corresponding discrimination models

During the discrimination tuning for transition categories, 60min 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.

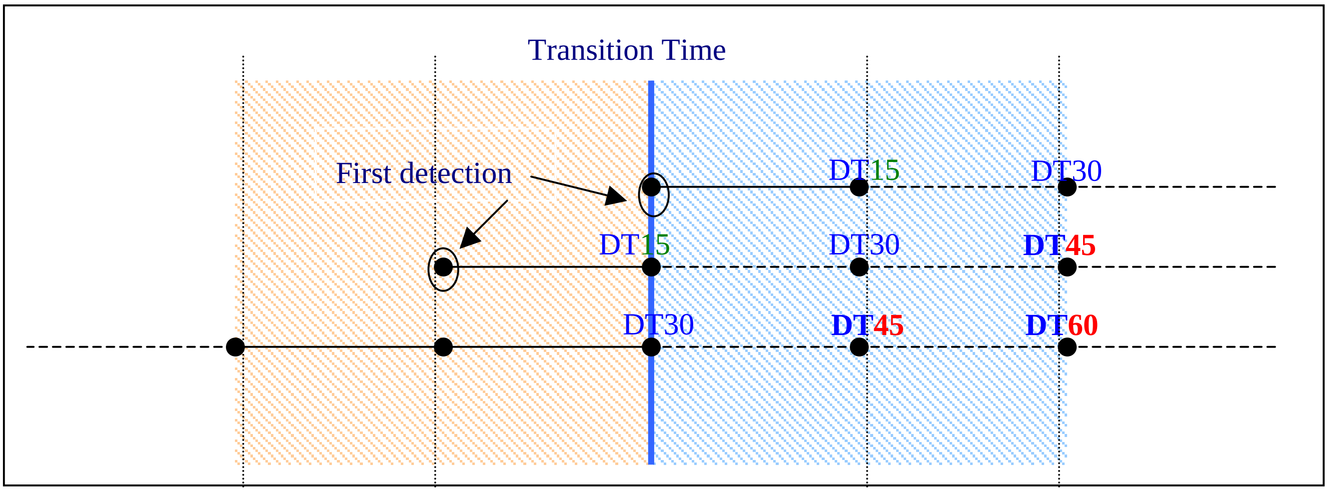


Figure 19: Temporal view : Transition model applicability depending on available historic. 3 cases depending on time of first detection. Transition time may be Tmin or Tseuil crossing their respective thresholds.

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.

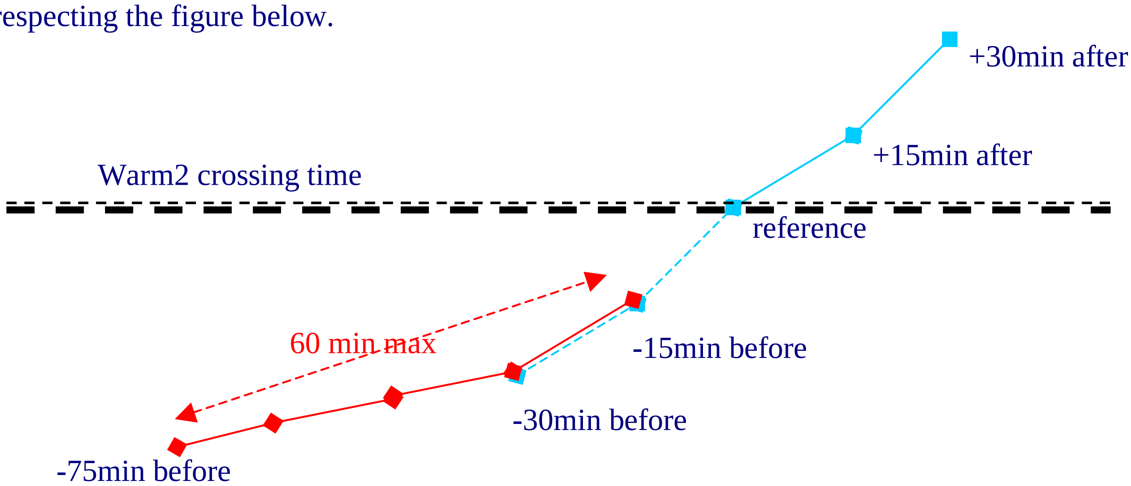


Figure 20: Spatial and temporal view for Warm category.

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 [RD 1]) to be incorporate into the discrimination scheme. The best results were obtained with random forest method (with 600 tress) 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.

3.1.2.3.4 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.

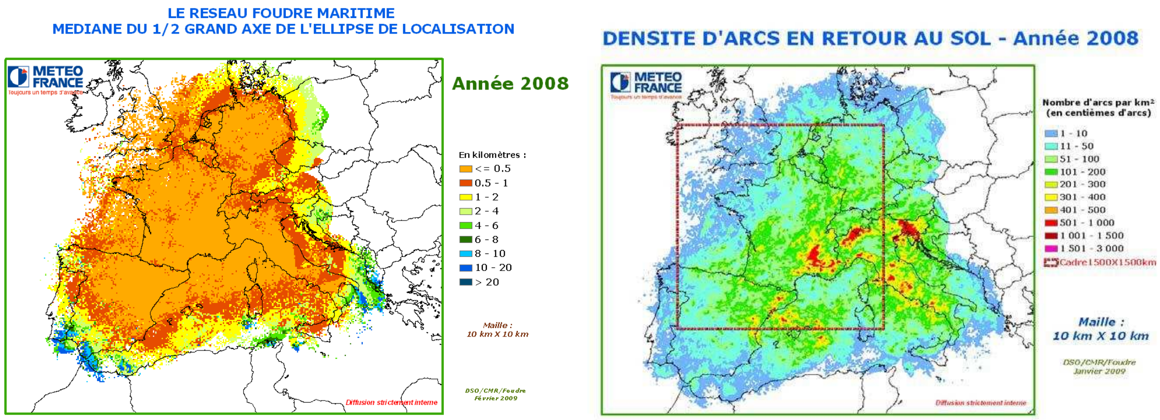


Figure 21: Extension and quality (precision left, density right) of Meteorage+partners network.Meteorage network coverage appears in red on right image

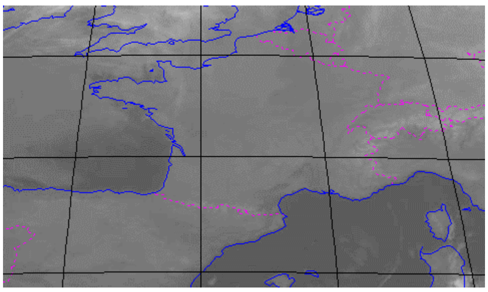


Figure 22:Domain used for RDT v2011 discrimination tuning

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

1. 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.
2. 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).
3. 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.
4. 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

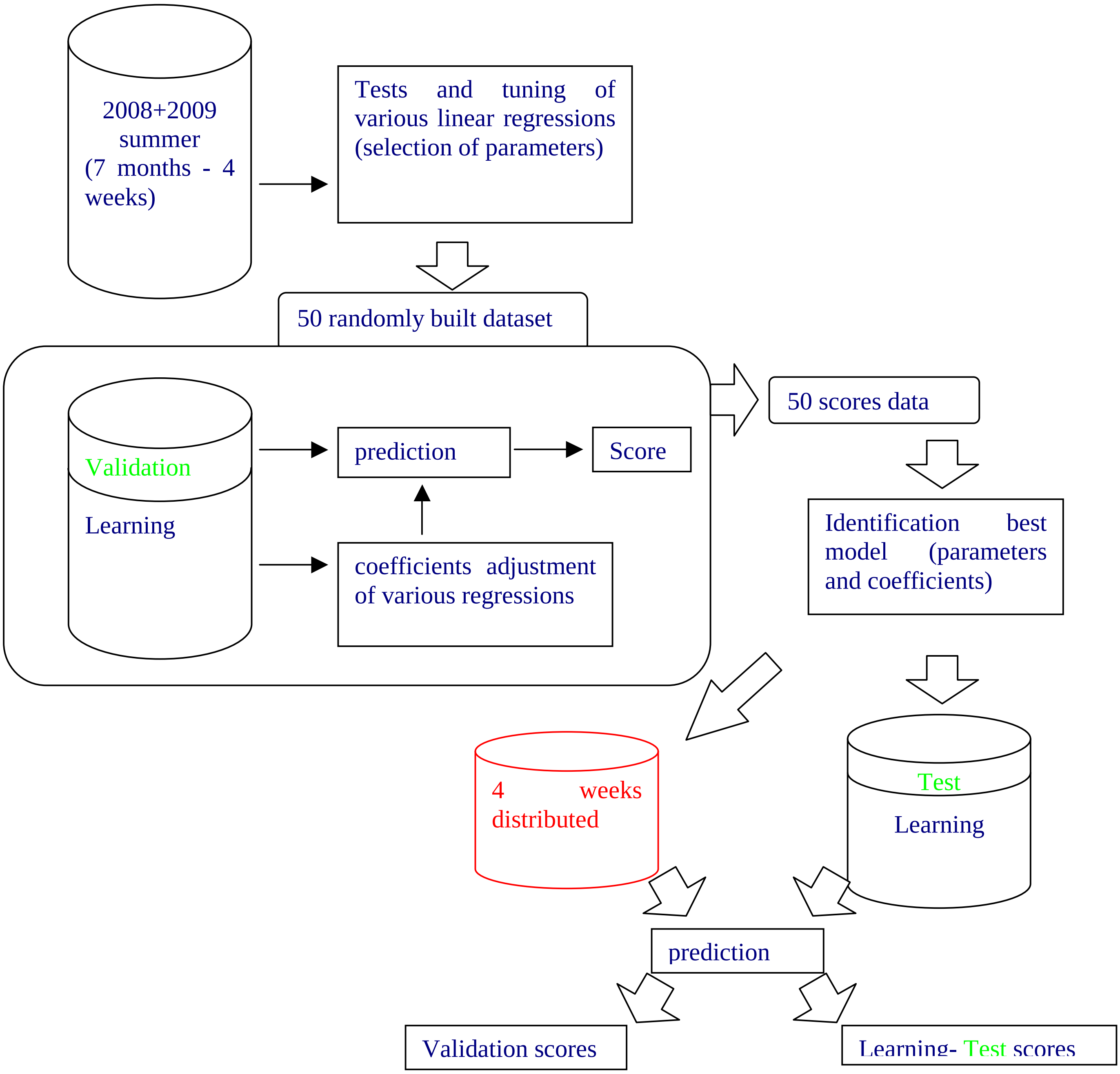


Figure 23: Discrimination tuning methodology.

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 rate (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 a strict comparison of scores and graph with previous PGE11 releases is difficult for several reasons:

- ⇨ The constitution of database is quite different, with now a NWP convective mask as a first filter of clouds
- ⇨ The methodology is also quite different, with a cross-validation process and a different manner to consider learning dataset, test dataset and validation dataset. Validation dataset in particular is quite restricted in comparison with learning one.
- ⇨ The period of tuning is much larger, consequently the tuning is more reliable
- ⇨ The ground truth is slightly different taking flashes proximity into account to define non convective population
- ⇨ The area of tuning is a little bit wider

The comparison with previous version has been undertaken on a subjective basis, using case studies and analyzing real time situations, for a larger domain than the tuning-domain.

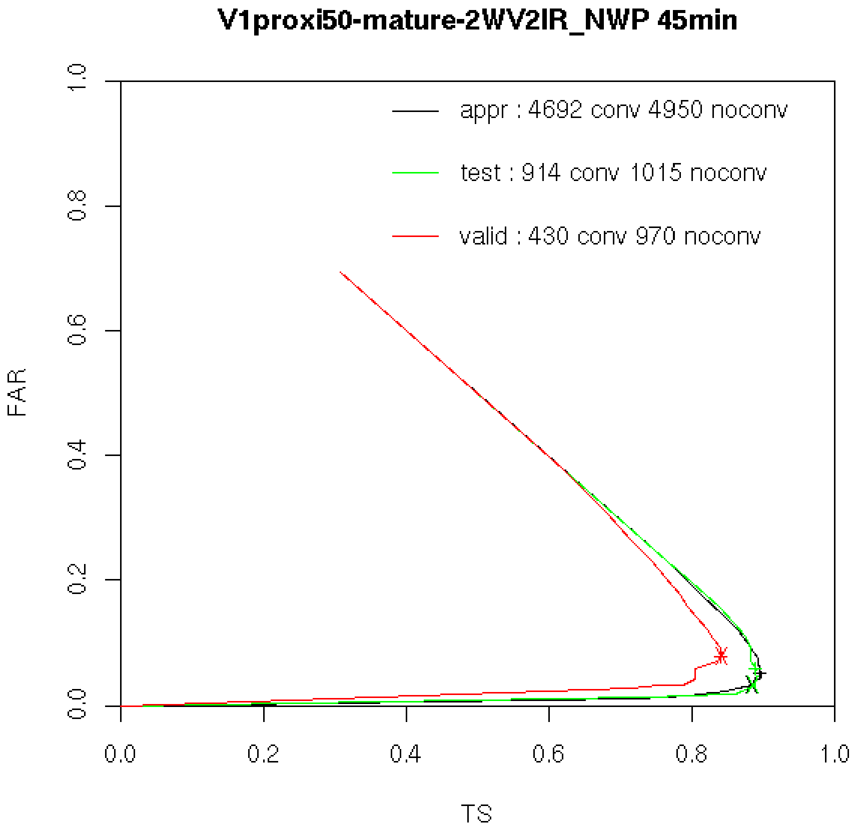


Figure 24: MSG V2011 tuning. TS/FAR curves for mature discrimination (DM), full configuration 6.2µm+7.3µm +8.7µm +10.8µm +12.0µm +NWP, 45 min depth, for a moderate ground truth with proximity to flashes taken into account

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 PGE11 upon scores, whatever the categories :

1. "Full" configuration IR10.8µm+all additional channels (6.2µm+7.3µm +8.7µm +12.0µm) +NWP data
2. "All channels" configuration IR10.8µm+all additional channels (6.2µm+7.3µm +8.7µm +12.0µm)
3. "Limited with NWP" configuration IR10.8µm+WV6.2µm + NWP data
4. "Limited" configuration IR10.8µm+WV6.2µm
5. "Mono channel with NWP" configuration IR10.8µm+ NWP data
6. "Mono channel with NWP" configuration IR10.8µm

The automatic choice of configuration mode by PGE11 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/PGE11/files_for_discri/ConvCoeffRegr_mask (ConvCoeffRegr_5_mask for rapidscan tuning) , sorted by configuration/category/depth. This file is read as a guidance in real time at the discrimination step of PGE11.

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

3.1.2.3.5 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 problematics.

To manage change of RDT objects into discrimination scheme (Figure 18), 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 rate, 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 to improve the stability of diagnosis, and focus on cloud systems in ascending phase.

The category 1 is associated to mature phase. The declassification rules can not 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 declasified 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

3.1.2.3.6 The 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.

The tracking algorithm allows to link an object to objects defined on the previous image. The object matching are named "father". The main father is the father which the higher surface (defined at a common temperature). The convective father is the colder convective father. In some cases, the main father and the convective father could be the same.

The discriminating parameters are processed on main trajectory. The convective trajectory allows to manage the convective time and temperature category change used into the declassification rules.

If an object has a convective father, the object is classified like convective before to check declassification conditions on convective trajectory.

In the case of decreasing temperature category change, the convective time is initialised to zero for the new class. In the other cases, the convective time is raised.

3.1.2.3.7 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.

3.1.2.3.8 The conditional use of lightning data to for convection diagnosis in BUFR coding

Lightning data, if available in real time, greatly contribute to the diagnosis of convection. The object approach allows the data fusion with auxiliary data. The "-lightning" option 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 during the bufr coding step. Using this option, there's only one possibility of change of convection diagnosis: from "no" to "yes".

Please note that an object not classified as convective by the discrimination scheme can be convective in the product output if more than N flashes strokes are paired with the cloud system.

3.1.2.3.9 The conditional use of Convective Rain Rate data for convection diagnosis in BUFR coding

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

Please note that an object not classified as convective by the discrimination scheme can be convective in the product output if CRR attribute becomes greater than N mm/h (default 50mm/h if N = 1).

