Validation report of the Convection Product Processors of the NWC/GEO

NWC/CDOP2/GEO/MFT/SCI/VR, Issue 1, Rev. 0

15th October 2016

Applicable to

GEO-CI v1.0 (NWC-052)

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

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REPORT SIGNATURE TABLE

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Version	Date	Pages	Changes
1.0d	*15 January 2016*		Draft version for STRR
1.1d	1st April 2016	18	Draft version after STRR
1.0	*15th October 2016*	58	Final version after DRR

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1 INTRODUCTION

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

1.1 SCOPE OF THE DOCUMENT

This document is the convection product validation report applicable to NWC/GEO software package v2016. The accuracies of the Convection Products components PGE18 (GEO-CI, Convection Initiation) and PGE19 (GEO-RDT-CW, Rapid Development Thunderstorm Convection Warning) are discussed.

1.2 SOFTWARE VERSION IDENTIFICATION

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

1.3 REQUIREMENTS

Skill requirements had been expressed in PRD Table for RDT and CI (see [RD.2.]).

- CI:
  - accuracy : FAR<0.6 POD>0.4
  - target FAR<0.5 POD>0.5
  - optimal: FAR<0.4 POD>0.6 "
- RDT
  - Accuracy
    - 1) early detection (before first lightning occurrence) 10%
    - 2) 30 minutes after first lightning occurrence 30%
    - 3) overall thunderstorm detection skill 50%"
  - Target
    - 1) early detection (before first lightning occurrence) 25%
    - 2) 30 minutes after first lightning occurrence 50%

        - 3) overall thunderstorm detection skill 70%"
    - Optimal
        - 1) early detection (before first lightning occurrence) 50%
        - 2) 30 minutes after first lightning occurrence 75%
        - 3) overall thunderstorm detection skill 90%"

1.4 Definitions, Acronyms and Abbreviations

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

1.5 References

1.5.1 Applicable documents

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

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

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

Ref	Title	Code	Vers	Date
[AD.1.]	Proposal for the Second Continuous Development and operation Phase (CDOP) march 2012 – February 2017	NWC/SCDOP2/MGT/AEMET/PRO	1.0	15/3/2016
[AD.2.]	NWCSAF Project Plan	NWC/CDOP2/SAGF/AEMET/MGT/PP	1.9	15/10/2016
[AD.3.]	Configuration Management Plan for the NWCSAF	NWC/CDOP2/SAF/AEMET/MGT/CMP	1.4	15/10/2016
[AD.4.]	NWCSAF Product Requirement Document	NWC/CDOP2/SAF/AEMET/MGT/PRD	1.9	Aug 2016
[AD.5.]	System and Components Requirements Document	NWC/CDOP2/GEO/AEMET/SW/SCRD	1.2	15/10/2016
[AD.6.]	Interface Control Document for Internal and External Interfaces of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/ICD/1	1.1	15/10/2016
[AD.7.]	Interface Control Document for the NWCLIB of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/ICD/2	1.1	15/10/2016
[AD.8.]	Data Output Format for the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/DOF	1.1	15/10/2016
[AD.9.]	Architectural Design Document for the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/ACDD	1.1	15/10/2016
[AD.10.]	Component Design Document for the Convection Product Processors of the NWC/GEO	NWC/CDOP2/GEO/MFT/SW/ACDD/Convection	1.1	15/10/2016
[AD.11.]	Algorithm Theoretical Basis Document for the Convection Product Processors of the NWC/GEO	NWC/CDOP2/GEO/MFT/SCI/ATBD/Convection	1.1	15/10/2016

Table 1: List of Applicable Documents

1.5.2 Reference documents

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

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

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

Ref	Title	Code	Vers	Date
[RD.1.]	The Nowcasting SAF glossary	NWC/CDOP2/SAF/AEMET/MGT/GLO	1.2	18/2/2014
[RD.2.]	NWCSAF Product Requirements Document	SAF/NWC/CDOP/INM/MGT/PRD	*1.9*	*aug 2016*

Table 2: List of Referenced Documents

2 CONVECTION INITIATION (GEO-CI) VALIDATION

2.1 OVERVIEW

2.1.1 General objectives of the validation

The main objective of this section is to document Convection Initiation product accuracy. The method used has to compare POD and FAR scores to the threshold accuracies listed in the NWCSAF product requirements document [RD.2.]: FAR<0.6, POD>0.4

2.1.2 Methodology outline

The following validation of the CI product has to be performed:

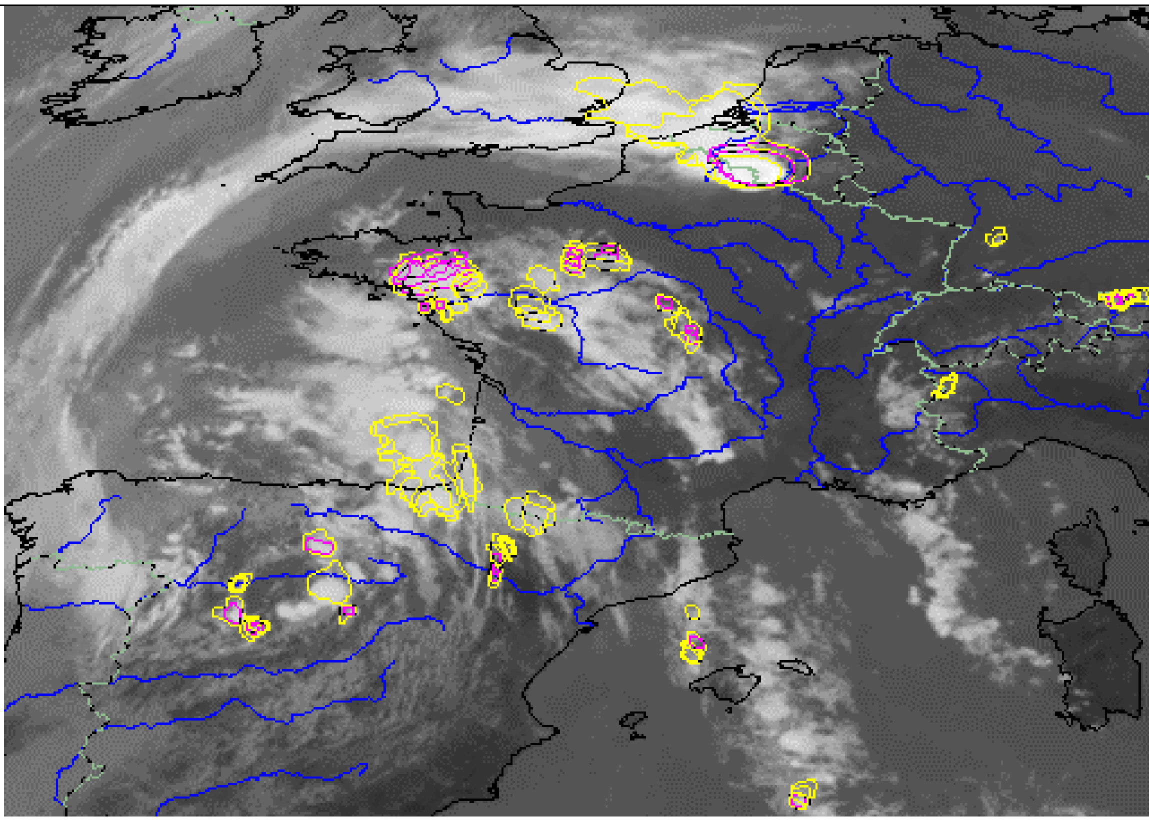
- The CI probabilities over identified pixels will be assessed regarding the evolution of convection during the following corresponding period over those pixels: 30 minutes for parameter ci_prob30, 60min for ci_prob60, etc.
- Presence of convective cloud cell from RDT-CW product will first be used as ground truth to assess the product. Smoothed path tracks of convective cloud cells over the corresponding period will allow to define areas of pixels where convection has been observed from a satellite point of view.
  Using radar data above 30dBZ or lightning data strokes will complement this ground truth, but only inside specific coverage areas (French radar or lightning network areas). In order to take into account representativity issues, those data will be cumulated over the corresponding periods, smoothed and enlarged.
- Once convective masks have been elaborated for each slot over the corresponding periods, each CI parameter (ci_prob30 only for this first v2016 release) is regarded vs the ground truth of the corresponding period.

2.2 CI VERIFICATION

RDT cloud cells are not always defined by the same temperature threshold from one slot to another. The most realistic approach to identify "convective" areas during a given period is to gather successive contours of a given convective cloud cell and process a convex hull of those elements, producing a whole path track over the period. Such an approach provides a "convective mask" valid for a given period, with pixels sets to 0 or 1 depending on their position relative to the convective path track (see *Figure* 1).

Similar approach is undertaken with radar images, which are thresholded over 30 dBZ, then smoothed (median filter over 3 km) and enlarged (dilation operation over 3 km) to take into account uncertainty and tolerance. Corresponding pixels provide a radar convective mask over the period.

Finally, lightning data network allow to complete this approach, with enlarged strokes (10 km) during a given period providing a convective lightning mask.



RDT contours cumulated over 30min, superimposed on IR image of 11h00Z slot on 25/05/2009

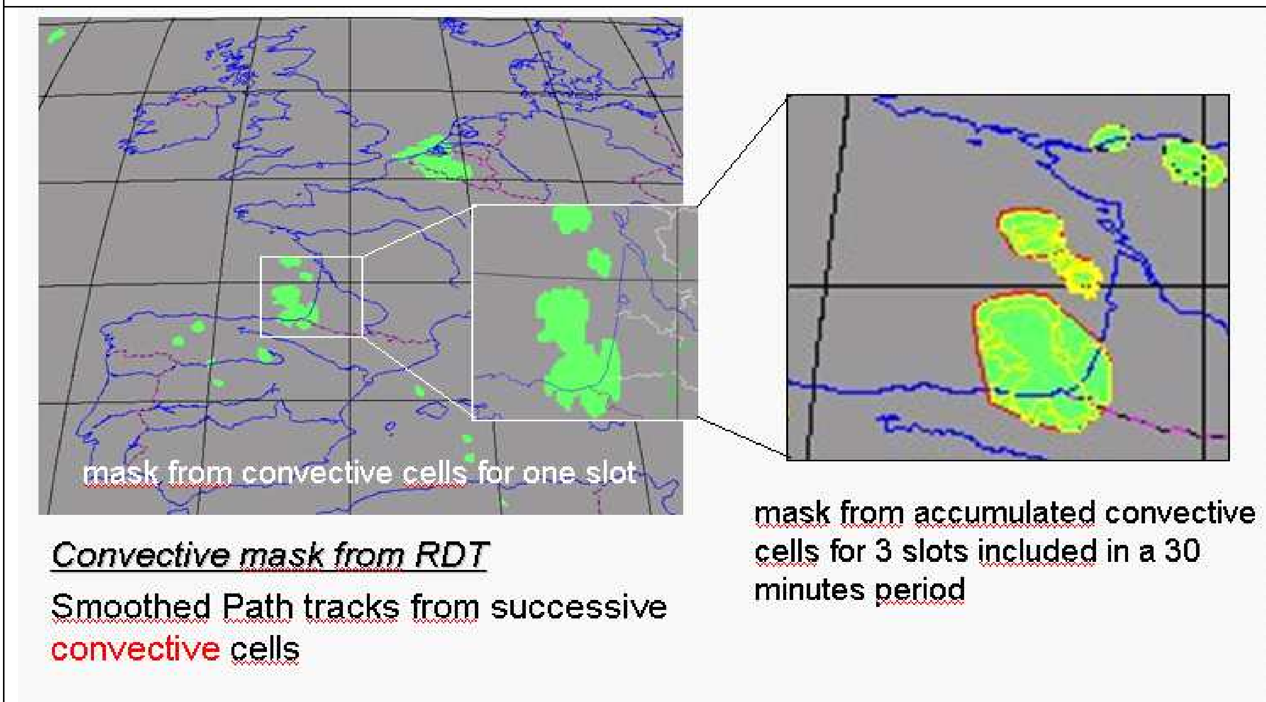
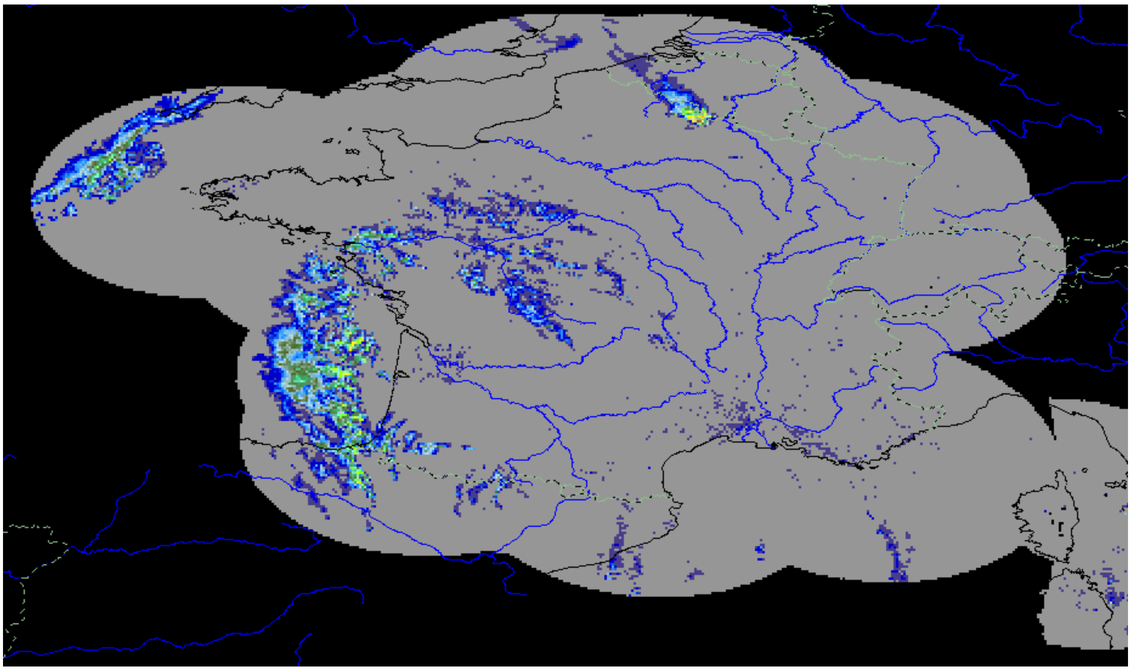