3.1.2.3.10 The non-optional use of overshoot information for convection diagnosis in BUFR coding

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" during the bufr coding step. There's only one possibility of change of convection diagnosis: from "no" to "yes". No option is offered to skip this possibility.

Please note that a cloud cell not classified as convective by the discrimination scheme will be convective in the product output if the cell is associated with one or several overshoots.

3.1.2.4 Processing additional attributes

A lot of cloud cell's attributes are directly determined during the detection step: extreme and average temperatures, gradients, brightness temperature differences (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.

3.1.2.4.1 Lightning

Lightning data are paired with cloud cells when it is possible. A first check takes into account the temporal tolerance for this pairing, as provided through "dt_before" and "dt_after" arguments of the model configuration file. A second check considers the region over which PGE11 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 ("-tolerance" argument).

Negative, positive and intra-cloud lightning data are ***counted*** for each cloud cell.

3.1.2.4.2 Cloud type and phase

Cloud type value extracted from PGE02 is examined for each pixel of cloud object. The ***most frequent value*** is attributed to the cloud cell when enough values are available.

Similar approach is undertaken for the "phase" parameter. 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 quality of PGE02 product is directly taken into account to assess the quality of those attributes.

3.1.2.4.3 Cloud Top Pressure

PGE11 uses mainly Cloud Top Pressure value of PGE03 product. This parameter fulfil aeronautical users needs (through FL conversion with International Standard Atmosphere).

The ***10% percentile*** value of pressure is determined considering the pixels of the cloud-cell (equivalent to 90% percentile when considering altitude, thus being representative of cloud top). The quality of PGE03 product is directly taken into account to assess the quality of the attribute.

3.1.2.4.4 Convective Rain Rate

Convective Rain Rate intensity is the parameter used as input from PGE05 to PGE11. Values are analyzed for the cloud-cell 2D extension and the ***99% percentile is calculated*** and associated to the RDT object.

3.1.2.4.5 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.

3.1.2.4.6 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 <u>inside</u> the cloud cell in order to

- confirm that the colder spot is above at least two surrounding warmer pixels, identified as following:
    - limited 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"

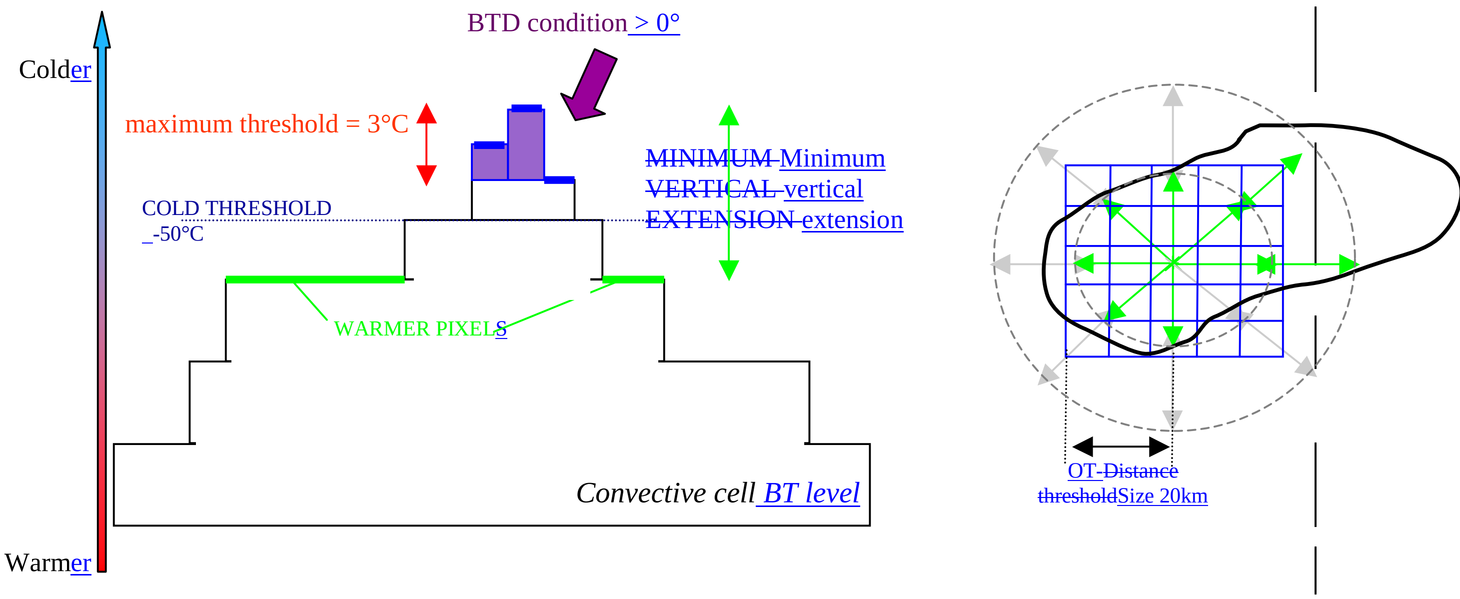


Figure 25: First step of OT detection: Values of criteria for vertical morphological analysis (left), illustration of a horizontal analysis (right). Arrows point surrounding pixels to check (green when belonging to the cloud cell), blue grid represent the research window for OT extension.

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

or

- OT colder than NWP tropopause or no NWP tropopause and 2 of following:
  - 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, PGE11 OTD will be less reliable.

3.1.2.4.7 The "phase of life" information

Initially, the attribute "phase of life" of a cloud system was diagnosed using cooling and/or expansion characteristic of the cell. The variability of this attribute has lead, since v2009, to use mainly the information of temperature "category" to qualify the development stage. This diagnosis has been consolidated since *v2013*. In order to to confirm or infirm growing/mature/decaying information not only cooling/warming rate are used but also expansion, activity (convective, electric, overshoots). Very few differences with the previous version have been observed, but modifications allow now to take into account all relevant input. .

3.1.3 Error Budget Estimates

The improvement of cell definition, tracking and discriminating parameters computation lead to process a complete validation on convective discrimination accuracy. These validations have not been taken care into CDOP proposal.

3.2 PRACTICAL CONSIDERATIONS

3.2.1 Calibration and Validation

3.2.1.1 Objective validation

The validation of RDT v*2013* has been limited on study cases. No modification has been brought to the discrimination scheme. Thus, the discrimination skill processes on the previous version remains valid.

An objective validation of PGE11 v2011 has been lead over Europe for an extended period (April to October). The lightning activity issued from EUCLID data base 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 whith 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 has also been validated on several cases study, and in real time configuration. More than objective score, PGE11 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 provides a right depicting of convective phenomena, from triggering phase to mature stage. The RDT 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.

3.2.1.2 Subjective validation

The subjective evaluation of RDT had pointed out some improvements from v2011 and the use of NWP data:

- 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.

PGE11 discrimination tuning focuses on precocity 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.

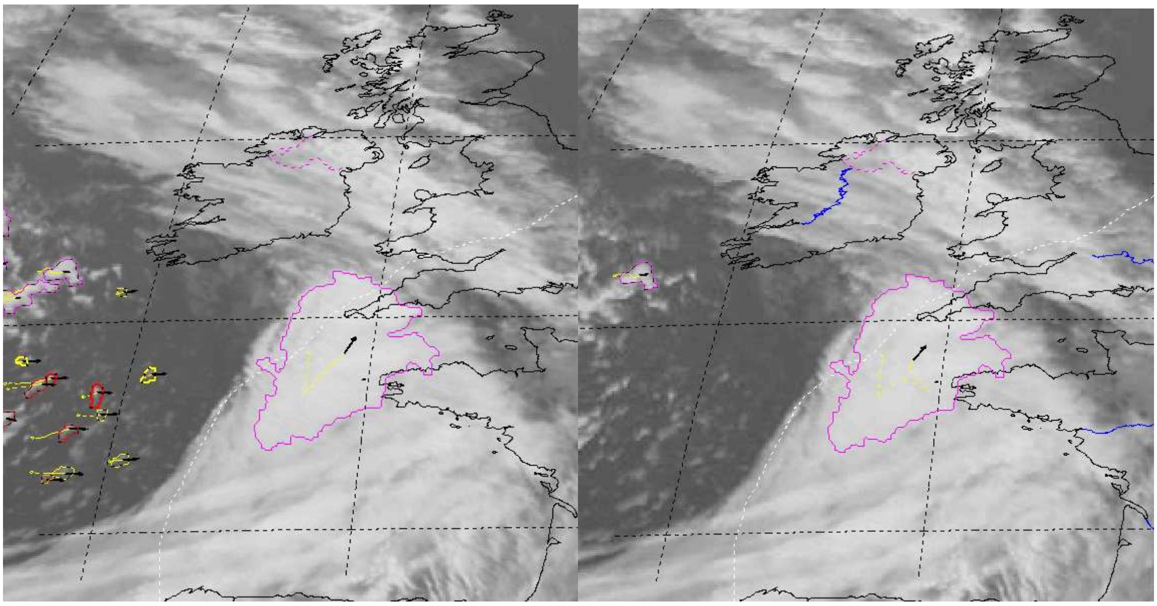
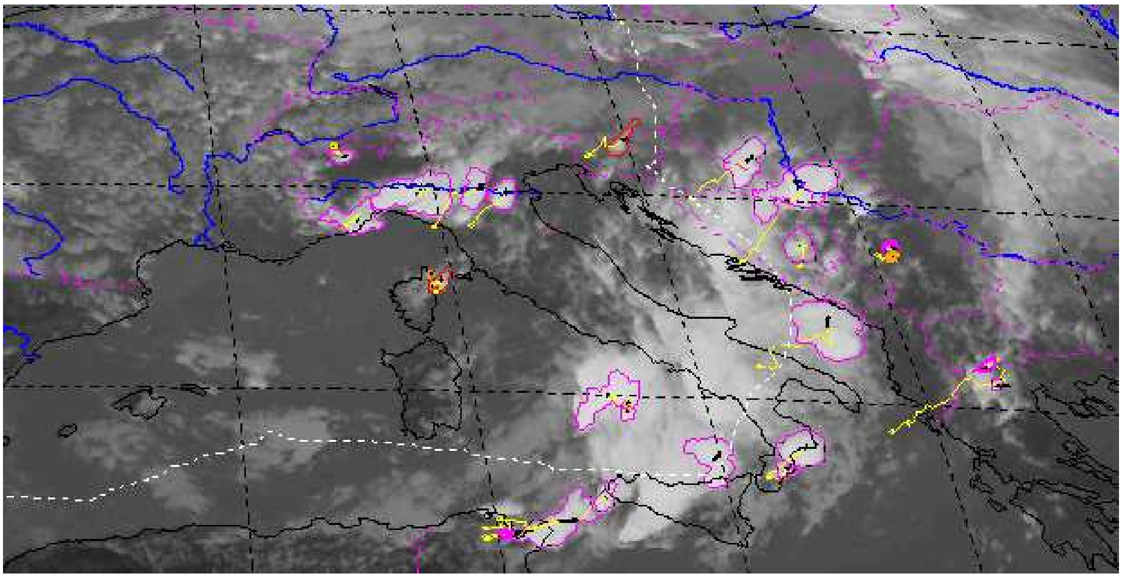


Figure 26:Comparison of RDT with NWP data vs RDT without NWP data.6 September 2010, 07h30

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.



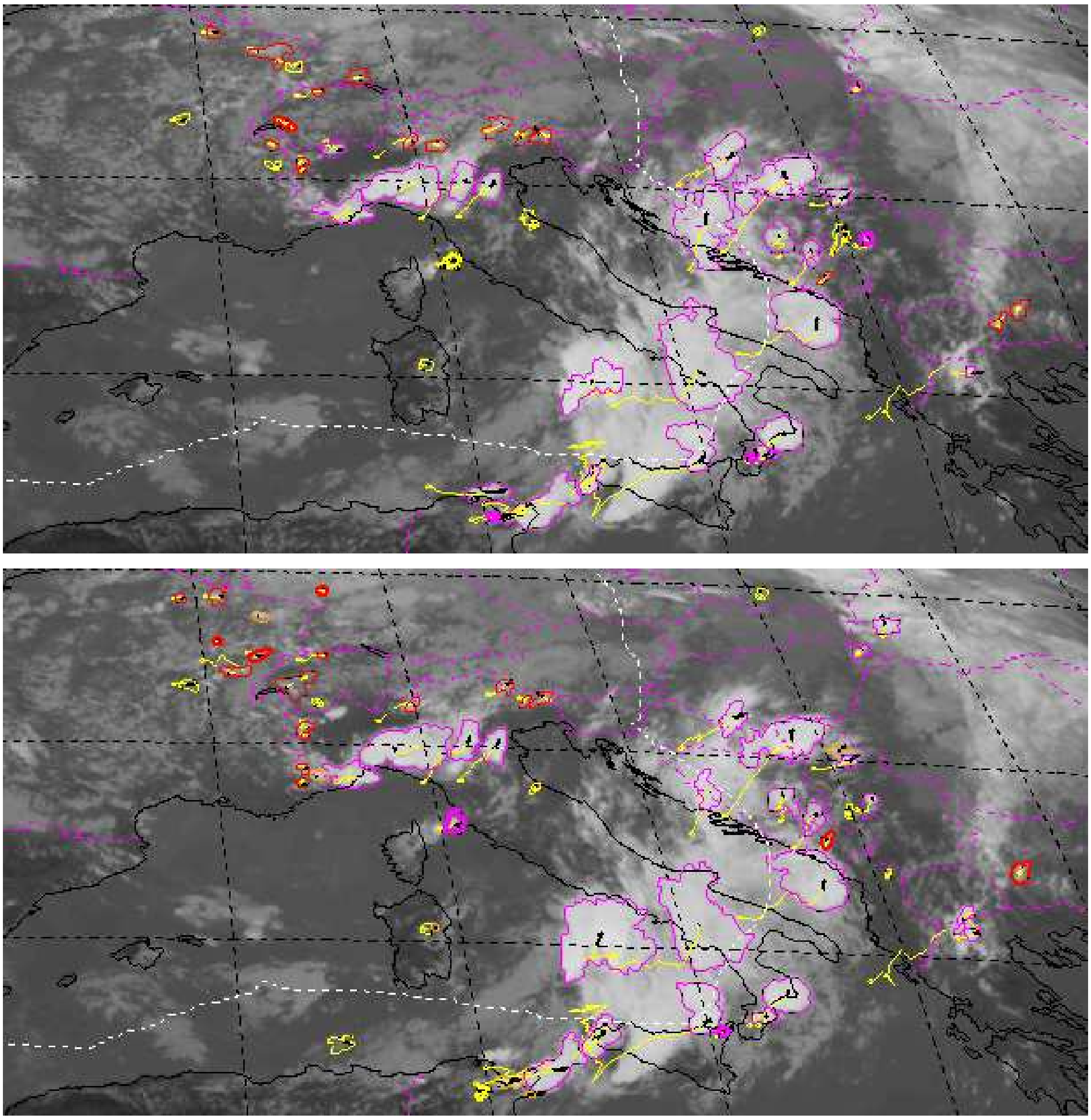


Figure 27:Comparison of RDT with NWP data (top).vs RDT without NWP data, 9 September 2010, 13h15(middle) 13h30 (bottom). Yellow contours for Warm and Warm1 categories, red for Warm2 and Cold, violet for mature and transition mature.

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

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 to decrease false alarms and increase 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.

Thus, the activation of warm discrimination remains an (default) option of users (-precocite argument of PGE11 model configuration file), and can be eventually desactivated .

3.2.2 Quality Control and Diagnostics

The RDT doesn't process real time quality control on tracking or discrimination result.

3.2.3 Exception Handling

The RDT doesn't manage a quality of satellite data input due to lack of it. Nevertheless, RDT manages the flag quality of CT, CTTH and CRR products

Moreover, the RDT software produces some code error in exception cases.

Type (E/W)	Code Number	Code	Message	Comment	Recovery Action
E	11000	PGE11_SETREGION_ERROR	ERROR: BAD ALLOCATION OF THE REGION STRUCTURE (OUTPUT OF SETREGION SUBROUTINE)	The region structure of the HRIT processed image has been badly allocated (problem with the "setregion" routine of the NWCLIB).	Write a SPR
E	11001	PGE11_SEVINIT_ERROR	ERROR: BAD ALLOCATION OF THE IMAGE STRUCTURE (OUTPUT OF SEVINIT SUBROUTINE)	The image structure of the HRIT processed image has been badly allocated (problem with the "sevinit" routine of the NWCLIB).	Write a SPR
E	11002	PGE11_SEVREAD_ERROR	ERROR: PROBLEM WHEN READING THE INPUT SATELLITE IMAGE (OUTPUT OF SEVREAD SUBROUTINE)	An error occurs when reading the HRIT processed image (problem with the "sevread" routine of the NWCLIB).	Write a SPR
E	11003	PGE11_READ_IMAGE_CANAL_NULL	ERROR: WRONG CHANNEL NAME (PGE11_READ SUBROUTINE)	An error occurs when reading the HRIT processed image (bad channel name).	Write a SPR
E	11004	PGE11_READ_IMAGE_DONNEES_NULL	ERROR: WRONG DATE OF SATELLITE IMAGE (PGE11_READ SUBROUTINE)	An error occurs when reading the HRIT processed image (wrong date of the image).	Write a SPR
E	11005	PGE11_DUP_IMAGE_NULL_ENTRY	ERROR: WRONG IMAGE TO DUPLICATE (PGE11_DUP_IMAGE SUBROUTINE)	The image structure to duplicate was corrupted.	Write a SPR
W	11006	PGE11_SUPPRIME_DESCENDANCE_COHERENCE_PROBLEM	PB. WITH THE RELEASE OF CELL STRUCTURES (SUPPRIME_DESCENDANCE SUBROUTINE)	The release of a trajectory has failed.	Write a SPR
E	11007	PGE11_BUFR_NO_TABLES	ERROR: THE CONFIGURATION FILE PGE11_BUFR_table IS CORRUPTED OR NOT ACCESSIBLE. THE RDT PRODUCT IS NOT PROCESSED	A problem has occurred with the PGE11_BUFR_table	1. Ensure that the file PGE11_BUFR_table is located at the directory `$SAFNWC/import/Aux_data/PGE11`. 2. Ensure that this file has been adapted in accordance with the "Interface Control Document for the External and Internal Interfaces for the SAF NWC/MSG"
E	11008	PGE11_BUFR_CREATE_TEMP_FILE_ERROR	ERROR: CREATION OF A TEMP. FILE USED TO WRITE THE BUFR OUTPUT FILE FAILED. THE RDT PRODUCT IS NOT PROCESSED	The BUFR writing of the RDT product has failed (unable to create an internal file used to write the RDT product in BUFR format).	Write a SPR

Type (E/W)	Code Number	Code	Message	Comment	Recovery Action
E	11009	PGE11_BUFR_READ_TEMP_FILE_ERROR	ERROR: ACCESS TO A TEMP. FILE USED TO WRITE THE BUFR OUTPUT FILE FAILED. THE RDT PRODUCT IS NOT PROCESSED	The BUFR writing of the RDT product has failed (unable to read an internal file used to write the RDT product in BUFR format).	Write a SPR
W	11010	PGE11_CALCUL_POIDS_AVAL_PROBLEM	PB. WITH THE COMPUTATION THE INTERNAL PARAMETER POIDS_AVAL	The computation of an internal characteristic of a cloud system ("poids aval") has failed.	Write a SPR
W	11011	PGE11_COOLING_RATE_CALCULATION_PROBLEM	PB. WITH THE COMPUTATION THE COOLING RATE OF A CELL	The computation of the cooling rate of a cloud system has failed.	Write a SPR
W	11012	PGE11_CONTOURS_NO_GROUP	PB. WITH THE COMPUTATION OF CONTOURS (NO GROUP)	The computation of the contour of a cloud system has failed.	Write a SPR
W	11013	PGE11_CONTOURS_NO_CELLS	PB. WITH THE COMPUTATION OF CONTOURS (NO CELL)	The computation of the contour of a cloud system has failed.	Write a SPR
E	11014	PGE11_DICRIMINATION_WRONG_PARAM	ERROR: UNKNOWN DISCRIMINATION PARAMETER	The satellite-based method of the discrimination method has failed (an unknown discrimination parameter has been found)	Ensure that the content of the files located in the directory `$SAFNWC/import/Aux_data/PGE11/files_for_discri` and its subdirectories is the same as originally delivered with the SAFNWC/MSG software.
E	11015	PGE11_FOUDRE_WRONG_LINE	ERROR: LINE WITH WRONG FORMAT IN THE INPUT LIGHTNING DATA FILE	The corresponding line is not in the correct format	Ensure that the content of the file `$SAFNWC/import/Obs_data/PGE11_lightning_data` is filled according to the format given in the "Interface Control Document for the External and Internal Interfaces for the SAF NWC/MSG"
W	11016	PGE11_FOUDRE_INCORRECT_FILE	PB. WHEN OPENING THE INPUT LIGHTNING DATA FILE	The content of the input lightning data file is corrupted.	Ensure that the content of the file `$SAFNWC/import/Obs_data/PGE11_lightning_data` is filled according to the format given in the "Interface Control Document for the External and Internal Interfaces for the SAF NWC/MSG"
E	11017	PGE11_FOUDRE_FILE_NOT_FOUND	ERROR: INPUT LIGHTNING DATA FILE NOT FOUND	The file "PGE11_lightning_data" was not found.	Ensure that this file is located at the directory `$SAFNWC/import/Obs_data/`

Type (E/W)	Code Number	Code	Message	Comment	Recovery Action
E	11018	PGE11_UNKNOWN_PROGRAM_ARGUMENT	ERROR: PGE11 SOFTWARE UNKNOWN ARGUMENT. THE RDT PRODUCT IS NOT PROCESSED	An unknown input argument has been detected by the PGE11 software	1. Ensure that the corresponding model configuration file is filled in accordance to the Software User Manual. 2. Ensure that the file `$SAFNWC/bin/PGE11` is the same as the file `$SAFNWC/src/PGE11/PGE11` delivered within the SAFNWC/MSG software
E	11019	PGE11_INVALID_DISCRIMINATION_DIRECTORY	ERROR: INVALID DISCRIMINATION DIRECTORY	The directory $SAFNWC/import/Aux_data/PGE11/files_for_discri was not found.	Install this directory and its subdirectories delivered within the SAFNWC/MSG software
E	11020	PGE11_CONFIGURATION_FILE_NOT_FOUND	ERROR: MODEL CONFIGURATION FILE NOT FOUND. THE RDT PRODUCT IS PROCESSED WITH DEFAULT PARAMETER VALUES	The model configuration file specified by the user was not found.	1. Ensure that this file is located at the directory $SAFNWC/config 2. Ensure that there is no typo-mistake in the corresponding run configuration file.
W	11021	PGE11_TOO_MANY_IMAGES_MISSING	TOO MANY CONSECUTIVE SATELLITE IMAGES ARE MISSING: THE TRACKING IS REINITIALIZED	The PGE11 software has analysed that the time gap between the satellite image to process and the previously processed one was greater than 2h30.	1. No specific action when the time gap between the satellite image to process and the previously processed one is greater than 2h30. 2. Write a SPR if this warming message occurs in other circumstances.
W	11022	PGE11_COLD_START	INITIALIZATION OF THE TRACKING (FIRST IMAGE)	The tracking is initialzed.	1. No specific action when running the PGE11 software for the first time on a given region and with a given PGE11 model configuration file. 2. Write a SPR if this warming message occurs in other circumstances.
E	11023	PGE11_NO_IMAGE_TO_PROCESS	PB. WHEN READING THE INPUT SATELLITE IMAGE. THE RDT PRODUCT IS NOT PROCESSED	An error has occurred when reading the input satellite HRIT image.	1. Ensure that the corresponding HRIT file is correctly located at the directory `$SAFNWC/import/SEVIRI_data`. 2. Write a SPR if this error message occurs in other circumstances.
W	11024	PGE11_RESTORE_PROBLEM	PB. WHEN READING THE BACK-UP FILE OF CURRENT TRACKED TRAJECTORIES	The back-up of the speed of a given cloud system has failed.	Write a SPR
W	11025	PGE11_NO_SAVES_FILE	NO HISTORICAL FILE OF TRACKED TRAJECTORIES	The back-up file of tracked trajectories was not found.	1. No specific action when running the PGE11 software for the first time on a given region and with a given PGE11 model configuration file. 2. Write a SPR if this warming message occurs in other circumstances.

Type (E/W)	Code Number	Code	Message	Comment	Recovery Action
W	11026	PGE11_NO_SAVED_IMAGE	FILE OF THE PREVIOUS SATELLITE IMAGE NOT FOUND	The previous satellite image processed by the PGE11 software was not found	Ensure that the corresponding HRIT file is located at the directory `$SAFNWC/import/SEVIRI_data`
W	11027	PGE11_WRONG_DATAS_SAVE_FILE	PB. WITH THE HISTORICAL FILE OF TRACKED TRAJECTORIES	The back-up file of tracked trajectories was corrupted.	Write a SPR
W	11028	PGE11_SCANNING_PROBLEM	PB. WITH THE TEMPERATURE THRESHOLDING OF THE SATELLITE IMAGE	The detection algorithm of cloud systems has failed on a given satellite image pixel.	Write a SPR
W	11029	PGE11_SAT_INI_CARTE_ERROR	PB. WITH THE DETECTION OF CLOUD SYSTEMS (SAT_INI_CARTE SUBROUTINE)	Incoherence caused by the detection algorithm of cloud systems.	Write a SPR
E	11030	PGE11_MAX_NUM_CELL_TOO_LOW	PB. WITH THE DETECTION OF CLOUD SYSTEMS: TOO MANY CELLS ARE DETECTED	The detection algorithm of cloud systems has led an incoherence.	Write a SPR.
E	11031	PGE11_NUM_CELL_TOO_HIGH	ERROR: CORRUPTED CELLS AFTER THE DETECTION OF CLOUD SYSTEMS	The detection algorithm of cloud systems has led an incoherence.	Write a SPR.
E	11032	PGE11_MAP_NUM_TOO_HIGH	ERROR: CORRUPTED MAP AFTER THE DETECTION OF CLOUD SYSTEMS	The detection algorithm of cloud systems has led an incoherence.	Write a SPR.
W	11033	PGE11_COHERENCE_PROBLEM	PB. OF COHERENCE WITH THE OVERLAPPING OF CELLS	Incoherence caused by the tracking algorithm for the corresponding cloud systems.	Write a SPR
E	11034	PGE11_TAB_ERROR	ERROR: BAD COHERENCE BETWEEN MAP AND TEMP. TAB	The tracking algorithm of cloud systems has led to an incoherence	Write a SPR
E	11035	PGE11_NULL_CELL	ERROR: BAD COHERENCE BETWEEN DETECTED CELLS AND TEMP. TAB	The tracking algorithm of cloud systems has led to an incoherence	Write a SPR
E	11036	PGE11_WRONG_DETECTION_METHOD	ERROR: UNKNOWN DETECTION METHOD	Unknown name of the detection method used by the PGE11 software.	Ensure that the file `$SAFNWC/bin/PGE11` is the same as the file `$SAFNWC/src/PGE11/PGE11` delivered within the SAFNWC/MSG software
W	11037	PGE11_DISCRIMINATION_PROBLEM	PB OF COHERENCE IN THE DISCRIMINATION ALGORITHM	The discrimination algorithm has failed for a given cloud system.	Write a SPR
E	11038	PGE11_DISCRIMINATION_FILE_NOT_FOUND	ERROR: DISCRIMINATION FILES NOT FOUND	The file "qualities_disponibles" was not found.	Ensure that this file is located at the directory `$SAFNWC/import/Aux_data_PGE11/files_for_discri`.
E	11039	PGE11_CTTH_FILE_ERROR	ERROR: INPUT CTTH FILE NOT FOUND	The input CTTH file was not found	Ensure that the CTTH product is processed on the same region than the RDT product before running the PGE11 software
E	11040	PGE11_READ_CTTH_ERROR	ERROR: PROBLEM WHEN READING THE CTTH FILE (OUTPUT OF READUS SUBROUTINE)	An error occurs when reading the CTTH file.	Write a SPR

Type (E/W)	Code Number	Code	Message	Comment	Recovery Action
W	11041	PGE11_COHERENCE_DATE	PB OF COHERENCE WITH THE DATE OF THE IMAGE TO PROCESS: THE TRACKING IS REINITIALIZED		Write a SPR
W	11042	PGE11_LINE_DATATION	PB OF DATATION: LINE DATE SET TO IMAGE DATE	The HRIT data has no or wrong line datation The scanning date of RDT objects is set to the slot	Write a SPR
E	11043	PGE11_CT_FILE_ERROR	ERROR: INPUT CTTH FILE NOT FOUND	PGE 02 is not available	Ensure that PGE02 is processed
E	11044	PGE11_READ_CT_ERROR	ERROR: PROBLEM WHEN READING THE CTTH FILE (OUTPUT OF READUS SUBROUTINE)	An error occurs when reading the PGE02	Write a SPR
E	11045	PGE11_MASK_FILE_ERROR	ERROR: PROBLEM OPEN MASK FILE	An error occurs when opening the mask file (if available)	Write a SPR
E	11046	PGE11_READ_MASK_ERROR	ERROR: PROBLEM WHEN READING THE MASK FILE	An error occurs when reading the mask file (if available)	Write a SPR
E	11047	PGE11_INITPARAMNWP	ERROR: PROBLEM WHITH INITIALIZATING NWP PARAMETERS	An error occurs	Write a SPR
W	11048	PGE11_NWP_PB	WARNING: PROBLEMS WHEN ACCESSING NWP DATA	Not all NWP parameters or file are available. May be non relevant when concerns Meteo-France ARPEGE parameters, non available with ECMWF	Verify alimentation of NWP data. Eventually suppressing non available parameters with ECMWF from *.cfm
E	11049	PGE11_NWP_KO	ERROR: NWP DATA MISSING	Configuration file is not compliant with data providing, or NWP data are incomplete	Correct *.cfm file or provide full requested NWP data
E	11050	PGE11_CRR_FILE_ERROR	ERROR: INPUT CRR FILE NOT FOUND	the CRR product file (PGE05) has not been found	Write a SPR
E	11051	PGE11_READ_CRR_ERROR	ERROR: PROBLEM WHEN READING THE CRR FILE (OUTPUT OF READUS SUBROUTINE)	an error occurred when reading PGE05 product	Verify alimentation of NWP data. Eventually suppressing non available parameters with CEP from *.cfm

Table 1: PGE11 Error / Warning messages

3.2.4 Outputs

The final product is numerical data which depict satellital characteristics (spatial and time) and move information associated to RDT cells. Numerical data are provided under BUFR format. Thus, **operating the RDT needs development of a post-processing prior to visualization**.

RDT software is able to take flashes location as optional input data. These additional data allow to improve discrimination skill (3.1.2.3.8). Moreover, the object approach of RDT allows to characterize the lightning activity associated to a convective cloud object and to build its time serie.

The BUFR format is described in the Interface Control Document n°3(# 1.7.1) of SAFNWC. The RDT offers three BUFR versions (configurable with "-bufr" argument in configuration file).

- The default initial first version ("-bufr 1" in model configuration file) holds the full description of RDT cells without time series. A full RDT post-processing needs to build temporal links from previous outputs, step by step, using current and previous Id string of each cloud cell.
- The second version ("-bufr 2") includes a time serie of a limited amount of parameters for each cloud cell (gravity center location, minimum temperature and lightning activity), allowing to make simpler the visualization tool development. Nevertheless, a full historical description still implies to re-build temporal links from previous outputs. For this version the key relies on Id numbers of current cell and common ancestor cell (birth of trajectory), rather than successive Id strings. This version also allows to limit, on request by the user (negative argument "-bufr -2"), the BUFR description to clouds discriminated as convective only. This possibility leads to strongly reduce BUFR size.
- The third version ("-bufr 3") gives up parameters time series encoding, but offers a more complete spatio-temporal description of cloud cells :
    i. additional attributes are possible, when additional input from "Cloud Type", "Cloud Phase", and "Convective Rain rate" PGEs are available
    ii. depending on cloud morphology a second level may complete the description of a cloud system through an additional corresponding cell
    iii. on user's request (negative argument "-bufr -3"), it is still possible to limit the output to "significant" cells. Cloud will be considered as significant when convective, or electric (if RDT is operated with lightning data), or associated with high rain rates (if RDT is operated with PGE05/CRR). As the output is limited to those cells, the size of output file is hightly decreased. Newly significant cells are encoded at the first time with their complete historical description through the list of previous cells at successive time slots.
- The fourth version ("-bufr 4") presents a very similar structure to version 3, but with minor add-ons and substitutions:
    i. Some cloud cells may be associated with overshooting tops. This version of output allows encoding their characteristics through additional attributes of a given cell. Unused attributes have been suppressed to allow the description and localization of overshoots.
    ii. On user's request (negative argument "-bufr -4"), the output is also limited to "significant" cells. Cloud with overshoot are systematically set as "significant".