Figure 1: Elaboration of RDT ground truth for CI . A convex hull for accumulated contours over a given period identifies path tracks and thus areas of convective pixels



Radar reflectivity (dBZ) for 11h00Z on 25/05/2009

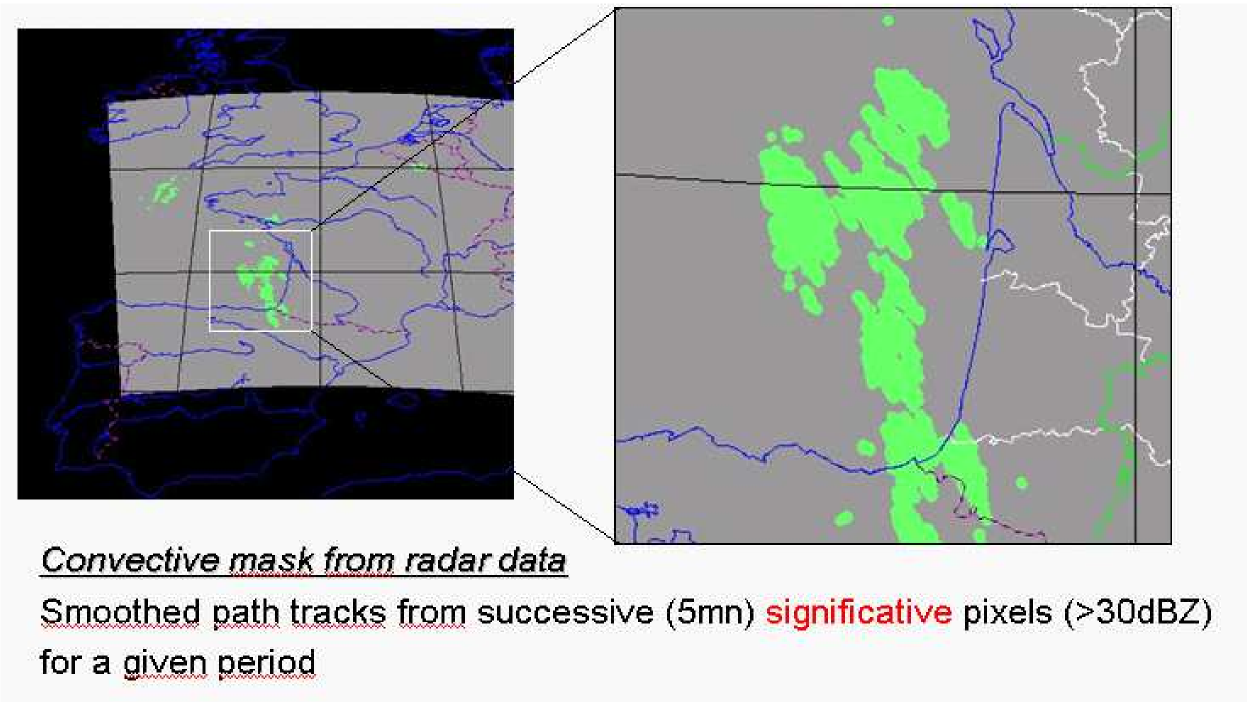
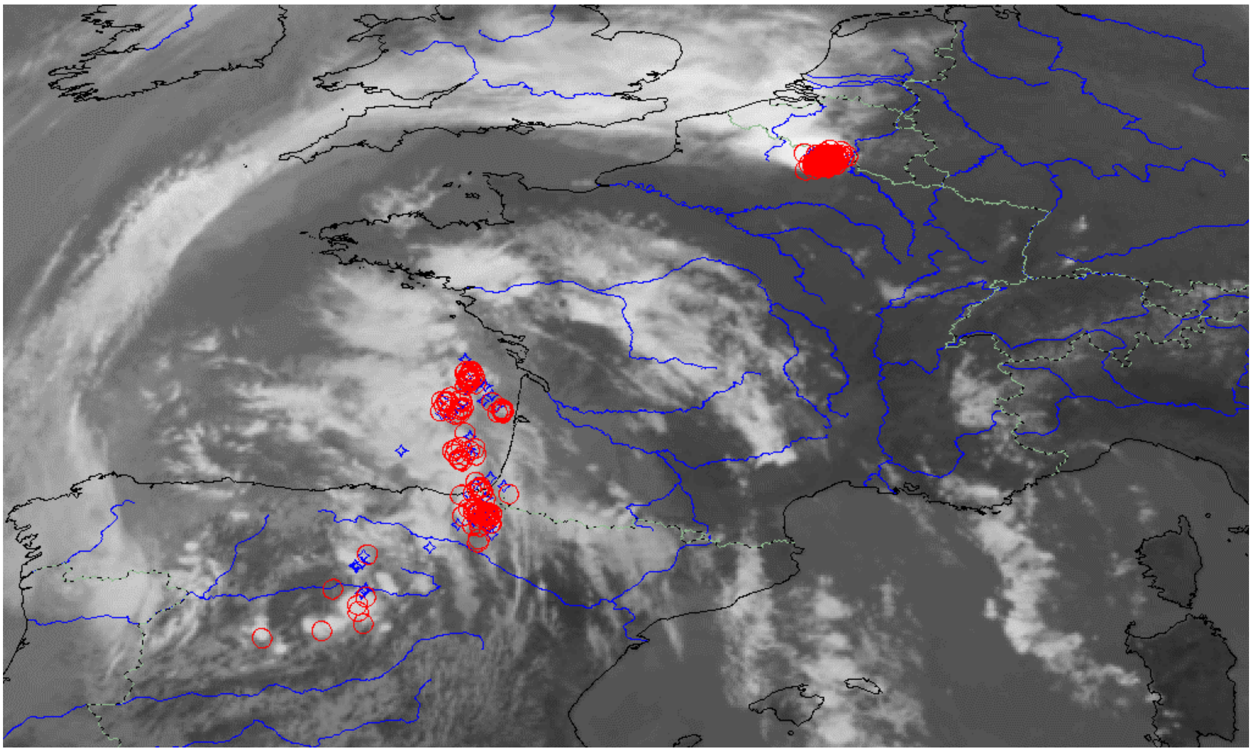


Figure 2: Elaboration of radar ground truth for CI over coverage area . Accumulated pixels with reflectivity over 30 dBZ during a given period identifies path tracks and thus areas of active pixels



Lightning strokes (red-negative, blue-positive) accumulated over 30min from 11h00Z on 25/05/2009

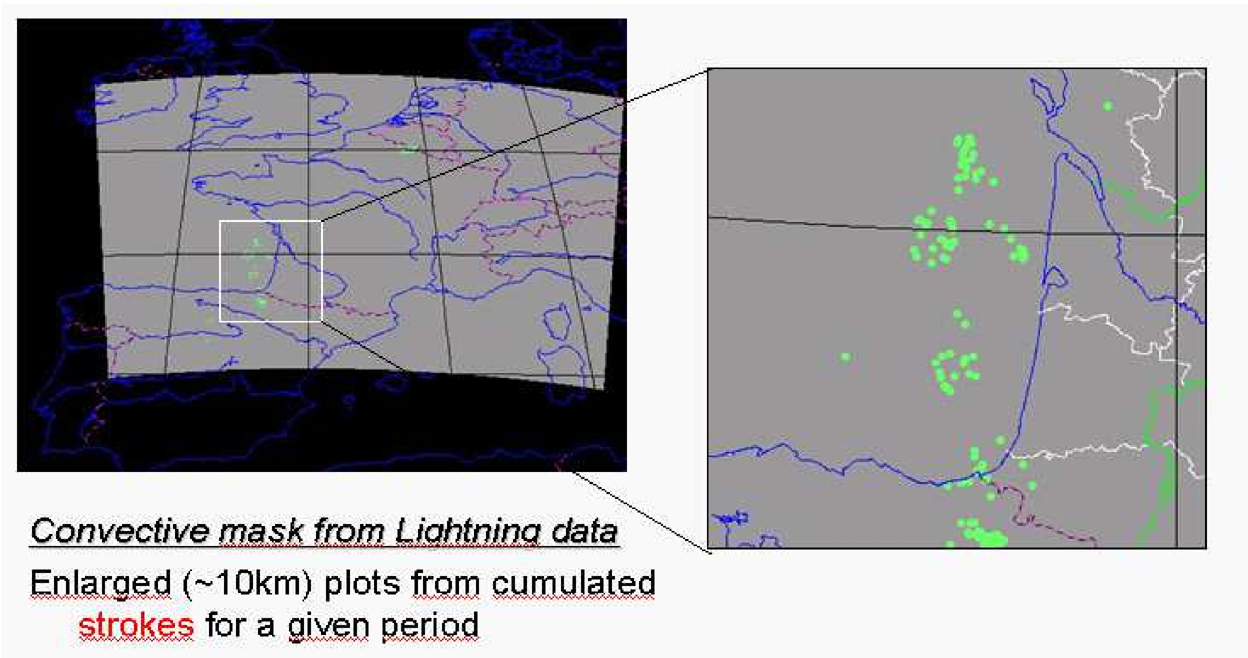


Figure 3: Elaboration of lightning ground truth for CI over specific coverage area. Accumulated and enlarged strokes over a given period identify areas of active pixels

2.3 CASES STUDY

The methodology described above should be applied to situations where CI may be produced in full configuration mode, i.e. with CT product and an estimation of pixel movement as precise as possible, using NWP and HRW data to manage a movement guess field. Thus, 2010 situations with corresponding reprocessed products have been identified: 25/05/2010, 15/06/2010, 28/06/2010, 02-03/07/2010, 06-07/09/2010.

Other pre-selected dates (25/05/2009, 1-6/06/2013) have been identified, even if less complete with optional input data.

CI and RDT product will have to be processed over those dates to undertake widest verification/validation data sets.

2.4 CONCLUSION

CI v2016 is the first delivery of the product. All forecasting aspects of the product are not available, since diagnosis is limited to [0-30min] period. The present validation is still fragmentary and remains based on subjective elements. Nevertheless this first release provides promising output.

3 RAPID DEVELOPMENT THUNDERSTORM – CONVECTION WARNING (GEO-RDT-CW) VALIDATION

3.1 OVERVIEW

The main objective of this section is to document RDT convective discrimination accuracies and compare them to the threshold accuracies listed in the NWCSAF product requirements document [RD.2.]. As the RDT discrimination scheme has remained unchanged between v2013 and v2016, we only remind the existing validation over European areas.

Concerning the forecast capabilities (forecast products) included in RDT-CW code (CW part) it is to note that thunderstorm conceptual models often show a rapid morphological evolution and intensity variability, for which satellite data bring not enough information. A subjective evaluation based on cases study will be undertaken for an analysis of the localization of extrapolated cloud cells, depending on moving speed estimate accuracy and morphological evolution of the cloud systems.