3.2.5 Links between successive Outputs

The temporal links between successive BUFR RDT products can be rebuilt in a post-processing scheme using :

- for the version 1 of BUFR RDT the identification marks of cloud systems in the current and previous images (descriptors 001220) (each cloud system holds the identification of its "father" in the previous product) , or

- for further versions of BUFR RDT the identification numbers in the current and initial image (descriptors 001222). (each cloud system holds the index of its ancestor, which becomes unique regarding the birth date; this reference can be found in any of the corresponding previous cells).

In any case, temporal links are necessary to benefit from the complete historical characteristics of a given cloud system. The "keys" to establish those links are illustrated in the figures below.

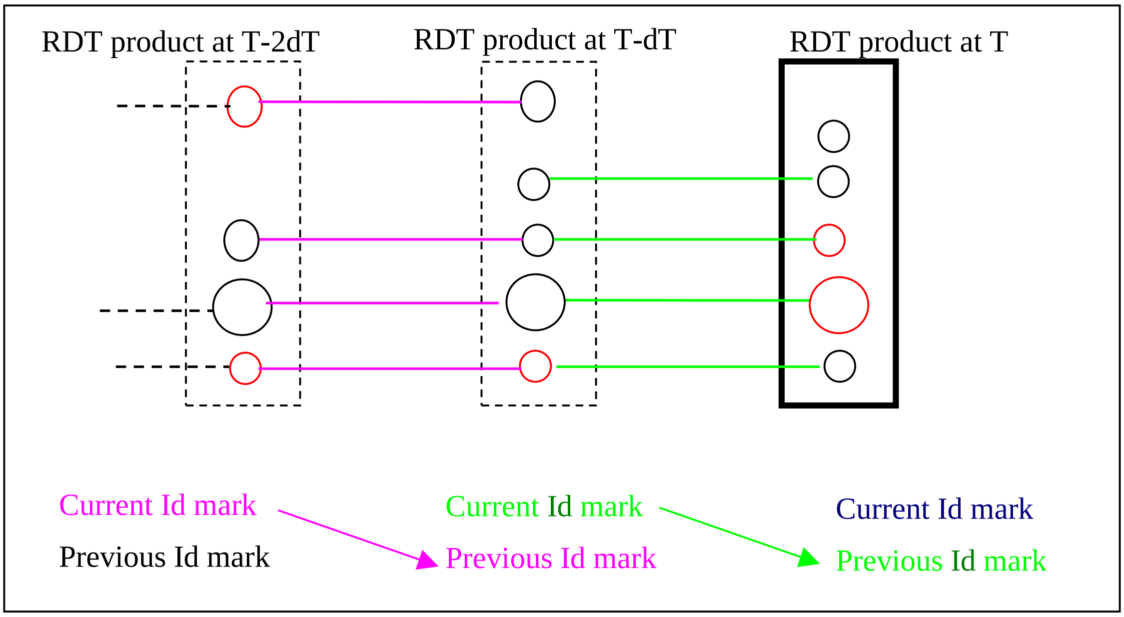


Figure 28 : version 1 of BUFR RDT. Illustration and key of temporal links between cells with successive RDT products. Products contain all detected and tracked cells (convectives symbolized in red)

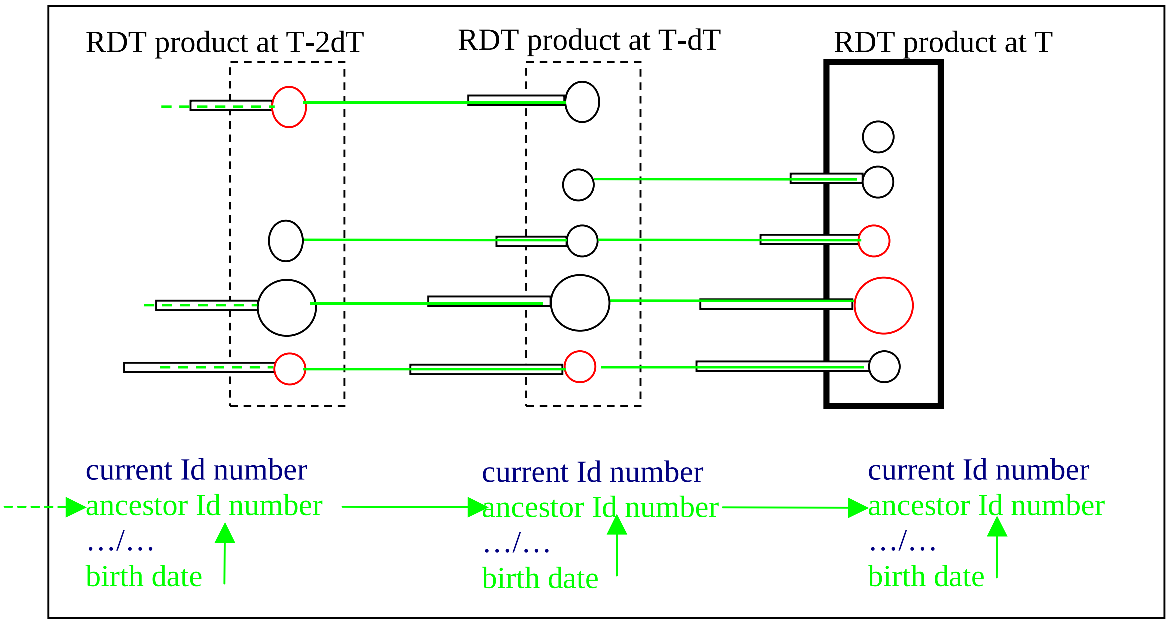


Figure 29 : version 2 of BUFR RDT. Illustration and key of temporal links between cells with successive RDT products. Included temporal series of parameters illustrated by thin rectangle, length depending on cell's history and software limit (default 180 min, tunable through "–bufr_histo" argument)

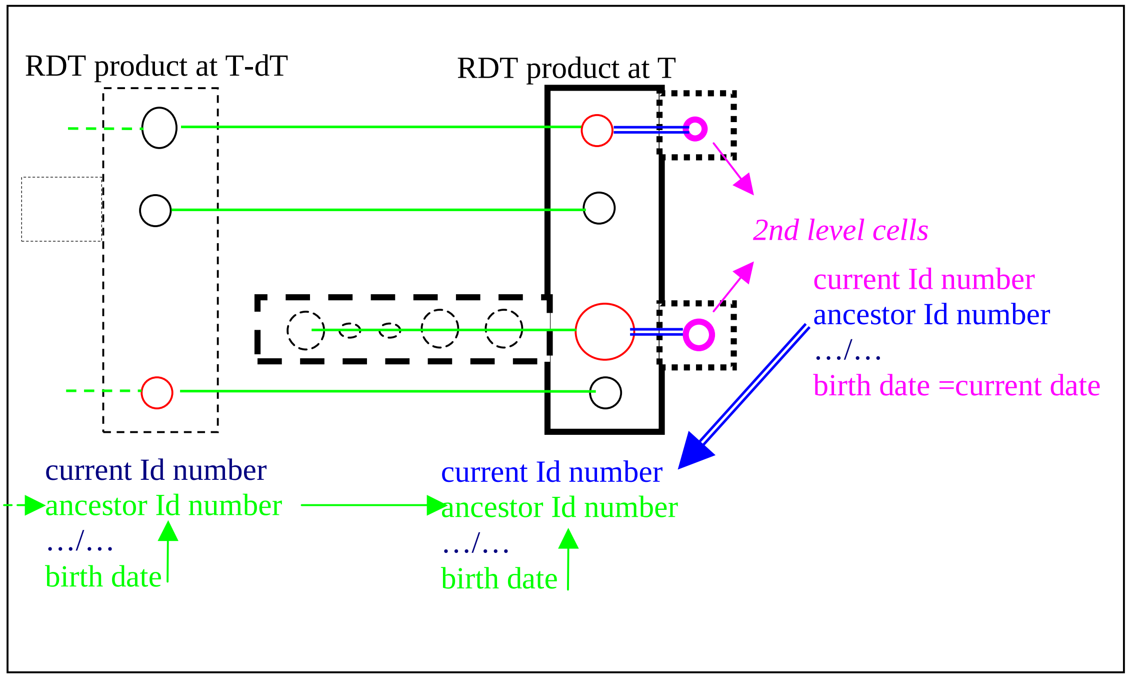


Figure 30 : version 3 or 4 of BUFR RDT : Illustration and key of temporal links between successive cells of successive product (or between included previous cells of newly significant if option "–bufr -3" or "–bufr -4"). Illustration and key of link between main cell and second level cell (magenta)

4. ASSUMPTIONS AND LIMITATIONS

4.1.1 Constraints and Limitations

The tuning has been carried out on a summer period over a domain centred over France. The discrimination score during winter period could be weak.

ANNEX A – The Discriminating parameters

The acronym "ST" characterizes a cell defined at a ΔTtower (6°C) warmer than top temperature

Values are extremes over the section (15, 30, 45 or 60min depth)

N°	Parameter	Meaning
1.	Min_Tmin	minimum of top temperature
2.	Max_TxTmin	Maximum of top temperature rate processed on two following images
3.	Min_TxTmin	minimum of top temperature rate processed on two following images
4.	Max_TxTmin2	Secondary maximum of top temperature rate processed on two following images
5.	Max_TxTmin10	Maximum of top temperature rate processed on ten minutes (Rapid Scan mode)
6.	Max_TxTmin15	Maximum of top temperature rate processed on 15 minutes (equal to parameter n°2 for image frequency = 15')
7.	Max_TxTmin30	maximum of top temperature rate processed on 30'
8.	Max_TxTmin45	maximum of top temperature rate processed on 45'
9.	Max_TxTmin60	maximum of top temperature rate processed on 60'
10.	MinMaxPos	continuous cooling Boolean
11.	Max_TxTmoyST	Maximum of mean temperature, defined on ST, processed on two consecutives images. ST is a cell defined at a ΔTtower (6°C) warmer than top temperature
12.	Max_DTmoyTmin	maximum mean temperature – top temperature
13.	Max_DTseuilTmoy	Maximum temperature of base – mean temperature
14.	Max_DTseuilTmoyST	Maximum temperature of base – mean temperature defined on ST
15.	Max_Gpm	Maximum of the mean peripheral gradient processed on IR10.8
16.	Max_Qgp95	Maximum of quantile 95% of peripheral gradient
17.	Max_Volume	Maximum of system volume The volume is calculated on IR10.8 data. The base of volume is –25°C for mature object and +5°C for transition object
18.	Max_RapportAspect	Maximum of long axe / small axe of ellipse enclosing
19.	Max_SurfaceST	Maximum of the ST surface
20.	Max_DSurfaceBTST	Maximum of cell surface – ST surface
21.	Min_WV	Mini ofWV62
22.	Min_WV2	Mini of WV73
23.	Min_IR87	Mini of IR87
24.	Min_IR120	Mini of IR120

25.	Max_TxWV	Maximum WV6.2 rate processed on two following images
26.	Max_TxWV10	Maximum WV6.2 rate processed on 10 minutes (Rapid Scan mode)
27.	Max_TxWV15	Maximum WV6.2 rate processed on 15 minutes
28.	Max_TxWV30	Maximum WV6.2 rate processed on 30 minutes
29.	Max_TxWV45	Maximum WV6.2 rate processed on 45 minutes
30.	Max_TxWV60	Maximum WV6.2 rate processed on 60 minutes
31.	Max_TxWV2	Maximum WV7.3 rate processed on two following images
32.	Max_TxWV210	Maximum WV7.3 rate processed on 10 minutes (Rapid Scan mode)
33.	Max_TxWV215	Maximum WV7.3 rate processed on 15 minutes
34.	Max_TxWV230	Maximum WV7.3 rate processed on 30 minutes
35.	Max_TxWV245	Maximum WV7.3 rate processed on 45 minutes
36.	Max_TxWV260	Maximum WV7.3 rate processed on 60 minutes
37.	Max_TxIR87	Maximum IR8.7 rate processed on two following images
38.	Max_Tx IR8710	Maximum IR8.7 rate processed on 10 minutes (Rapid Scan mode)
39.	Max_Tx IR8715	Maximum IR8.7 rate processed on 15 minutes
40.	Max_Tx IR8730	Maximum IR8.7 rate processed on 30 minutes
41.	Max_Tx IR8745	Maximum IR8.7 rate processed on 45 minutes
42.	Max_Tx IR8760	Maximum IR8.7 rate processed on 60 minutes
43.	Max_TxIR120	Maximum IR120 rate processed on two following images
44.	Max_Tx IR12010	Maximum IR120 rate processed on 10 minutes (Rapid Scan mode)
45.	Max_Tx IR12015	Maximum IR120 rate processed on 15 minutes
46.	Max_Tx IR12030	Maximum IR120 rate processed on 30 minutes
47.	Max_Tx IR12045	Maximum IR120 rate processed on 45 minutes
48.	Max_Tx IR12060	Maximum IR120 rate processed on 60 minutes
49.	Max_BTDmax	Maximum of WV6.2-IR10.8
50.	Max_BTD	maximum of quantile 75% of WV6.2-IR10.8
51.	Max_BTD90	maximum of quantile 90% of WV6.2- IR10.8
52.	Max_BTDRatio	maximum of BTD structure BTD=WV6.2 – IR10.8 structure is the ratio between contiguous BTD pixel >-2 and BTD pixel > -2
53.	Max_WBTDmax	maximum of WV6.2- WV7.3
54.	Max_WBTD	maximum of quantile 75% of WV6.2- WV7.3
55.	Max_WBTD90	maximum of quantile 90% of WV6.2- WV7.3
56.	Max_WBTDRatio	Maximum of WBTD structure WBTD= WV6.2- WV7.3 structure is the ratio between contiguous WBTD pixel > -1 and

		WBTD pixel > -1
57.	Max_BTD4max	Maximum of IR87-IR108
58.	Max_BTD4Q1	maximum of quantile 75% of IR87-IR108
59.	Max_BTD4Q2	maximum of quantile 90% of IR87-IR108
60.	Max_BTD4Ratio	maximum of BTD structure BTD= IR8.7-IR10.8 structure is the ratio between contiguous BTD pixel >-2 and BTD pixel > -2
61.	Max_BTD5max	maximum of IR120-IR108
62.	Max_BTD5Q1	maximum of quantile 75% IR120-IR108
63.	Max_BTD5Q2	maximum of quantile 90% IR120-IR108
64.	Max_BTD5Ratio	maximum of BTD structure BTD= WV12-IR10.8 structure is the ratio between contiguous BTD pixel >0 and BTD pixel > 0
65.	Max_TxBTD	maximum of WV6.2-IR10.8 rate processed on two following images
66.	Max_TxBTD10	maximum of WV6.2-IR10.8rate processed on 10 minutes (Rapid Scan Mode)
67.	Max_TxBTD15	maximum of WV6.2-IR10.8 rate processed on 15 minutes
68.	Max_TxBTD30	maximum of WV6.2-IR10.8 rate processed on 30 minutes
69.	Max_TxBTD45	maximum of WV6.2-IR10.8 rate processed on 45 minutes
70.	Max_TxBTD60	maximum of WV6.2-IR10.8 rate processed on 60 minutes
71.	Max_TxWBTD	maximum of WV6.2- WV7.3 rate processed on two following images
72.	Max_TxWBTD10	maximum of WV6.2- WV7.3 rate processed on 10 minutes
73.	Max_TxWBTD15	maximum of WV6.2- WV7.3 rate processed on 15 minutes
74.	Max_TxWBTD30	maximum of WV6.2- WV7.3 rate processed on 30 minutes
75.	Max_TxWBTD45	maximum of WV6.2- WV7.3 processed on 45 minutes
76.	Max_TxWBTD60	maximum of WV6.2- WV7.3 processed on 60 minutes
77.	Max_NWPIndexConv	Maximum of Lifted index
78.	Max_NWPTtropo – Min_Tmin	Distance (°C) to tropopause

ANNEX B – The statistical model scores for MSG

1. MATURE DISCRIMINATION (DM)

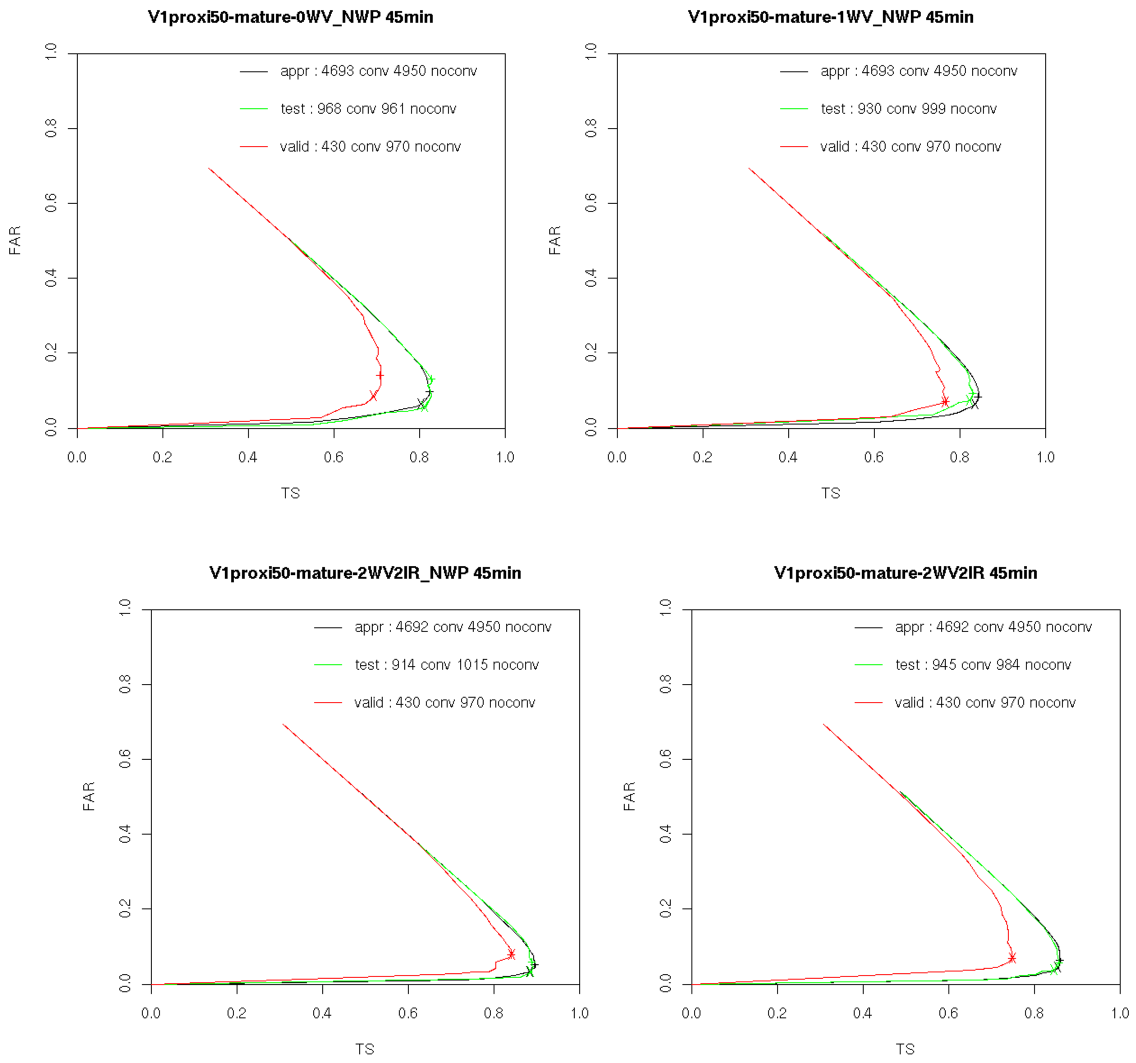


Figure c: *MSG V2011 tuning for mature category, 45 min depth, for 4 configurations :* With NWP (top) with IR10.8 only (top left), IR10.8 and WV6.2 (top right), with 2 WV et 2 IR (bottom left) and with 2 WV et 2 IR without NWP (bottom right)

2. DISCRIMINATION ON MATURE TRANSITION (DTM)

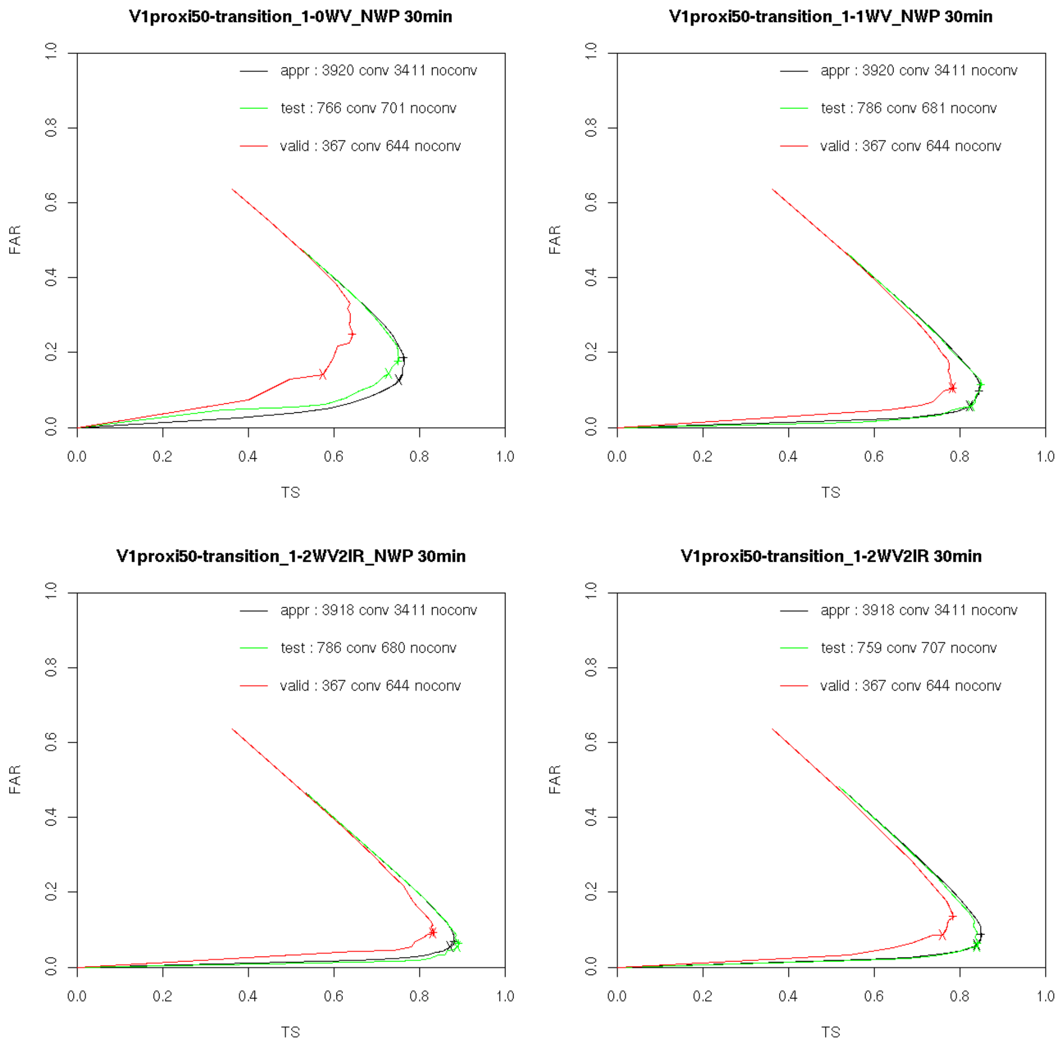


Figure 31: MSG V2011 tuning for transition mature category, 45 min depth, for 4 configurations : With NWP (top) with IR10.8 only (top left), IR10.8 and WV6.2 (top right), with 2 WV et 2 IR (bottom left) and with 2 WV et 2 IR without NWP (bottom right)

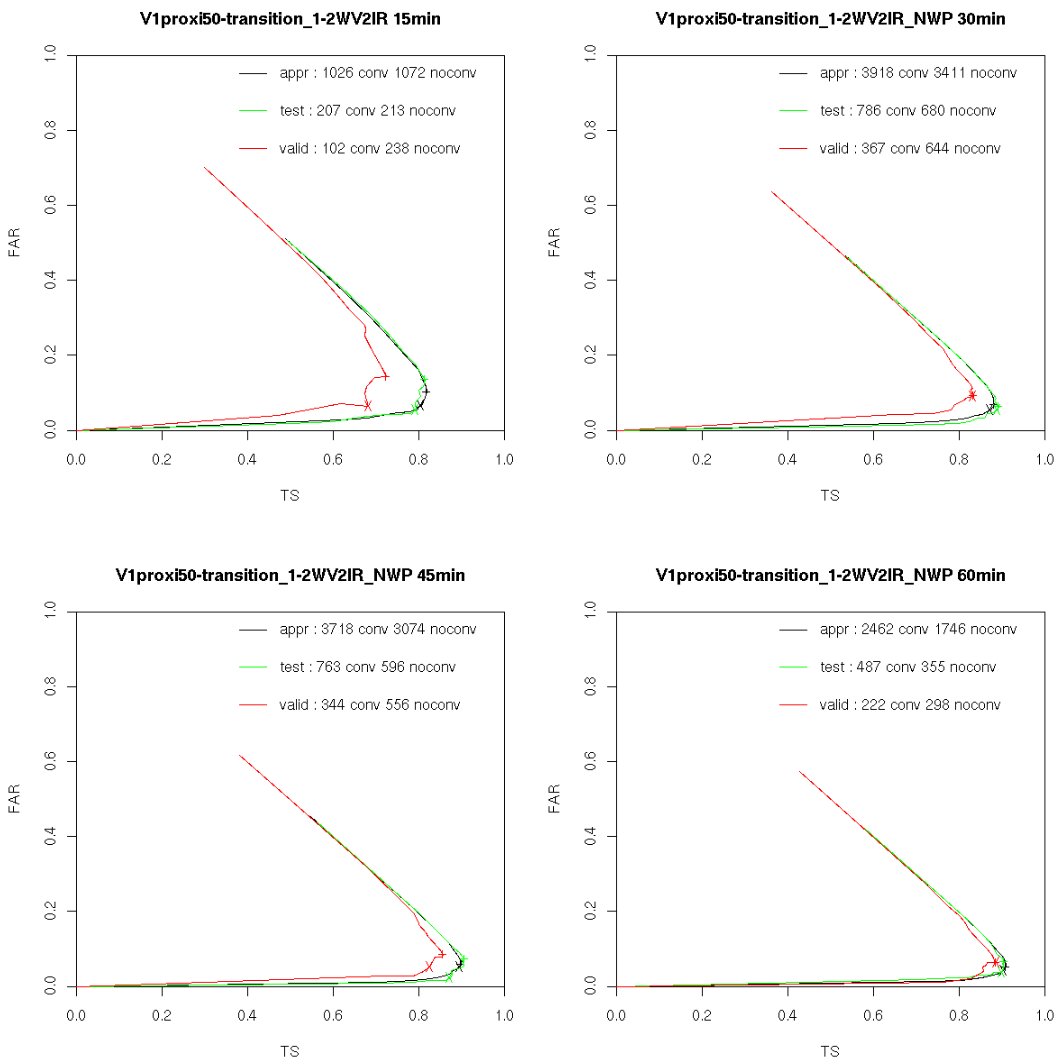


Figure 32: MSG V2011 tuning for transition mature category, full configuration, 4 available depth

3. DISCRIMINATION ON COLD TRANSITION (DTC)

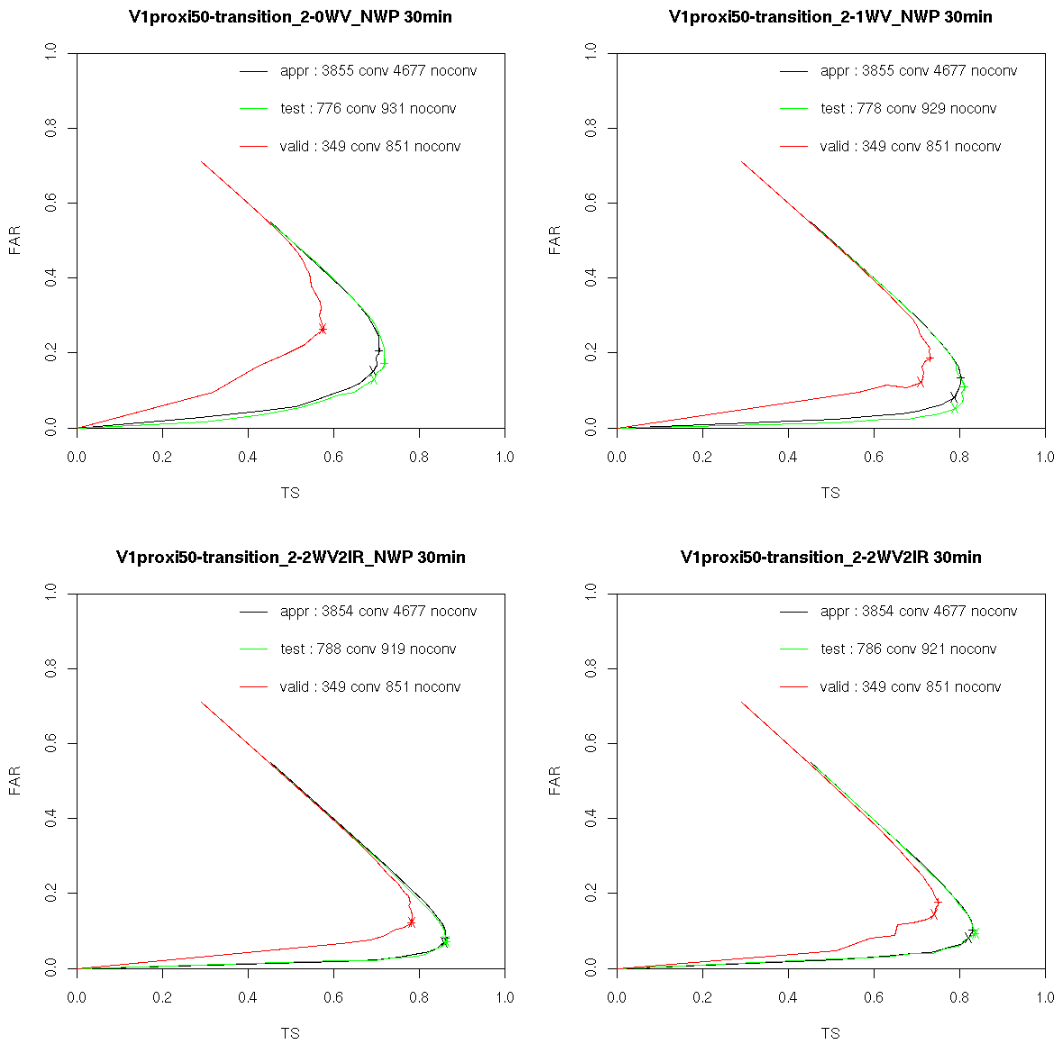


Figure 33: MSG V2011 tuning for cold transition category, 45 min depth, for 4 configurations : With NWP (top) with IR10.8 only (top left), IR10.8 and WV6.2 (top right), with 2 WV et 2 IR (bottom left) and with 2 WV et 2 IR without NWP (bottom right)