3.2 VALIDATION DATA FOR DISCRIMINATION DIAGNOSIS

3.2.1 Lightning EUCLID data

Those data concern stroke returns of Cloud-to-Ground flashes, collected from several interconnected national lightning detection networks over Europe.

Available parameters are: time of the event, impact point coordinates (latitude and longitude), Current intensity and polarity.

Database has been explored to assess the geographical and temporal coverage of the data.

The requested period is fully covered, with high continuity, as illustrated for example in the figure below for summer 2008.

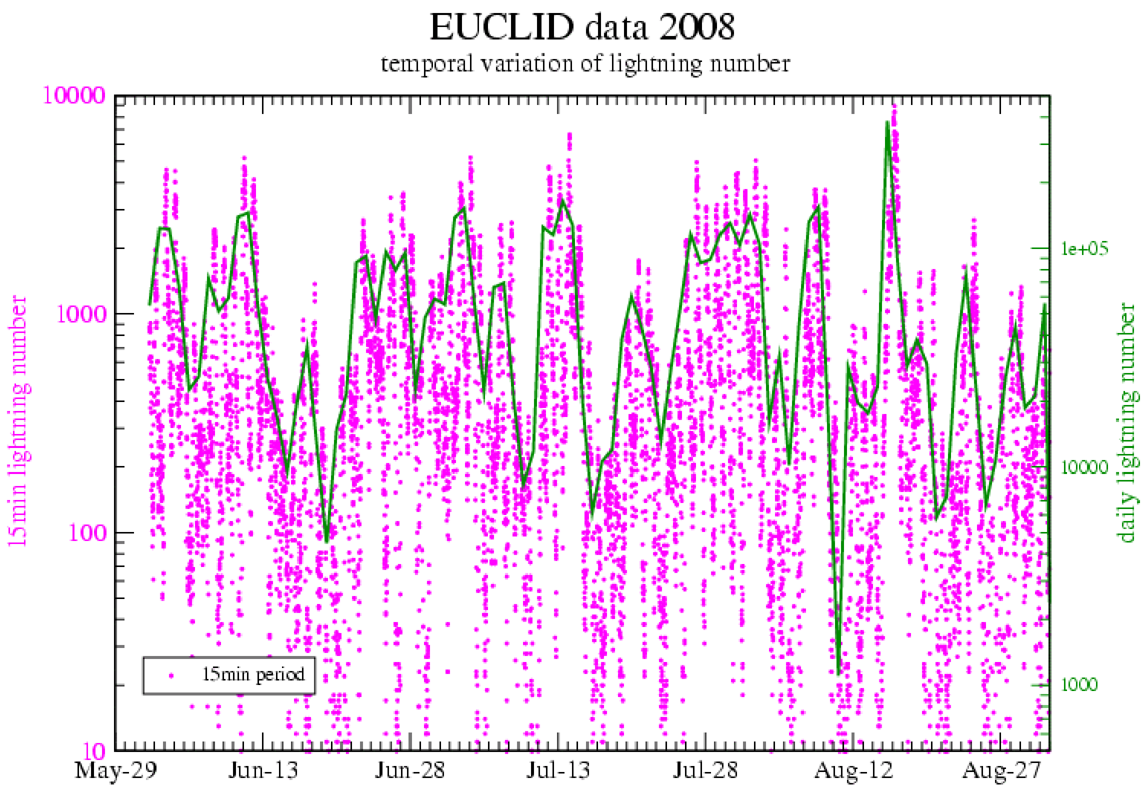


Figure 4: June-August 2008 - Temporal series of lightning impacts, cumulated over 15min (pink) or daily (green)

On the other hand, monthly and total density charts have pointed the most active areas, as well as the lack of coverage (following figure).

There are very few data over United Kingdom. Network at the time of validation were sparser than nowadays (cf EUCLID source). Consequently, although in the present nominal coverage area (see Annex I), this area has to be considered carefully when lightning data is used as ground truth (a lightning detection weakness should lead to bad scores for RDT).

The Iberian peninsula shows also a relatively weak electrical activity over the period, but no additional element allows ignoring this region. We have assumed that EUCLID data are representative of a rather low convective activity during 2008 and 2009 periods over this region.

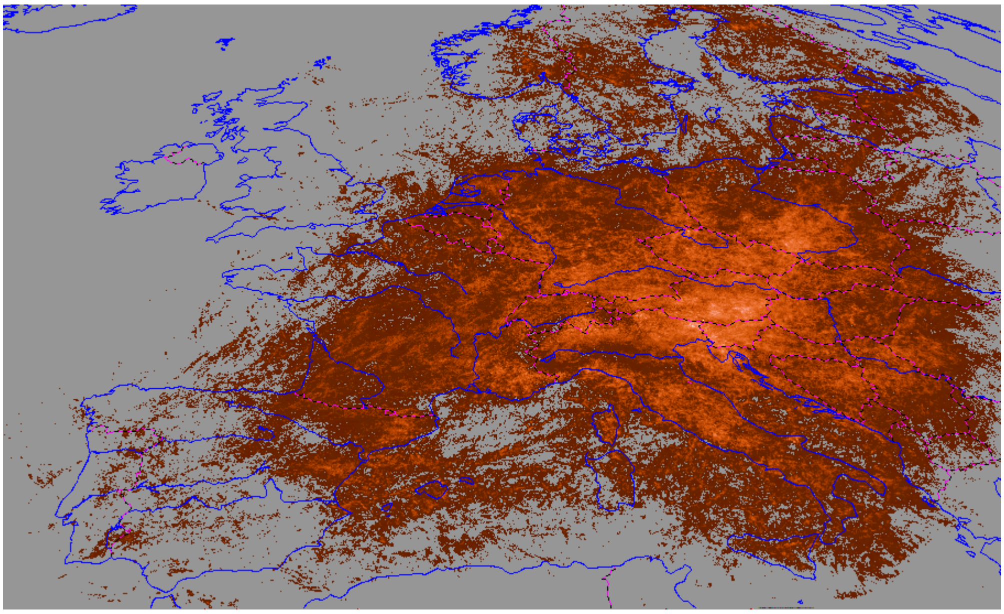


Figure 5: Total geographical density (nb / pixel) of EUCLID lightnings over customized region (summer 2008 + April-October 2009)

This exploration lead to define a new domain for the validation, as the intersection between EUCLID coverage data and local MSG archived data.

Moreover, a mask of non-detection has also been defined, merged from nominal detection area (see Annex I) and the observed availability of data over the period. This mask allows ignoring suspicious areas (from detection point of view) in the validation process.

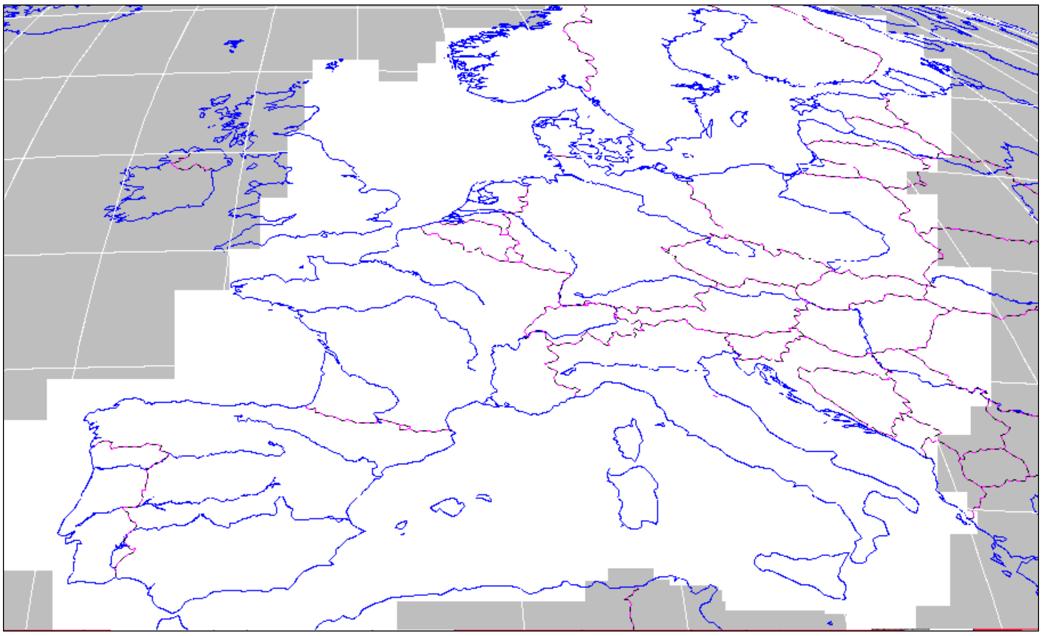


Figure 6: Domain and detection mask defined and applied for validation purpose

3.2.2 RDT Cloud trajectories

Validation needs cloud-cell trajectories, processed over the period and the domain described above. A trajectory aggregates all RDT objects linked in time. RDT Discrimination diagnosis is activated for each cloud cell using satellite information only, and a passive matching with lightning data is undertaken at this stage for further evaluation.

Concerning the matching between cloud cells and lightning flashes, some limitations have to be taken into account: on one side, the lightning location is limited to cloud to ground flashes strokes; on the other side, the RDT object depicts cloud tower and not the whole cloud system. Thus, some matching misses between lightning data and cloud object are possible. Thus, a spatial tolerance of about 10 km has been taken into account, and a proximity distance to the nearest flash evaluated.

An illustration of the process result is proposed below, by comparing lightning and cloud cell data. The figure describes:

- Total lightning number over the region for each slot, number of paired flashes (association lightning – cloud cell), number of orphan flashes (despite a 10 km spatial tolerance), number of flashes out of domain or temporal range (slot ± 8min)
- Total number of detected and tracked cloud cells, number of convective RDT-diagnosed cells, and repartition of total cloud cell number against NWP convective environment (result of NWP guidance)

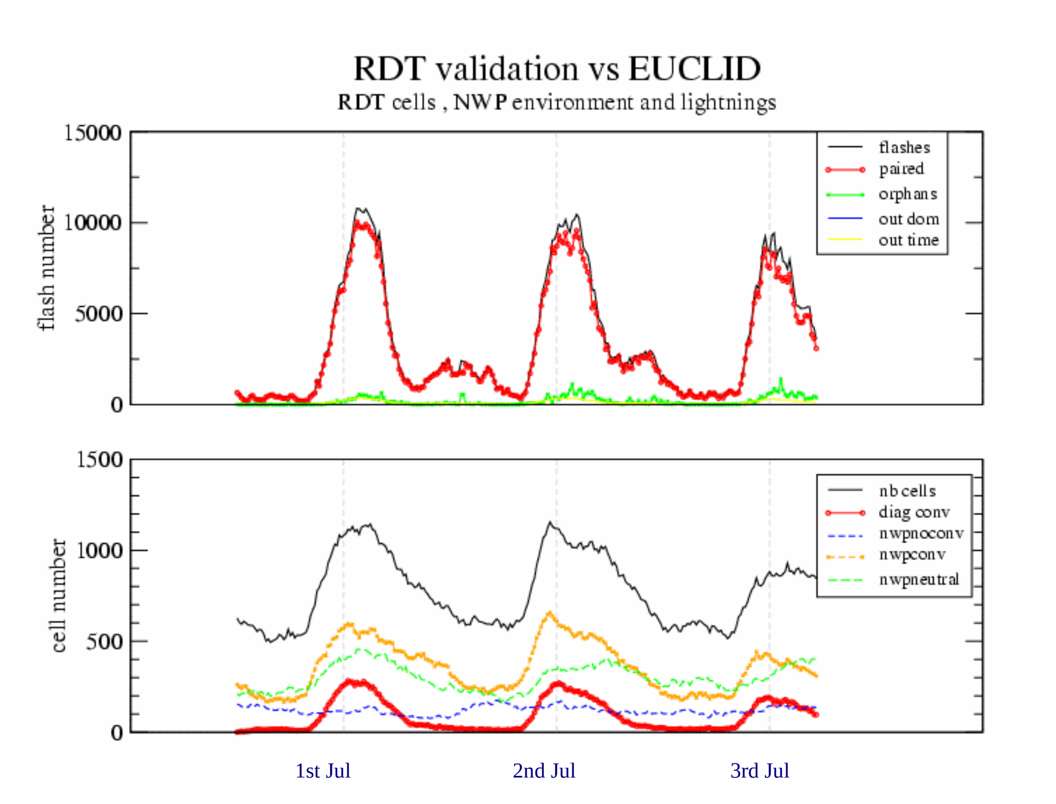


Figure 7: Example 1-3rd July 2009. Total, paired and orphans lightning number for each slot (top). Total and convective Cloud cell number for each slot (bottom)

3.3 VALIDATION METHODOLOGY FOR DISCRIMINATION DIAGNOSIS

The validation process relies on a detailed analysis of the electrical activity of cloud trajectories. This electrical activity analyzed over the life of the cloud systems constitutes the "ground truth".

3.3.1 The Ground truth

3.3.1.1 The Ground truth for trajectories

The definition retained to identify a trajectory as "observed" convective or non-convective is seen globally as a first step, based on the total number of flashes strokes paired during the whole RDT object life.

In order to ignore eventual less reliable cases due to wrong matching, several level of intensity are considered. Three levels of ground truth have been defined:

- **Low**: a trajectory is assumed convective if it is matching with one flash stroke at least
- **Moderate**: a trajectory is assumed convective if it is matching with 5 flashes strokes at least
- **Severe**: a trajectory is assumed convective if it is matching with more than 20 flashes strokes, and if it reveals a continuous activity

Considering a higher intensity for ground truth implies

- that the number of trajectories observed as convective decreases
- that the number of undetermined trajectories, which are not enough electrically active, increases.

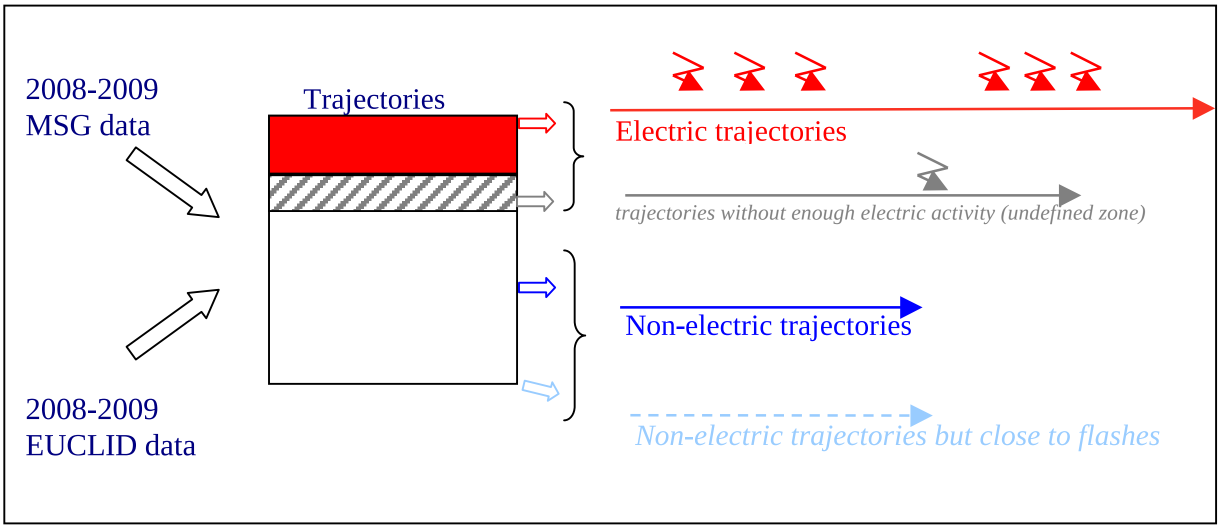


Figure 8: Full-trajectory approach. Population are split considering ground truth and flashes proximity

When the level is fixed at "low", there is no undetermined trajectory. When the level is fixed at "severe", the number of undetermined trajectories is maximum. The trajectory without lightning activity are assumed non convective. Indeterminate trajectory are eliminated of the validation

Here again the uncertainty of cloud-flash matching may be taken into account, by the use of distance to nearest flash (called here **proximity to flashes**). Some cumuliform cloud systems are in the nearest of active thunderstorms but do not degenerate themselves to thunderstorms. Do these clouds have to be considered as convective or not ? Depending on the sense given to a False Alarm (would in that case a RDT convective diagnosis be unacceptable?), it can be useful to ignore ambiguous non-electric trajectories close to flashes. Several levels of filters (distance to flashes) have been evaluated.

3.3.1.2 Detailed analysis of activity on sections and time steps

This full-trajectory ground truth does not take into account the variability of electric activity, neither its time of occurrence. An assessment of RDT discrimination with this approach allows providing only gross scores. Moreover, it neglects the synchronicity between RDT discrimination and lightning occurrence. A similar limitation appears at finest time scale if we consider each single moment of a trajectory independently of the others.

In order to focus on most active periods of cloud systems or on precocity characteristics prior to first flashes, a more conceptual approach is necessary.

A ground truth is here defined closer to convective periods. The cloud trajectories will be cut in several homogeneous periods, depending on the occurrence, intensity and continuity of electrical activity.

3.3.1.2.1 Definition of sections and time steps

The lightning activity is not permanent on an electric (or undefined) trajectory. Six kinds of homogeneous periods may be defined as sections and time steps:

- Black: first non-electric period of an electric trajectory, preceding first flash of more than one hour.
- Green: The precocity section. Non-electric period of 1 hour, preceding an electric period. The length of this period is empirically sized to include the growing stage of convective systems.
- Red: The electric section. Electrically active period including all time steps continuously electric or surrounded by electric time steps spaced out of less than 45 minutes. The lapse time of 45 minutes corresponds to the pre-supposed validity of convective diagnosis in the RDT-CW code, beyond which a de-classification test is undertaken.
- Orange: The decaying section. Non-electric period of 45 minutes following an electric period (same remark as above concerning the value of 45 min). Its duration could be reduced in advantage to another following precocity section.
- Violet: The intermediate section. Non electric period between two electric sections excepted precocity and decaying section.
- Gray: last non electric period following the last decaying section.

A non-electric trajectory can define only one kind of section and time steps:

- Yellow: unique non electric period of a non electric trajectory

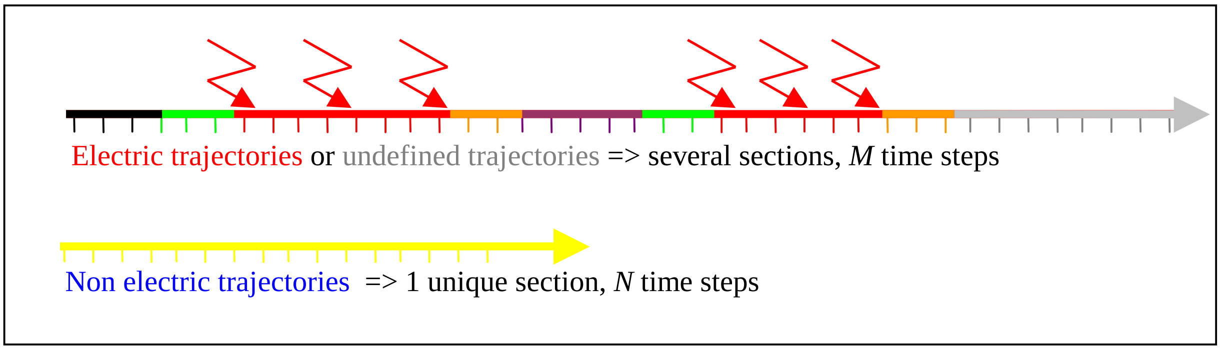


Figure 9: Section and time step examples for an electric trajectory (top) and for a non electric trajectory (bottom)

3.3.1.3 Conclusion on ground truth

The statistical elements evaluated in this report will be either the whole life cycle duration (so called "trajectory"), a part of this life cycle (so called "section"), or a single moment of the cloud cell life cycle (so called "time step"). Those elements have to be examined against RDT diagnosis.

- Convective "observation" for Trajectory elements = full-trajectory ground truth (total electric activity)
- Convective "observation" for Section elements = "colour" of the section
- Convective "observation" for Time step" elements = "colour" of the corresponding section

3.3.2 RDT diagnosis of statistical elements

The RDT-CW discrimination scheme allows a convective diagnosis for each detected and tracked cloud cell, i.e. for each time step. This diagnosis is the result of a statistical model, or is inherited from previous diagnosis.

- RDT Diagnosis for Time step element = result of discrimination scheme (type of cell)

Concerning sections of trajectories, all RDT diagnosis of all time steps of a section have to be taken into account. A convective diagnosis of a single cell at any given time of this section will apply the whole section that cell belongs to.

- RDT diagnosis for Section element = convective if at least one time step of section has convective RDT diagnosis, non convective in other case

As for section elements, all RDT diagnosis of all time steps of a trajectory have to be taken into account. A convective diagnosis of a single cell at any given time will apply to the entire trajectory of that cell.

- RDT diagnosis for Trajectory element = convective if at least one time step of trajectory has convective RDT diagnosis, non convective in other case

3.3.3 Evaluation methodology

3.3.3.1 Full trajectory approach

In this case, RDT diagnosis is directly assessed against YES or NO electric characteristics, while these characteristics are modulated with the ground truth intensity or the flashes proximity.

This leads to contingency tables, from which POD, POFD, FAR or other skills can be derived.

	Convective « Observed »	Non convective « Observed »
Convective diagnosis	Good Detection: **GD** *Trajectory*: electric	False Alarm: **FA** *Trajectory*: non electric
Non convective diagnosis	Miss: **MI** *Trajectory*: electric	Correct Rejection: **CR** *Trajectory*: non electric

Probability of detection (hit rate): POD= GD/(GD+MI)

Fraction of the observed "yes" events correctly forecast

Characteristics: Range: 0 to 1. Perfect score: 1. Sensitive to hits, but ignores false alarms. Very sensitive to the climatological frequency of the event. Good for rare events. Can be artificially improved by issuing more "yes" forecasts to increase the number of hits. Should be used in conjunction with the FAR Source : The Centre for Australian Weather and Climate Research, http://www.cawcr.gov.au/projects/verification/).

False alarm ratio : FAR= FA/(GD+FA)

Fraction of the predicted "yes" events which did not occur (i.e., were false alarms)

Characteristics: Range: 0 to 1. Perfect score: 0. Sensitive to false alarms, but ignores misses. Very sensitive to the climatological frequency of the event. Should be used in conjunction with POD.

Probability of false detection (false alarm rate) POFD= FA/(FA+CR)

Fraction of the observed "no" events incorrectly forecast as "yes"

Characteristics: Range: 0 to 1. Perfect score: 0. Sensitive to false alarms, but ignores misses. Can be artificially improved by issuing fewer "yes" forecasts to reduce the number of false alarms.

Threat Score : TS= GD/(GD+FA+MI)

Combination of hits, false alarms and misses

Characteristics: Range: 0 to 1. Perfect score: 1. Sensitive to false alarms and misses.

Relatively frequently used because a more balanced score. Somewhat sensitive to the climatology of the event, tending to give poorer scores for rare events.

In order to increase the readability of the report, the numbers associated to the scores will be listed in percentage (%).

3.3.3.2 Section and time steps approach

In this case, diagnosis is assessed against the « color », which represents the “observed” characteristic. Here again, this can be modulated upon ground truth intensity (ignoring some electric trajectories, and corresponding sections and time steps) and/or flashes proximity (ignoring some non electric trajectories, and corresponding sections and time steps).