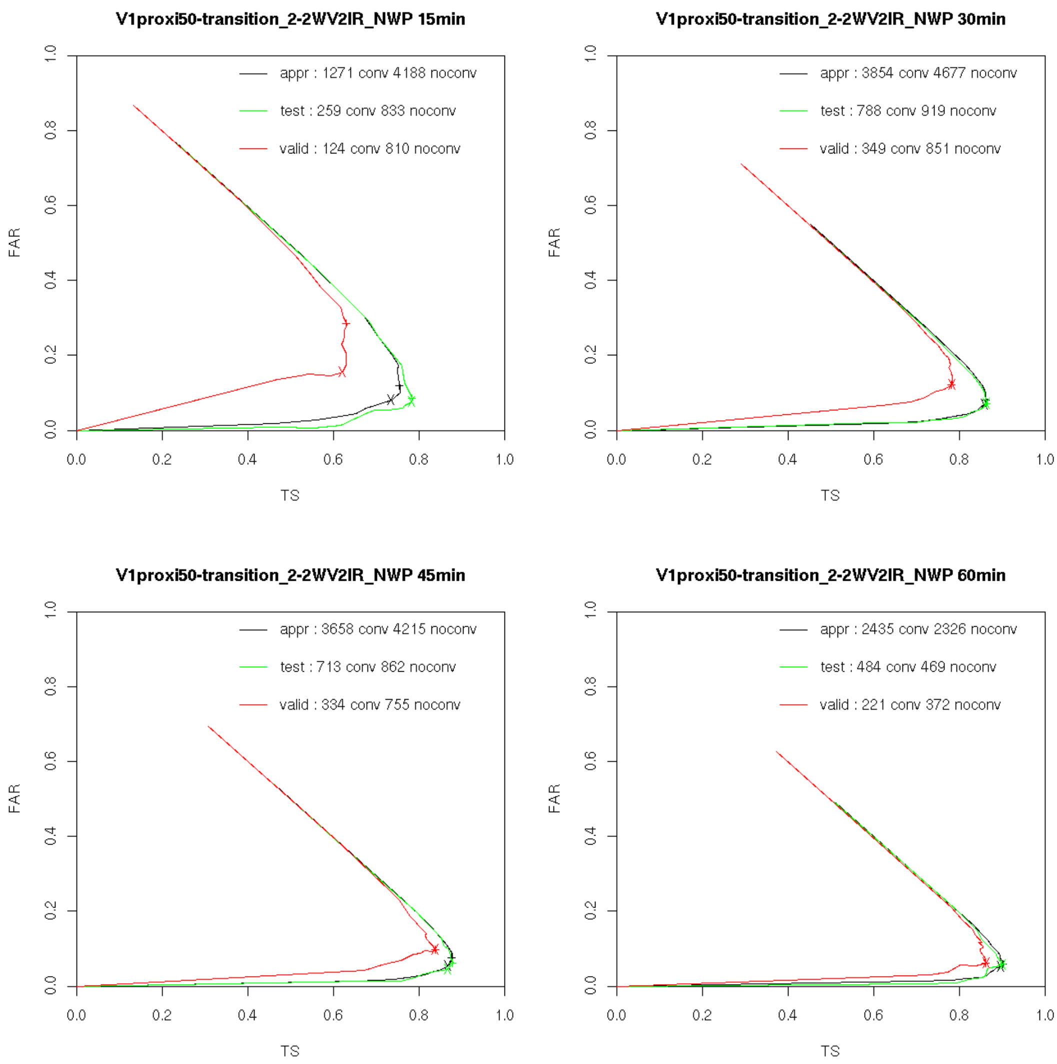


Figure 34 MSG V2011 tuning for cold transition category, full configuration, 4 available depth

4. DISCRIMINATION ON WARM2 TRANSITION (DTW2)

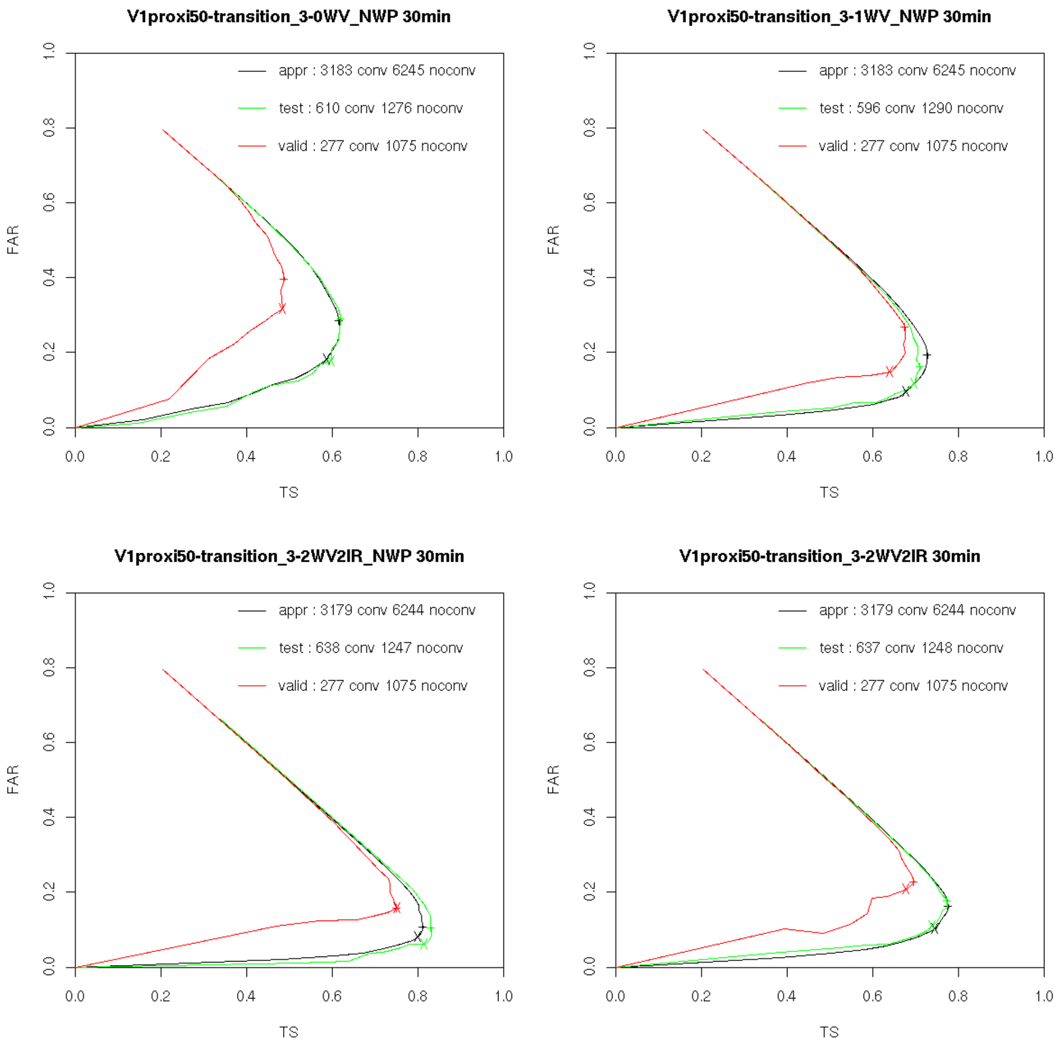


Figure 35: MSG V2011 tuning for Warm2 transition category, 45 min depth, for 4 configurations : With NWP (top) with IR10.8 only (top left), IR10.8 and WV6.2 (top right), with 2 WV et 2 IR (bottom left) and with 2 WV et 2 IR without NWP (bottom right)

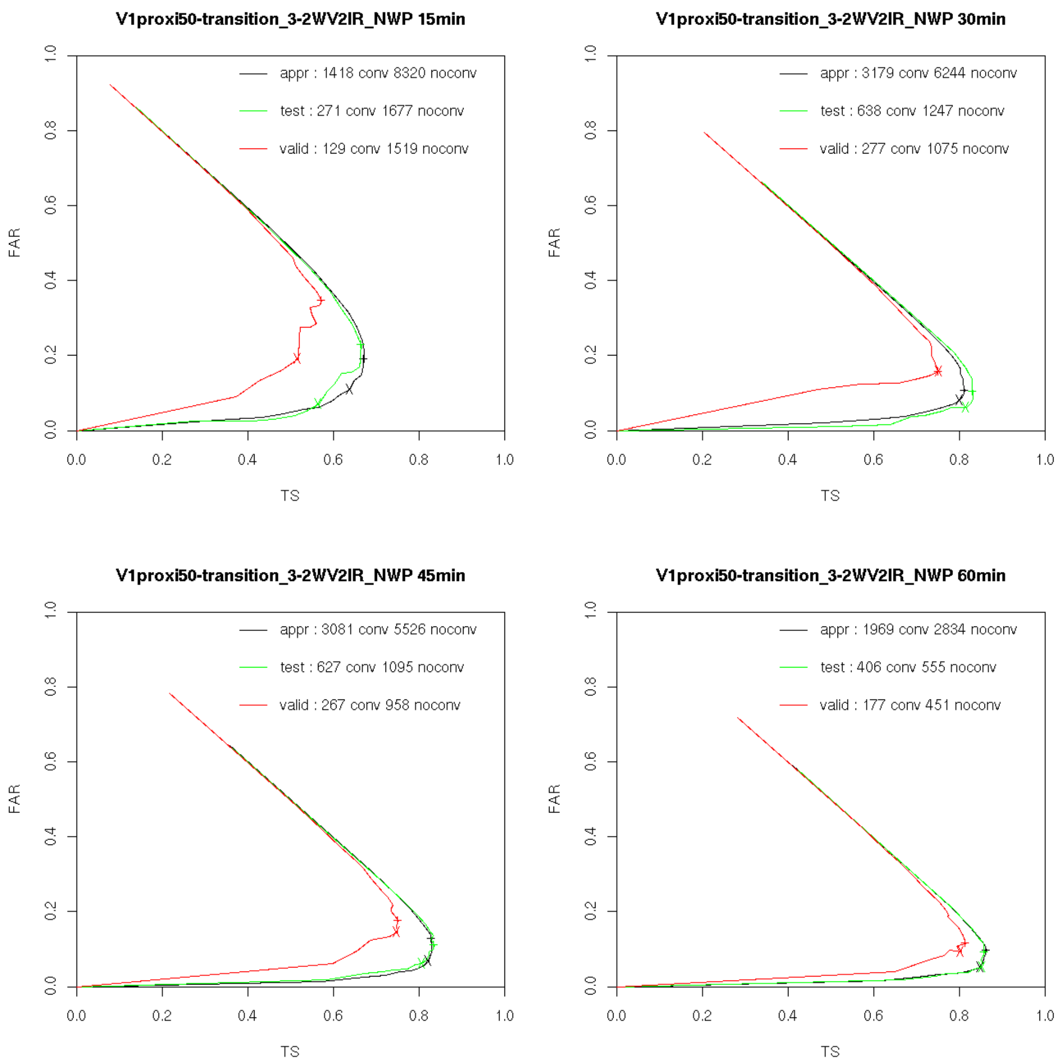


Figure 36 MSG V2011 tuning for Warm2 transition category, full configuration, 4 available depth

5. DISCRIMINATION ON WARM1 TRANSITION (DTW1)

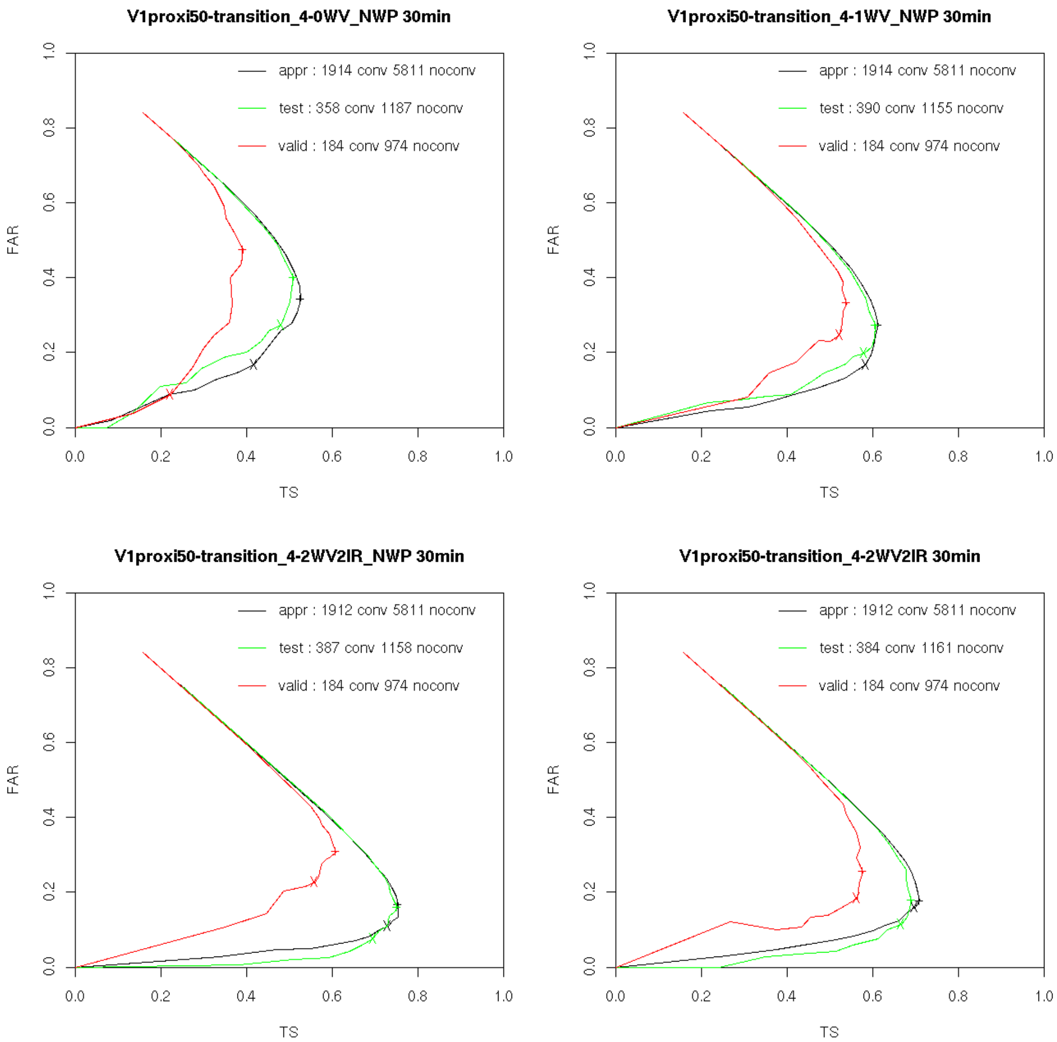


Figure 37: : MSG V2011 tuning for Warm1 transition category, 45 min depth, for 4 configurations : With NWP (top) with IR10.8 only (top left), IR10.8 and WV6.2 (top right), with 2 WV et 2 IR (bottom left) and with 2 WV et 2 IR without NWP (bottom right)

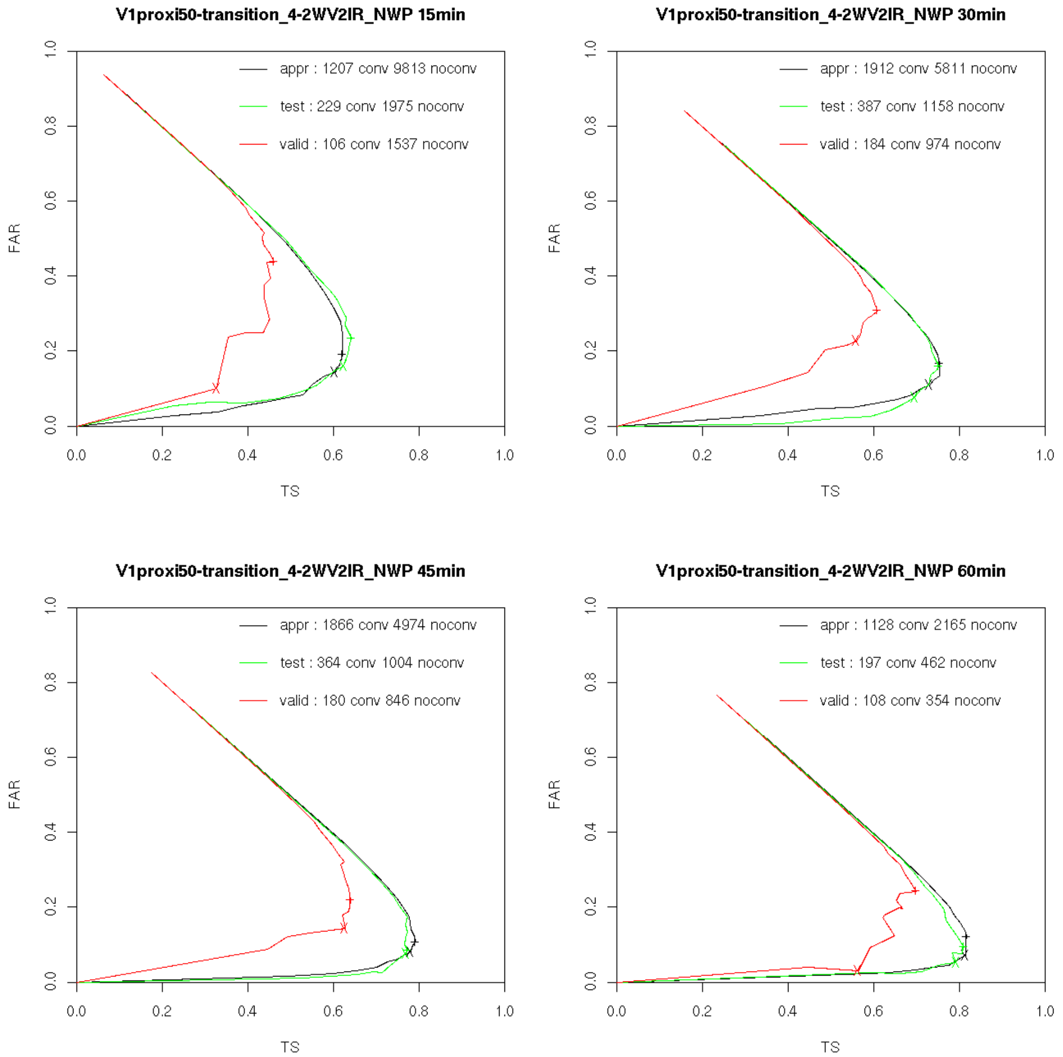


Figure 38 MSG V2011 tuning for Warm1 transition category, full configuration, 4 available depth

6. DISCRIMINATION ON WARM CATEGORY (DW)

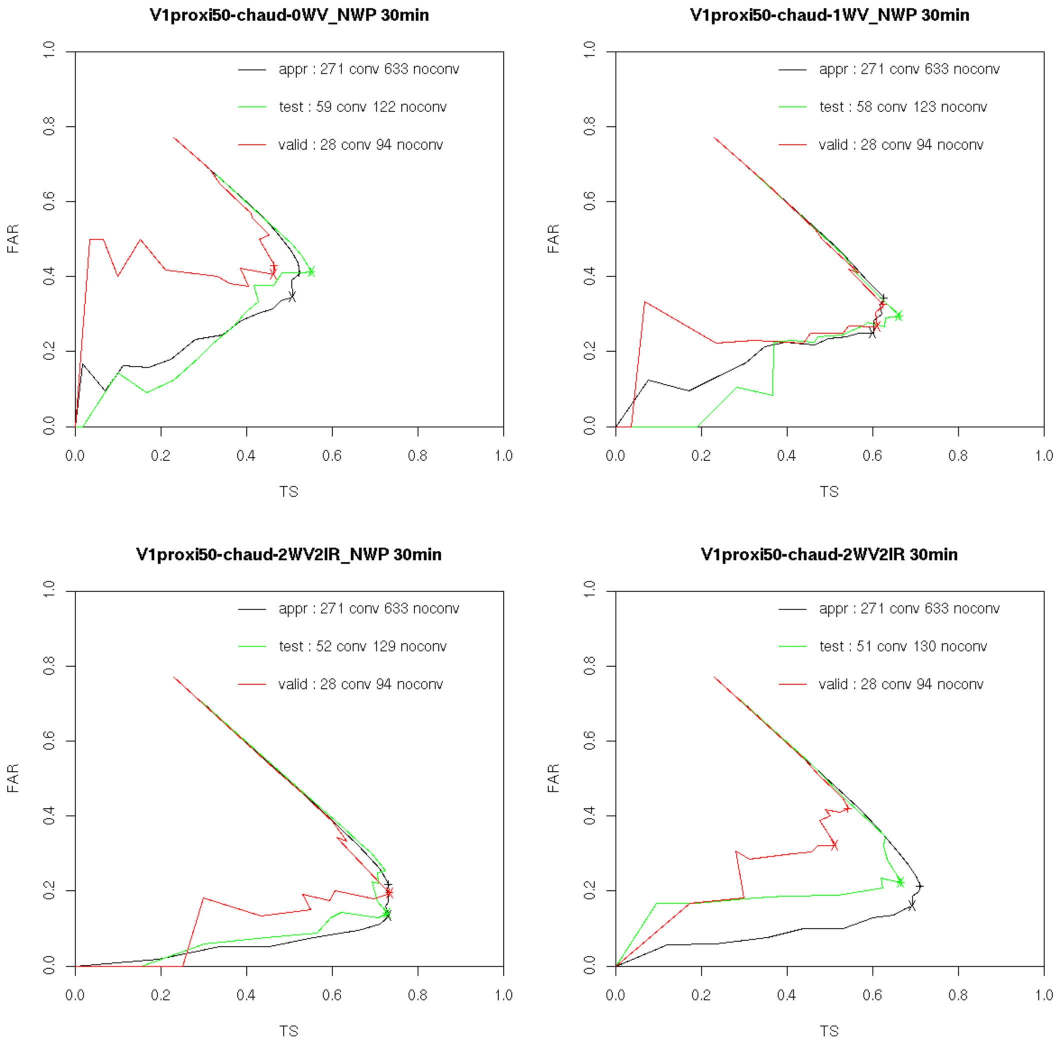


Figure 39: : MSG V2011 tuning for Warm category, 45 min depth, for 4 configurations : With NWP (top) with IR10.8 only (top left), IR10.8 and WV6.2 (top right), with 2 WV et 2 IR (bottom left) and with 2 WV et 2 IR without NWP (bottom right)

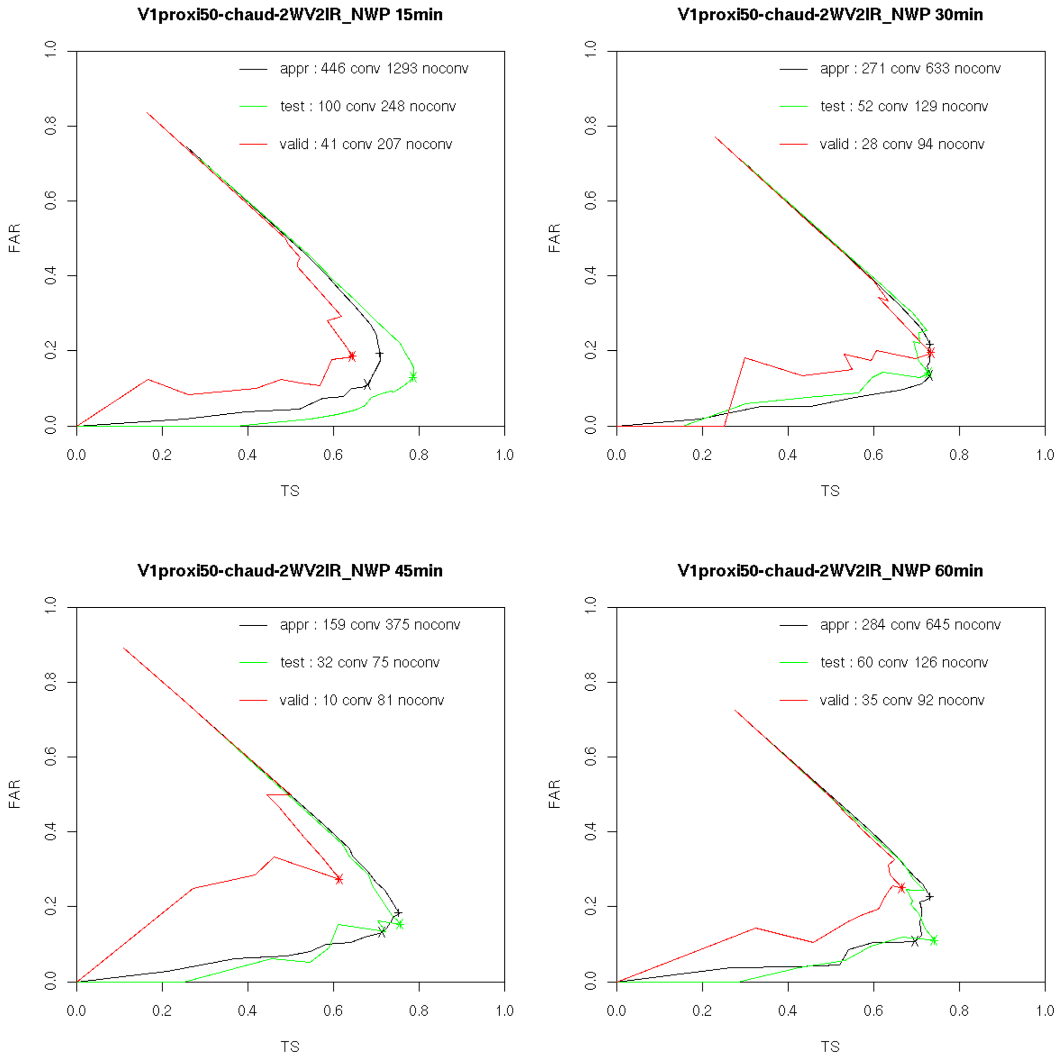


Figure 40 MSG V2011 tuning for Warm category, full configuration, 4 available depth

ANNEX C – The statistical model score for Rapid Scan

7. MATURE DISCRIMINATION (DM)

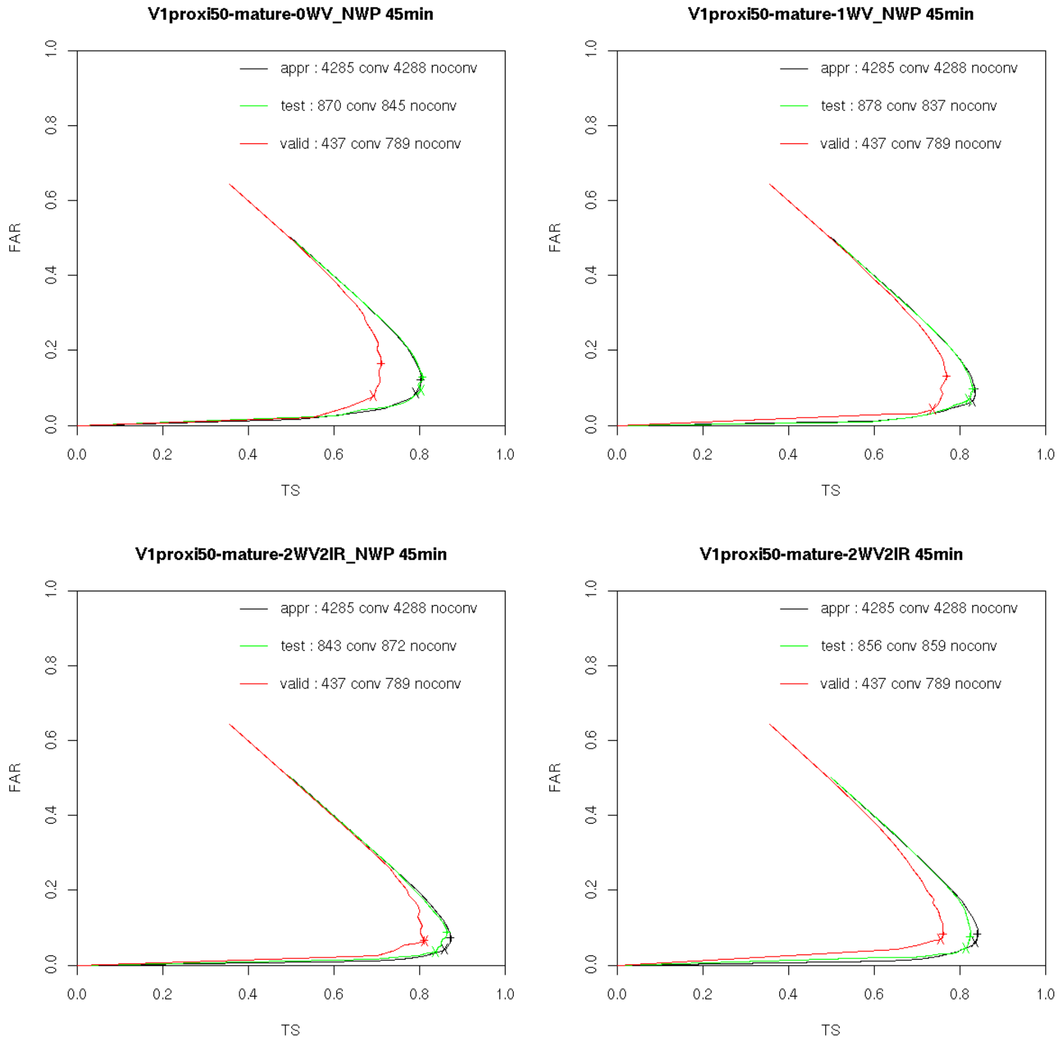


Figure 41: *RSS V2011 tuning for mature category, 45 min depth, for 4 configurations :* With NWP (top) with IR10.8 only (top left), IR10.8 and WV6.2 (top right), with 2 WV et 2 IR (bottom left) and with 2 WV et 2 IR without NWP (bottom right)

8. DISCRIMINATION ON MATURE TRANSITION (DTM)

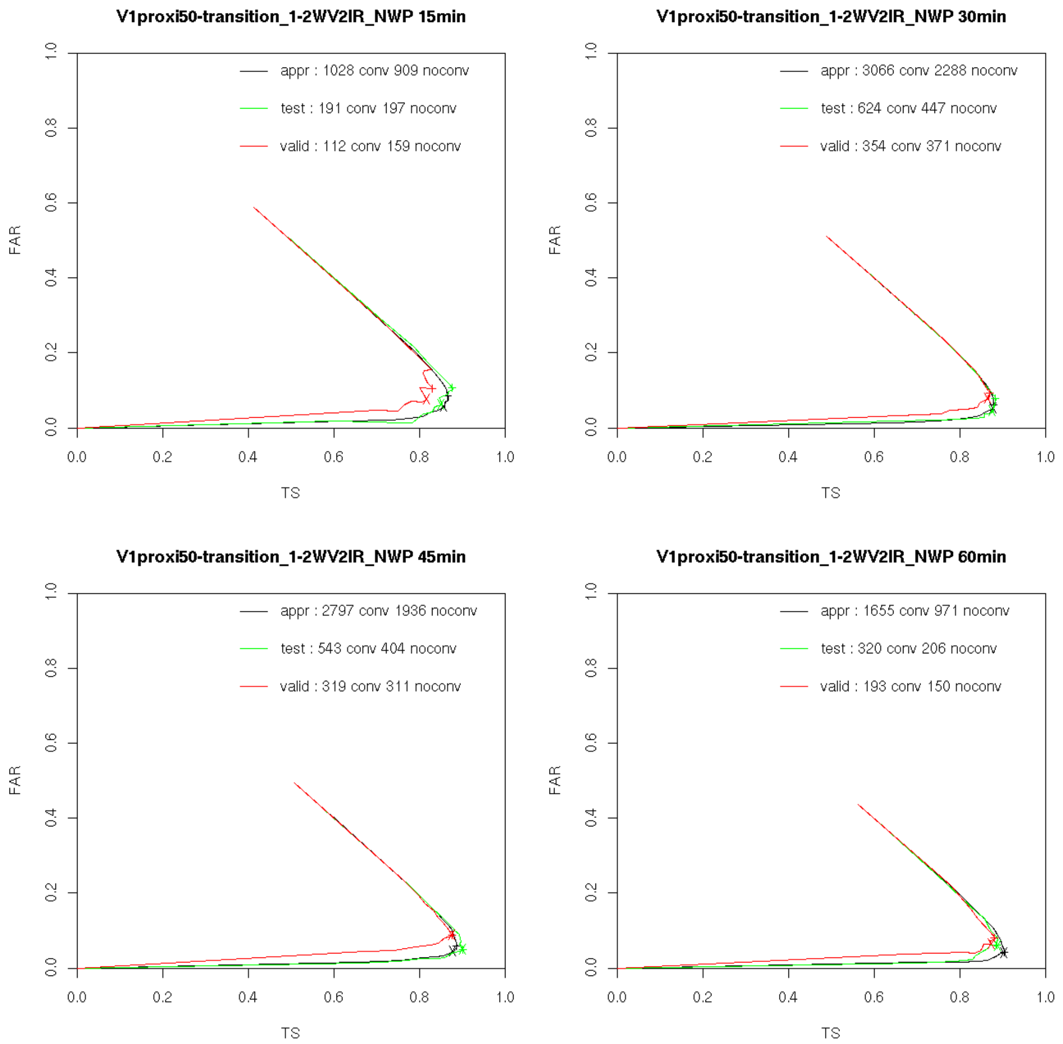


Figure 42: RSS V2011 tuning for transition mature category, full configuration, 4 available depths