But precocity and decaying sections, even if non electric, must not be systematically considered as non convective « observed »:

- Example 1: a convective RDT diagnosis during precocity (green) section is an early alert (goal of RDT product), and must not be seen as a false alarm. But a non-convective RDT diagnosis may correspond to a further late or missed diagnosis depending on following elements' characteristics
- Example 2: a convective RDT diagnosis in a decaying (orange) section may either be a late diagnosis or a coherent continuous diagnosis, never a false alarm. A non-convective RDT diagnosis should be seen as a correct rejection, except if none previous convective diagnosis had been issued.
- Example 3: black, violet, or grey sections can on the contrary be considered as non convective, when coherent behaviour of RDT diagnosis has to be assessed

Thus, following hypothesis have been considered for sections and time steps contingency tables:

1. H1: only red or yellow sections and time steps are taken into account for RDT quality assessment, thus focusing on electrical activity only
2. H2: green and orange sections and time steps discriminated as convective are considered as good detections. They are considered as correct rejection if discriminated as non convective. Thus, higher tolerance is given to convective diagnosis: green and orange are always correct
   Black, violet or grey sections and time steps are considered as non convective
3. H3: green and orange sections and time steps discriminated as convective are considered as good detections. They are considered as misses if discriminated as non convective. Thus, skills depend on precocity performance of RDT diagnosis.
   Black, violet or grey sections and time steps are still considered as non convective

H1 hypothesis	Convective « Observed »	Non convective « Observed »
Convective diagnosis	Good detection: **GD** *Sections and time steps*: red	False Alarm: **FA** *Sections and time steps*: yellow
Non convective diagnosis	Miss: **MI** *Sections and time steps*: red	Correct rejection: **CR** *Sections and time steps*: yellow

H2 hypothesis	Convective « Observed »	Non convective « Observed »
Convective diagnosis	Good detection: **GD** *Sections and time steps*: red + (green, orange)	False Alarm: **FA** *Sections and time steps*: yellow + (black, violet, grey)
Non convective diagnosis	Miss: **MI** *Sections and time steps*: red	Correct rejection: **CR** *Sections and time steps*: yellow + (green, orange) + (black, violet, grey)

H3 hypothesis	Convective « Observed »	Non convective « Observed »
Convective diagnosis	Good detection: **GD** *Sections and time steps*: red + (green, orange)	False Alarm: **FA** *Sections and time steps*: yellow + (black, violet, grey)
Non convective diagnosis	Miss: **MI** *Sections and time steps*: red + (green, orange)	Correct rejection: **CR** *Sections and time steps*: yellow + (black, violet, grey)

In order to illustrate those different approaches and hypothesis, a detailed example of electric trajectory analysis for RDT diagnosis assessment is given in Annex II.

3.4 Discrimination diagnosis skills

3.4.1 Contingency tables

3.4.1.1 Extended domain and period

Statistical element			Trajectory	Section			Time step (cell)		
Hypothesis				H1	H2	H3	H1	H2	H3
Low lightning activity	Population	Conv	40351	46400 (red) 34841 (green) 32184 (orange) 11771 (black) 15958 (grey) and 1350 (violet)			249940 (red) 97368 (green) 81449 (orange) 77981 (black) 124054 (grey) and 8018 (violet)		
		NoConv	292544	292544 (yellow)			2653671 (yellow)		
	Score	POD	61	52	66	40	57	63	42
		POFD	3.5	3.5	4	4.5	1	1.5	1.5
		FAR	29	29	26	26	18	20	20
		TS	49	43	54	34	50	54	38
Moderate lightning activity	Population	Conv	26079	30853 (red) 21566 (green) 19720 (orange) 6155 (black) 9731 (grey) 1127 (violet)			220241 (red) 57789 (green) 50875 (orange) 38494 (black) 79466 (grey) 6860 (violet)		
		NoConv	292544	292544 (yellow)			2653671 (yellow)		
	Score	POD	74	66	77	49	60	65	50
		POFD	3.5	3.5	4	4.5	1	1.5	1.5
		FAR	34	33	28	28	19	20	20
		TS	53	50	59	40	53	56	44
Severe lightning activity	Population	Conv	17066	20146 (red) 13268 (green) 12329 (orange) 3481 (black) 6413 (grey) 751 (violet)			183681 (red) 35025 (green) 32380 (orange) 21408 (black) 54648 (grey) 4778 (violet)		
		NoConv	292544	292544 (yellow)			2653671 (yellow)		
	Score	POD	81	75	83	55	65	69	56
		POFD	3.5	3.5	4	4.2	1	1.4	1.4
		FAR	42	40	33	33	21	21	21
		TS	51	50	58	43	56	58	48

Tab 1: RDT v2011 Discrimination skill table over Europe for full period (June-August 2008 + April-October 2009)

Results are firstly analysed on full validation domain for the complete period. There are presented in the table above for the three levels of ground truth, and for the three hypothesis concerning sections and time steps.

The sensitivity of score values depending on the various cases or approaches is discussed here.

The unbalance between “observed” convective and non-convective trajectory population is around 10%: from 9% and 6% for high intensities of ground truth to 14% for lower intensities. A comparable ratio can be observed in section and time steps approaches. This limited unbalance gives more reliability to the results.

Considering the dependency of scores on ground truth intensities, it can be noted that:

- POD increases with ground truth intensity, especially for trajectories and sections elements
- FAR increases with ground truth intensity,
- TS is minimum for low lightning activity.

Considering the dependency of scores on hypothesis for assessing sections and time step RDT discrimination, it can be noted that:

- H2 exhibits logically better scores, due to the tolerance given to precocity and decaying sections
- H3 POD differs from H2 ones: when the number of precocity sections diagnosed as convective is not high, POD is low
- Variations between H1 and H2 scores are less stressed, with lower POD, POFD and TS and higher FAR

Considering various statistical elements for a given ground truth, moderate for example, it can be noted that:

- POD and TS are both comparable between trajectories and sections, FAR are a little bit lower with section approach
- FAR is much lower for time steps (cells). POD is also lower. TS does not vary between sections and time step approaches. Despite a comparable ratio between convective and non convective populations, POFD is much lower for this approach

As a first analysis of these results, we can note that the section approach, which is close to the real time use of RDT product, exhibits very good results with a limited FAR and satisfying POD and TS. The results remain correct at trajectory time scale. When comparing with time step scores, better POD and TS has associated to higher FAR.

The moderate ground truth, represents a reliable “observation” point of view, ignoring less active cloud systems.

We consider that RDT follow the requirements .

3.4.1.2 Impact of the extension of the validation period on scores

The behaviour of RDT v2011 during intermediate seasons can be evaluated by the comparison of scores elaborated over the full validation period (June-August 2008 + April-October 2009, see par 3.4.1.1) and the results obtained below on summer months only (summer 2008+2009).

Statistical element			Trajectory	Section	Time step (cell)
Low lightning activity	Population	Conv	40351 ⬂ 28753		
		NoConv	292544 ⬂ 171390		
	Score	POD	61⬀63	66⬀68	63⬀64
		POFD	3.5⇨3.5	4⇨4.5	1.5⇨1.5
		FAR	29⬂27	26⬂24	20⬂18
		TS	49⬀51	54⬀56	54⬀56
Moderate lightning activity	Population	Conv	26079 ⬂ 19127		
		NoConv	292544 ⬂ 171390		
	Score	POD	74⬀75	77⬀78	65⬀66
		POFD	3.5⇨3.5	4⇨4.5	1.5⇨1.5
		FAR	34⬂31	28⬂27	20⬂18
		TS	53⬀56	59⬀61	56⬀57
Severe lightning activity	Population	Conv	17066 ⬂ 12799		
		NoConv	292544 ⬂ 171390		
	Score	POD	81⬀82	83⇨83	69⇨69
		POFD	3.5⇨3	4⇨4.5	1.4⇨1.5
		FAR	42⬂38	33⬂31	21⬂19
		TS	51⬀54	58⬀60	58⬀59

Tab 2: RDT v2011 Discrimination skill Table over full period (left green figures) vs summer period (right red figures), H2 hypothesis for sections and time steps. Arrows illustrate the changes (increasing, stable, decreasing) of the results between two periods.

On can note a light but very limited improvement of false alarms scores: the gain is limited to a maximum of 2 points when the assessment of RDT discrimination is limited to summer period. TS takes benefit of the gain in FAR.

A consequence is that ***the behaviour of RDT is quite good, relatively homogeneous and comparable whatever the months selected for the validation even*** with an increase of unbalance between convective/non convective population with an extended period of validation (about 50% more non electric cases vs 30% more electric).

The explanation of this good result is ***due to the use of NWP as guidance*** by RDT-CW code, which prevents diagnosis attempt on “uninteresting” areas like for example frontal zones. Those zones revealed in the past some false alarms cases, which has been a limit to the use of RDT product during intermediate seasons.

3.4.1.3 Impact of the extension of validation area on scores

In this part, we compare our result with the results of the previous validation. The differences between the two validations exercises are

- The version of RDT (v2009 / v2011)
- The domain (France / Europe)
- The period: always summer but 2008+2009 in one case and 2005 in the other

Considering the results above and our experience of RDT behaviour, we consider that the main impacts we will have to analyse will come from differences of version of RDT.

Statistical element			Trajectory	Section	Time step (cell)
Low lightning activity	Population	Conv	28753⇖ 4988		
		NoConv	171390⇖ 62180		
	Score	POD	63⇖47	68⇖55	64⇖55
		POFD	3.5⇖2	4.5⇖2	1.5⇖1
		FAR	27⇙36	24⇙30	18⇙24
		TS	51⇖37	56⇖44	56⇖47
Moderate lightning activity	Population	Conv	19127⇖ 2496		
		NoConv	171390⇖ 62180		
	Score	POD	75⇖66	78⇖71	66⇖59
		POFD	3.5⇖2	4.5⇖2	1.5⇖1
		FAR	31⇙44	27⇙36	18⇙25
		TS	56⇖43	61⇖50	57⇖49
Severe lightning activity	Population	Conv	12799⇖ 1354		
		NoConv	171390⇖ 62180		
	Score	POD	82⇖78	83⇖81	69⇖64
		POFD	3⇖2	4.5⇖2	1.5⇖1
		FAR	38⇙56	31⇙45	19⇙29
		TS	54⇖39	60⇖47	59⇖50

Tab 3: RDT Discrimination skill Table for summer periods v2011 over Europe (red figures) vs v2009 over France (grey figures) only. H2 hypothesis for sections and time steps. Arrows illustrate the changes (increasing, stable, decreasing) of the results between two domains

The much better behaviour of RDT v2011 than v2009 appears here in all cases: PODs are strongly increased (about 10 points for light or moderate activity, except for severe ground truth), false alarms strongly reduced (sometimes more than 10 points!), TS much largely increases.

Looking at observed population numbers, it appears that the unbalance convective/non convective was much marked with the previous validation: the ratio was [8%, 4%, 2%] for various ground truth, the ratio are [16%, 11%, 7%] for this validation. We propose the following explanation: the NWP convective mask (see ATBD) filters the non convective systems to consider. This filter explains higher POFD when v2011 is compared to v2009. Regarding the slight increase of POFD with the strong decrease of FAR, skills exhibit an high improvement of RDT behaviour: there are less false convective diagnosis, even if those represent a larger proportion of non convective observed trajectories.

RDT discrimination of v2011 shows a much better behaviour than discrimination of v2009, with scores largely beyond the requested requirements.

3.4.1.4 Impact of changes in flashes proximity on scores

As referred into previous paragraph, the ground truth that we use may lead to some matching error or ambiguous cases between cloud cells and lightning flashes. Once a detection mask has been taken into account, the errors may come from:

- Lightning sensors measurements uncertainty: sensors point some flashes outside the tolerance area of 10km, leading to ignore electric activity of convective cells
- Real ambiguous cases of cumuliform cloud systems developing in a thunderstorm zone without evolution to a cumulonimbus
- Failure of matching algorithm of RDT. Cloud cells are representative of the base of cloud towers but some lightning flashes are likely to occur on the edge of large cloud system, more than 10km away from top tower

Analysis of Cloud cell trajectories allow to take into account the flashes in the surrounding: RDT-CW code computes for each cloud cell the minimum distance to nearest flash, called flashes proximity.

- Below the tolerance value, this proximity is set to zero (matching cell-flash) for “observed” convective population.
- Beyond, it may be used for filtering statistical elements considered as non convective from “ground truth” point-of-view.

Thus, it is possible to check the sensitivity of the scores to this filter, and evaluate RDT performance despite the mentioned matching errors or limitations. .

		Trajectory			Section			Time step		
Flashes proximity filter (km)	**No conv trajectory number**	*POFD*	FAR	TS	*POFD*	FAR	TS	*POFD*	FAR	TS
0	292544	*3.5*	34	53	*4*	28	59	*1.5*	20	56
21	278426	*2.5*	27	58	*3.4*	23	62	*1*	16	58
35	266711	*2*	22	61	*3*	21	64	*1*	14	59
70	241178	*1.4*	15	65	*2.5*	17	66	*<1*	11	60
105	218678	*1*	11	68	*2*	15	68	*<1*	9	61
140	198995	*<1*	8	70	*2*	13	69	*<1*	8	62
175	181162	*<1*	6	70	*2*	12	70	*<1*	7	62

Tab 4: dependency of scores on lightning proximity (hypothesis 2 and moderate ground truth)

The false alarm ratio rapidly drops when flashes proximity filter is more permissive. FAR is divided by two when one considers a 70km filter area, which can be seen as a reasonable exclusion zone. A large part of false alarms are located beyond 70km of cloud-to-ground flashes.