9. DISCRIMINATION ON COLD TRANSITION (DTC)

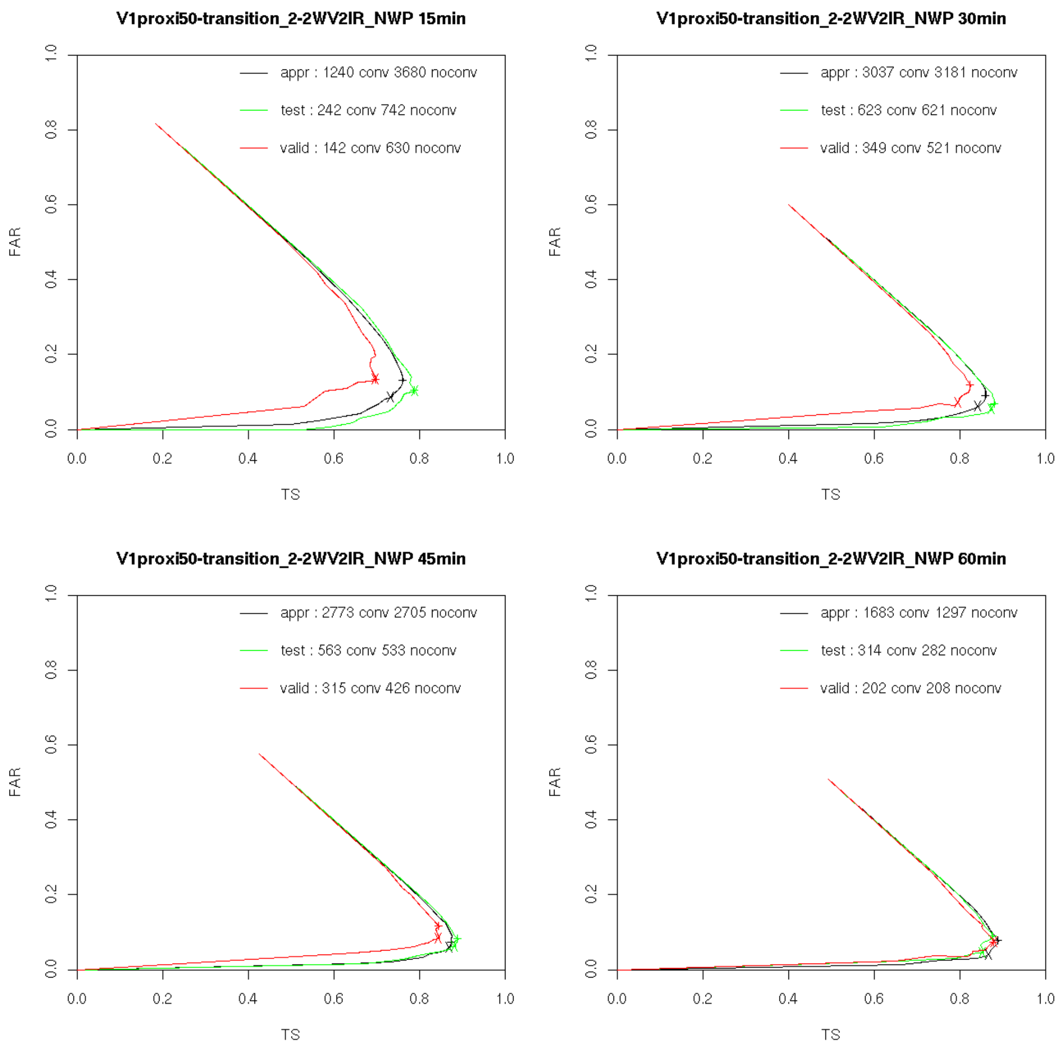


Figure 43: RSS V2011 tuning for cold transition category, full configuration, 4 available depths

10. DISCRIMINATION ON WARM2 TRANSITION (DTW2)

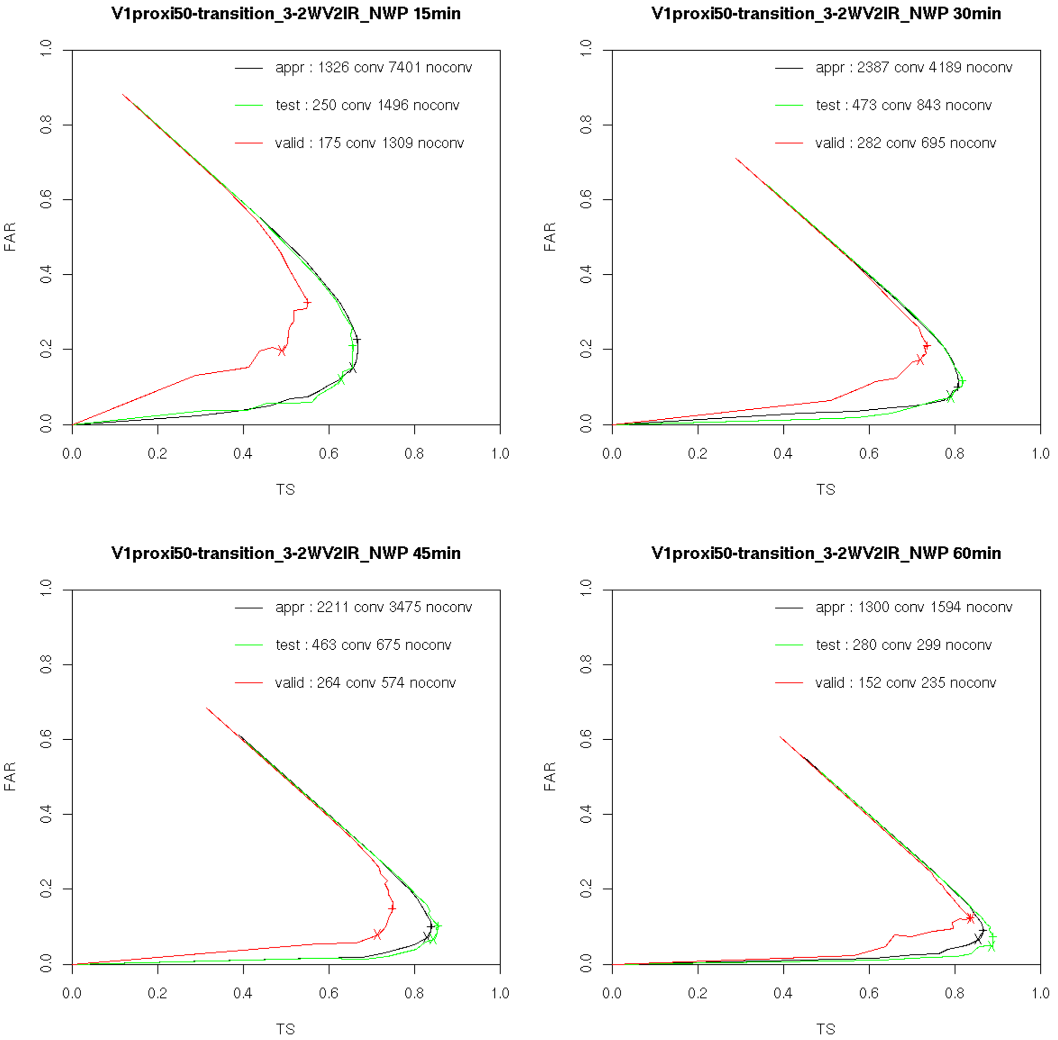


Figure 44: RSS V2011 tuning for Warm2 transition category, full configuration, 4 available depths

11. DISCRIMINATION ON WARM1 TRANSITION (DTW1)

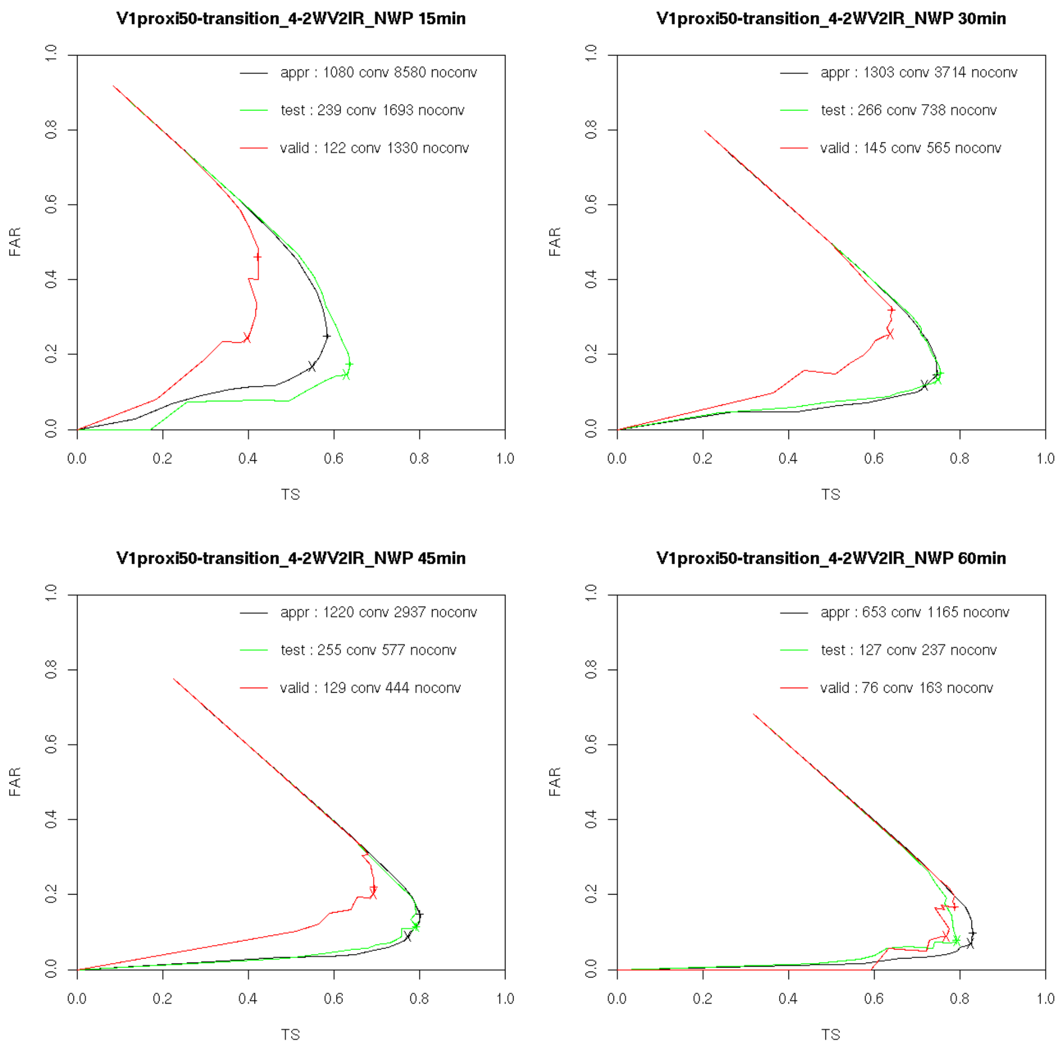


Figure 45: RSS V2011 tuning for Warm1 transition category, full configuration, 4 available depths

12. DISCRIMINATION ON WARM CATEGORY (DW)

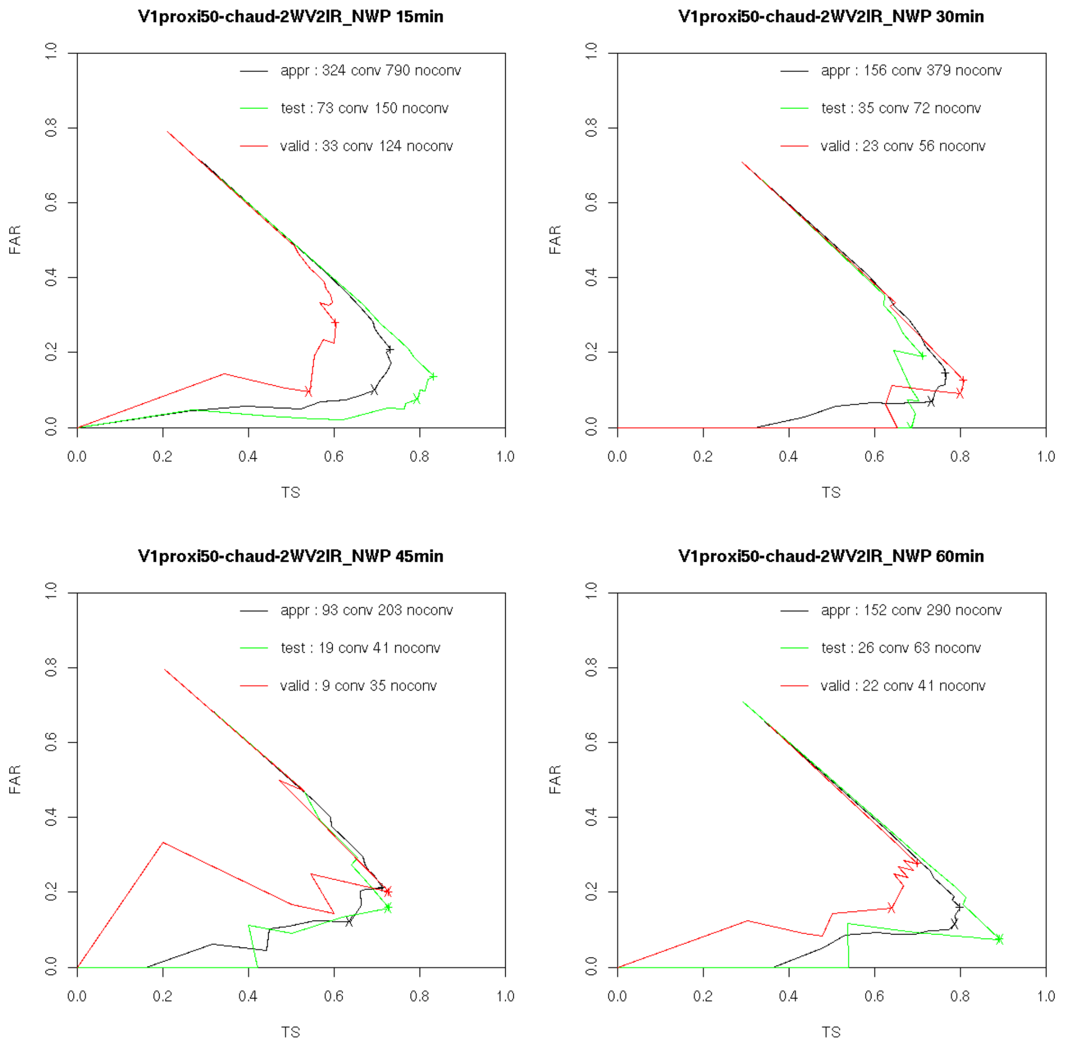


Figure 46: RSS V2011 tuning for Warm category, full configuration, 4 available depths