When flashes exclusion area and intensity of the ground truth are considered together, it is possible to get a realistic idea of RDT discrimination true skills. Intensity of ground truth has a positive impact on POD. Flashes proximity filter have a positive impact on POFD and FAR, like illustrated in the table below:

Flashes proximity filter (km)	Trajectory Light GT			Trajectory **Moderate GT**			Trajectory Severe GT		
	POD 61			POD **74**			POD 81		
	POFD	FAR	TS	*POFD*	FAR	TS	*POFD*	FAR	TS
0	*3.5*	29	49	*3.5*	34	53	*3.5*	42	51
21	*2.5*	22	52	*2.5*	27	58	*2.5*	33	57
35	*2*	18	53	***2***	**22**	**61**	*2*	28	62
70	*1.4*	12	56	*1.4*	15	65	*1.5*	20	68
105	*1*	9	57	*1*	11	68	*1*	15	72
140	*<1*	6	58	*<1*	8	70	*<1*	11	74
175	*<1*	5	59	*<1*	6	70	*<1*	8	76

Tab 5: Dependency of Full-Trajectory scores on lightning proximity and on ground truth intensity

With a moderate ground truth (defined by 5 flash impacts at least during a trajectory) and non convective trajectories defined by being away from flashes of more than about 35km, satisfying skills are reached for full-trajectory approach: POD of 74% together with 2% POFD, FAR 22% and a TS of 61%.

3.4.2 The discrimination precocity

One of the goals of RDT is to detect as early as possible convective systems evolving in thunderstorms. The precocity (earliness) of this diagnostic will be measured against the age of first lightning flash paired with a cloud cell of a convective trajectory.

When cloud systems are first detected in the low levels of the troposphere, one may expect that the tracking capacity of RDT-CW correctly monitors the evolution of the cloud system, and anticipates its thunderstorm state.

But among the detected and tracked cloud cells, a large part is first depicted in mid or high levels. Moreover, because morphological evolution lots of trajectories are split by the algorithm at cold temperatures. For those cloud systems, it will be difficult to correctly anticipate a thunderstorm state. Therefore, precocity results should be regarded against those limitations.

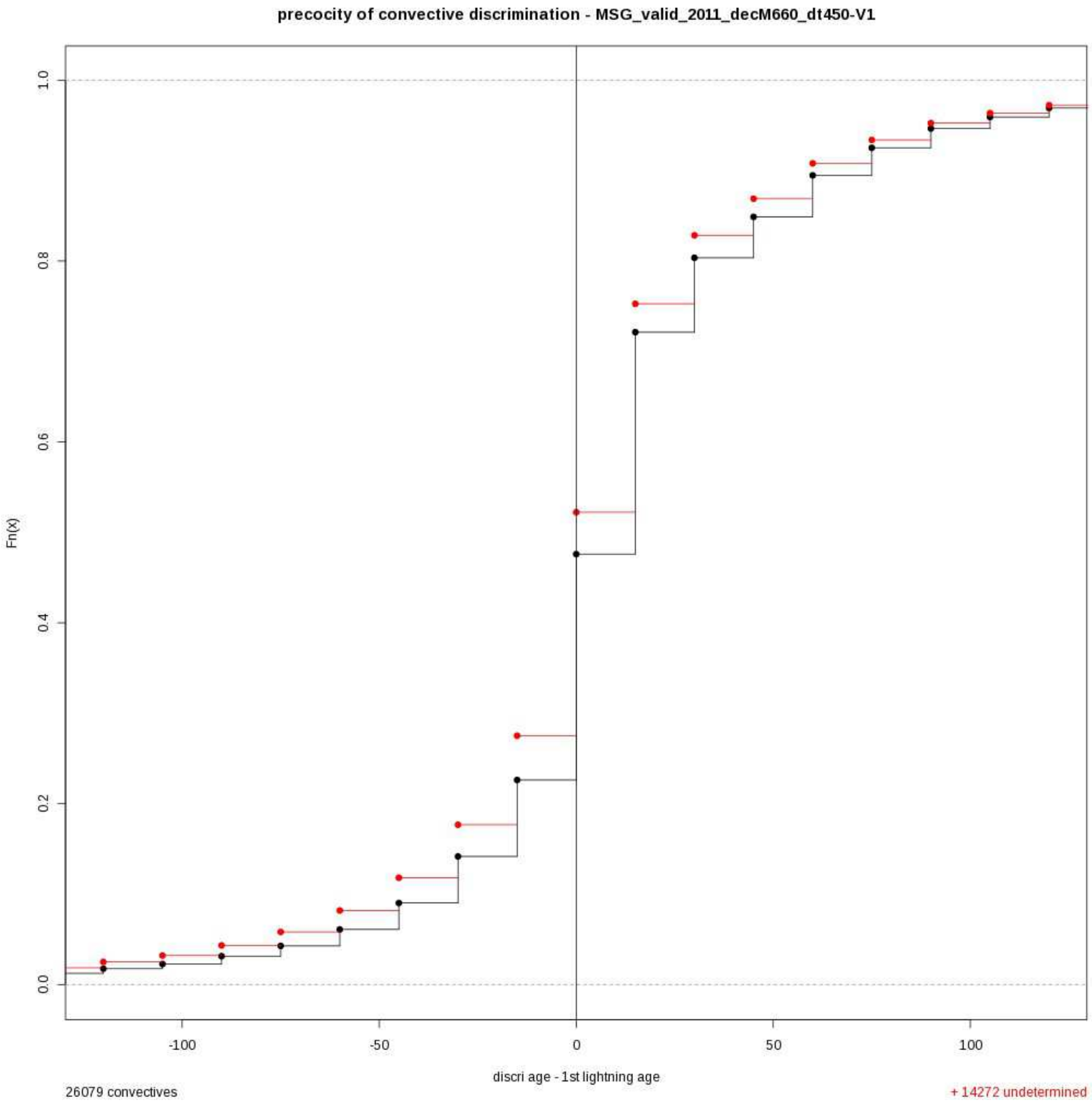


Figure 10: Precocity of RDT v2011 discrimination for moderate (black) and low (red marks) ground truths.

The figure above points out that more than 50% of good detection are already classified at the time of the first lightning occurrence, 80 % thirty minutes after. Nevertheless, only 25% are classified before the first flashes stroke (15 min before).

No major improvement appears when we compare the precocity of v2011 with the precocity of v2009. The precocity increases on the left part of the graph, but without modification of the overall score.

One can deduce a "shift" of previously early-diagnosed systems, taking all the benefit of improvement. Other systems do not seem to have got full advantage of this RDT version. This is illustrated on the graph below, where precocity is linked to the category of the first RDT diagnosis.

Categories used in RDT-CW code are detailed in ATBD document (section **3.1.2.3.3)**

- Mature systems (value 0, here labeled "Mat") beyond -40°C

- Mature Transition systems (value 1) when crossing -40°C : not used here because systems are switched to mature category when convective
- Cold Transition system (value 2, here labeled “TCold”) when crossing -35°C
- Warm Transition 2 system (value 3, here labeled “TWarm2”) when crossing -25°C
- Warm Transition 1 system (value 4, here labeled “TWarm”) when crossing -15°C
- Warm systems (value 5, here labeled “Warm”) above -15°C preceding TWarm state

Warmest categories (“Warm” and “TWarm”) correspond to the earliest diagnosis of RDT v2011. Compared to v2009, the v2011 version has taken advantage of a correct discrimination tuning in these categories (thanks to NWP guidance), where RDT v2009 did not. Early diagnosed systems of v2009 seem consequently to have been diagnosed earlier, in warmer categories, with v2011.

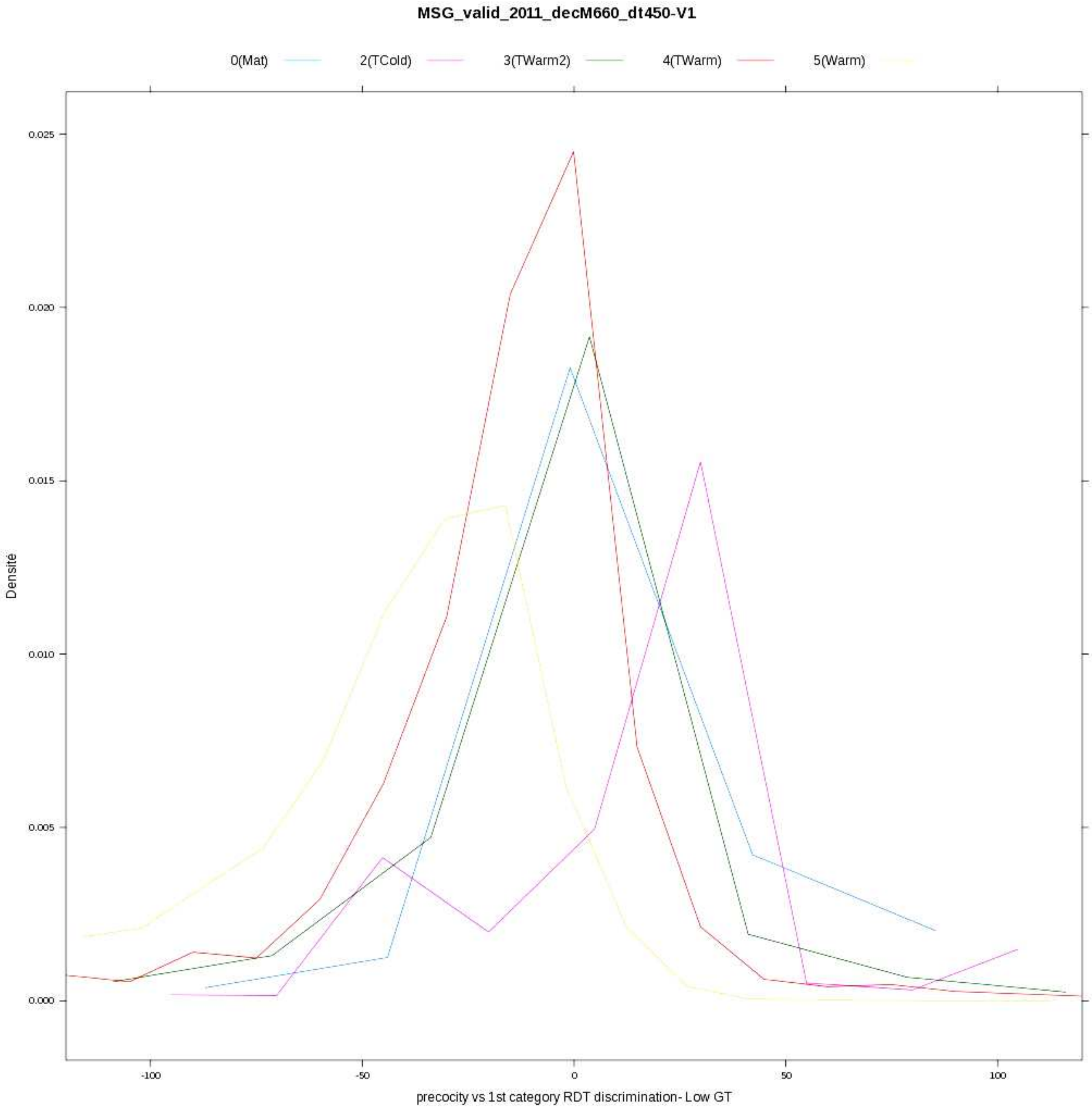


Figure 11: Precocity of discrimination for low ground truth, displayed for each category of first diagnosis. Left part of the graph corresponds to early diagnosis, right part to late diagnosis.

3.5 CASE STUDY EVALUATION

Main improvement of RDT v2011, compared to previous version, is the use of NWP data as input. The goal of this change was to improve convective discrimination. In order to elaborate a synthesis convective mask, NWP data are used to compute convective indexes. The use of the convective mask has a positive impact on both tuning and real-time processing.

- Tuning of discrimination scheme has taken benefit from the convective mask, ignoring trajectories in stable areas thus reducing the unbalance between convective and non convective populations when processing statistics, giving more reliable and robust statistical models

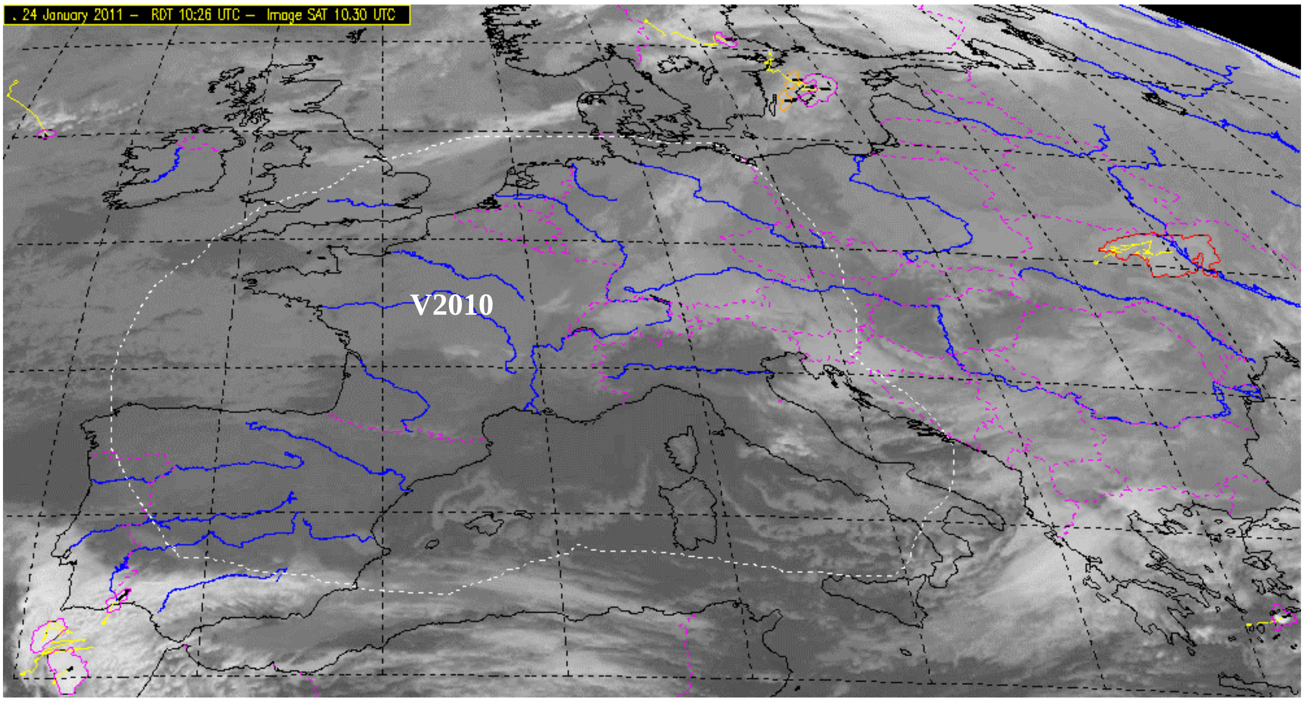
- Real time processing: Convective diagnosis of RDT-CW is attempted except in stable areas of this "NWP convective mask", thus avoiding non relevant diagnosis

3.5.1 NWP convective MASK: Lowering false alarms

Since the RDT is tuned over France with summer season satellite data, it may sometimes reveal false alarm cases when applied over winter or intermediate seasons.

NWP data allow undertaking guidance before attempting a diagnosis. Thus, discrimination scheme may focus on convective regions, and avoid eventual false alarms.

Figure below illustrates the benefit of this approach, by filtering occasional false alarms in a winter. RDT v2011 focuses on the real convective areas in south-east and south-west corners of the region.



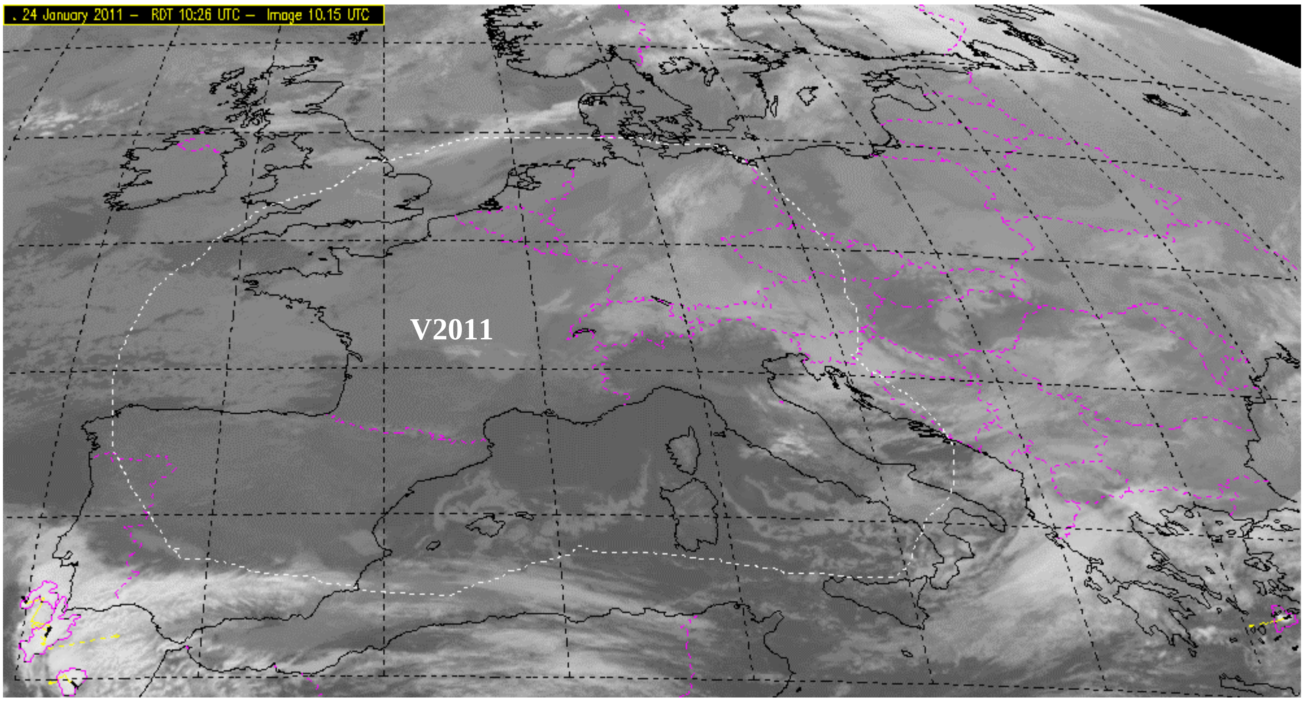


Figure 12 : 24 January 2011 - slot 10h15 - RDT v2010 (top) VS v2011 (bottom)

RDT v2010 exhibits obvious false alarms over Europe, while it is not the case for v2011. Convective diagnosis on real unstable areas are similar with v2010 and 2011.

3.5.2 Impact of NWP mask and data on discrimination Tuning

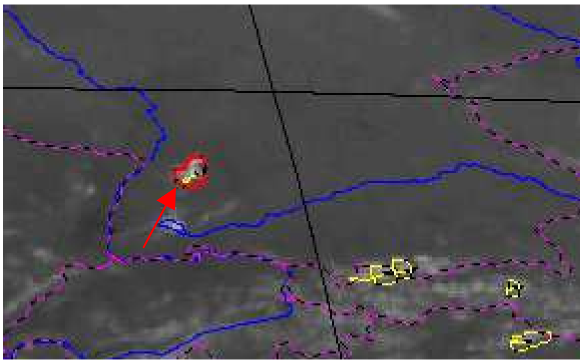
In order to exclude from the learning data bases areas and cloud systems without interest from a convective point of view, NWP mask approach has been applied during the tuning of discrimination scheme.

Thus, this leads to an improvement thanks to a strong decrease of the imbalance between convective and non-convective populations, especially in the warm categories. The consequence is a better tuning in these categories, and consequently a potential improvement concerning precocity, which is illustrated below.

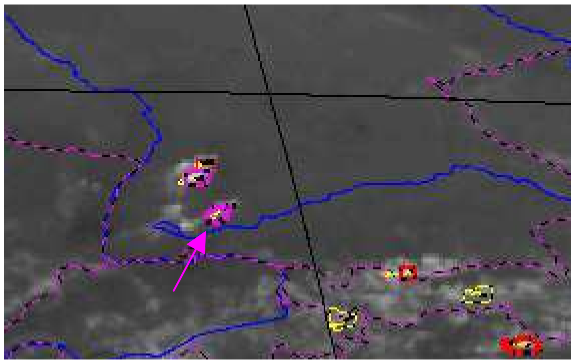
3.5.2.1 Locally earlier convective diagnosis

On 25th May 2009 ("Topical case" situation), convective cells are growing and merging in the south-west of Germany between 11h and 17h UTC. They are early depicted and diagnosed as convective by RDT v2011, even if those cells are already well developed (minimum temperatures of the cells are cold).

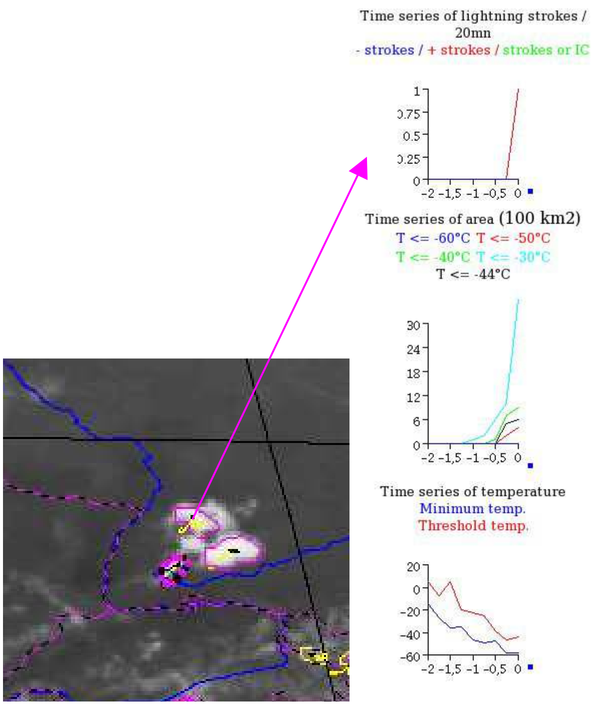
The precocity varies from 0 to 90 minutes for individual cells, but the value to retain is 45 minutes between first diagnosed cell and first paired flash in the neighbourhood. The first cell is diagnosed at 11h15 UTC, 30 minutes after its first detection, but 90 minutes before a lightning flash be paired with this cell. But the first paired flashes really appear at 12h UTC. All those cells finally merge together, and dissipate around 16h45. The lighting activity ends at 15h15.



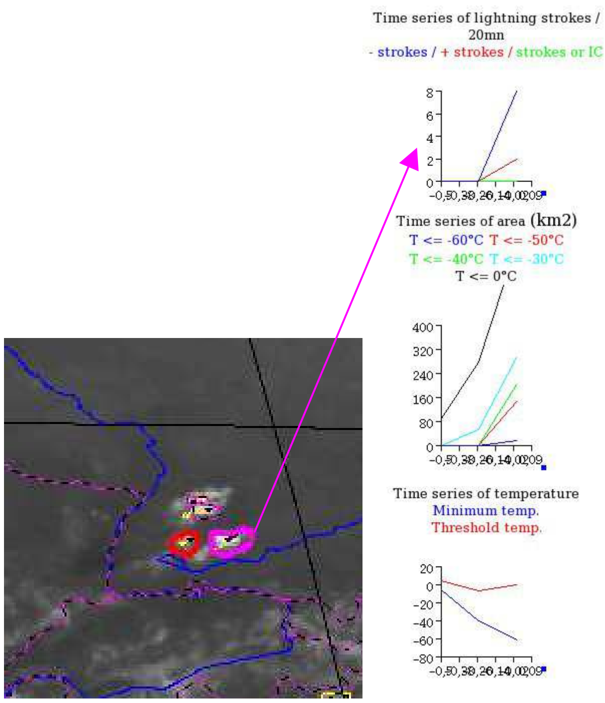
11h15: 1st convective cell diagnosed (Tmin -36°)



11h45: 2nd cell diagnosed (future main cell) in mature category



12h45: 1st lightning in 1st cell (see historical parameters on the right)



12h00: 1st lightning in 2nd cell (see historic parameters on the right), 3rd cell diagnosed synchronous with lightning

Figure 13: 25th May 2009 RDT v2011, zoom over SW-Germany. slots from 11h15 to 12h45. Trajectories, cells and motion vectors, cell history.

The figure below illustrates a detailed analysis of this situation, compared with a similar analysis done with RDT v2010 and Météorage data.

- When compared to previous RDT v2010, all cells have been diagnosed 15 min earlier with v2011.
- EUCLID data seem to be more numerous and earlier in this case than Meteorage data, but RDT v2011 keeps advantage on convective diagnosis when compared to lightning data

Conclusions about precocity are kept unchanged: there is an improvement of precocity thanks to the use of NWP data.

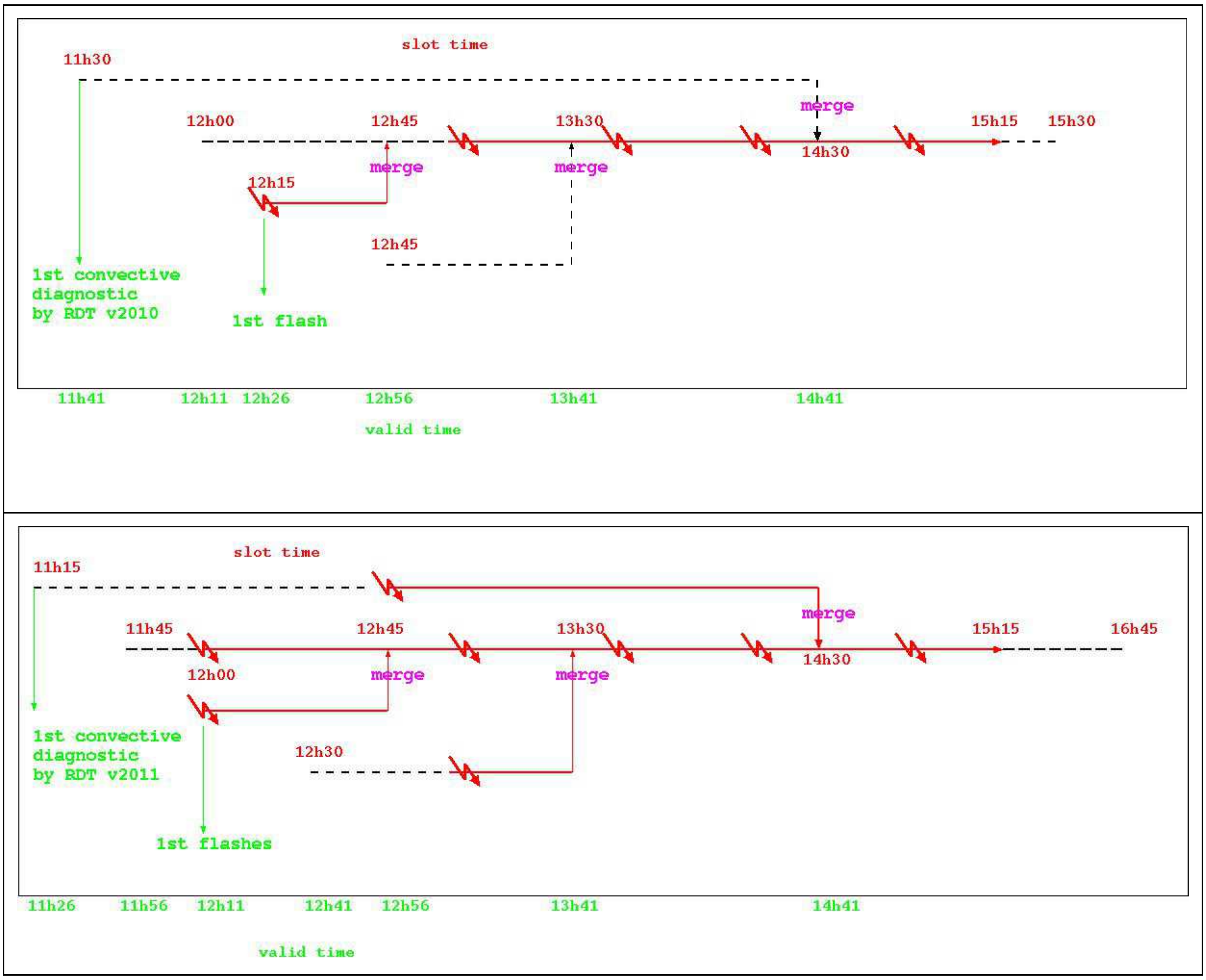


Figure 14: 25 May 2009, 11h15 to 16h45, zoom over SW-Germany. RDT v2010 analysis vs Météorage data (top) .RDT v2011 analysis vs EUCLID data (bottom).

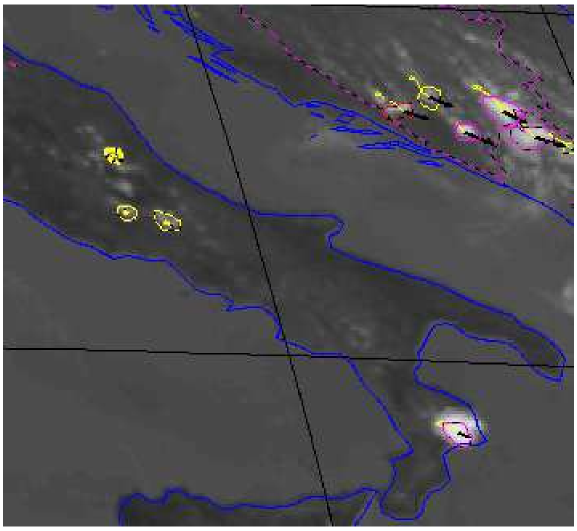
3.5.2.2 Improvement of discrimination:

All categories have taken benefit from this approach, with suitable statistical models even in warm categories.

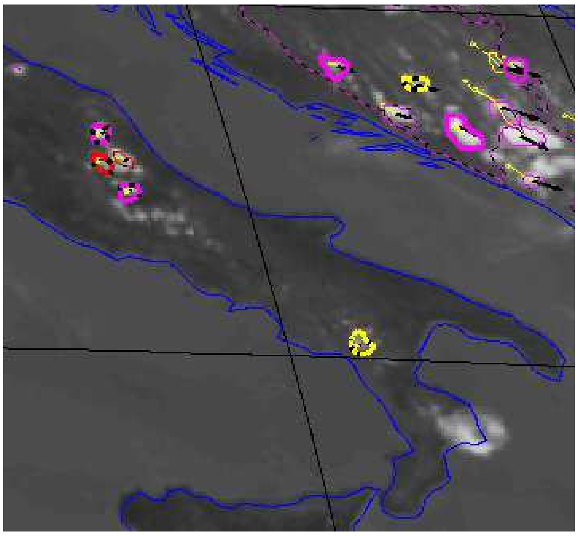
In the example below, v2011 obviously benefits from a better tuning in warmer categories, with better precocity for un-embedded convective systems. Cells over Italy are diagnosed 30 minutes previously to v2010. Sometimes mature convective systems are also depicted with v2011 earlier than v2010.

Here again one can note a good precocity of individual cell: 30 minutes for the southern cell, about 60 minutes in central part of Italy. But in the last case the effect of orography has to be taken into account

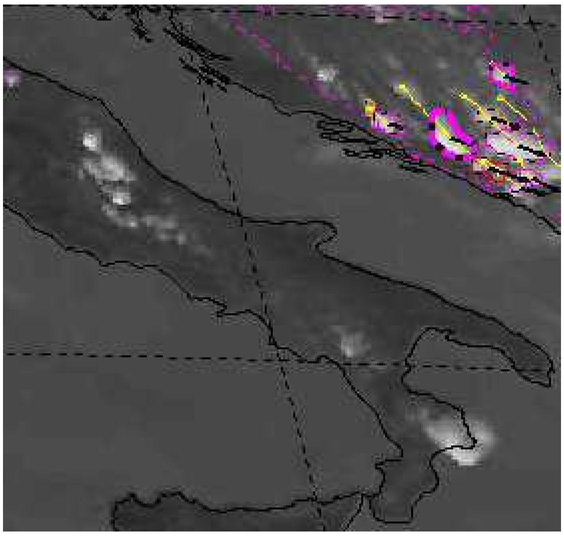
It is to note that false alarms increase when more numerous systems are diagnosed in the warmest categories. Among the three cells diagnosed in the centre of Italy, only one will evaluate towards an electric system. The two others will dissipate, even if they have exhibited convective characteristics in the growing stage. The question could be raised to know what is really to be considered as a false alarm, when looking at the further convective evolution in the same zone.



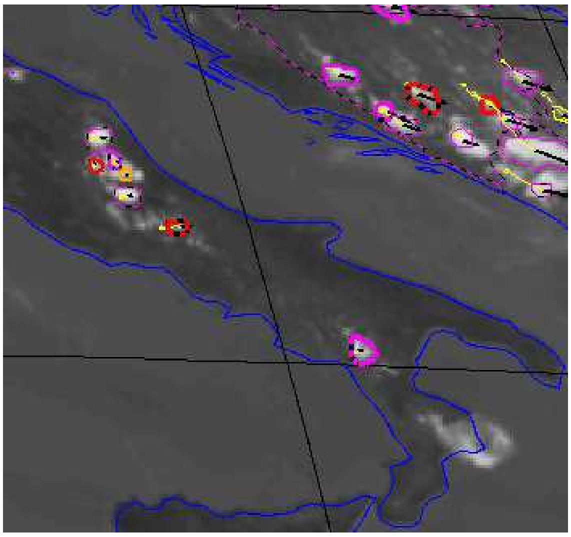
11h45: RDT **v2011** - First cells diagnosed (~ -20°C)



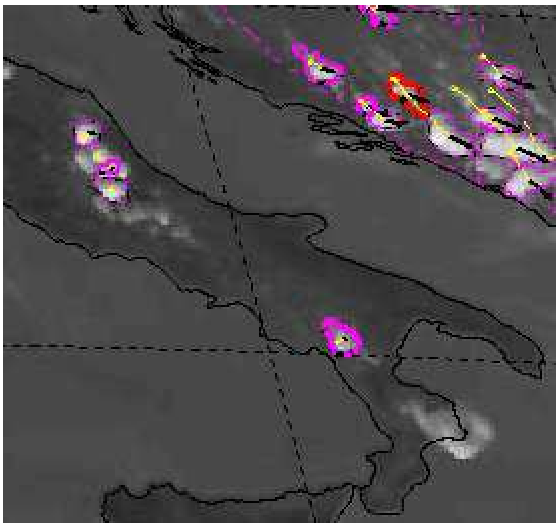
12h30: RDT **v2011** - new diagnosed cell in the south (-20°C, strong cooling -14°C in 15min)



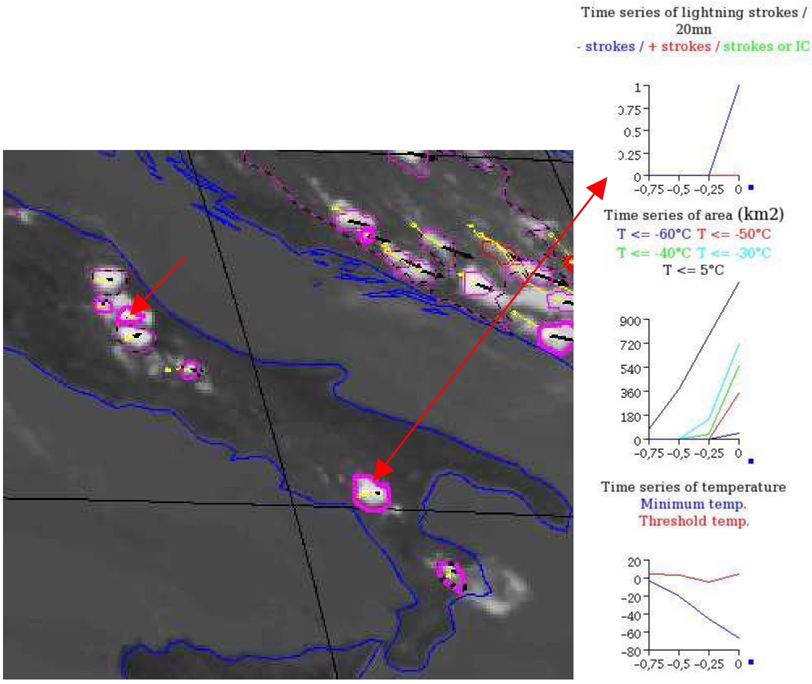
12h30: no cells with RDT v2010



12h45: RDT **v2011**



12h45: RDT v2010 – 1st cells diagnosed



13h00: RDT **v2011** – first lightings paired north and south cells (historic parameters on the right)

Figure 15: 25th May 2009, slots 11h45-13h00 UTC. RDT v2011 (central and left), v2010 (right).

3.5.3 Overshooting Top Detection

As detailed in AD.11, Overshooting Top Detection (OTD) in RDT-CW code is undertaken in two steps. First, morphological analysis of cloud cells allows identifying cell’s list of so-called “OT-candidates”. Then, OT candidates are eliminated or confirmed examinating gap to tropopause or criteria more severe than those in first step.

Criteria are inspired from existing bibliography about OTD, and have been adjusted on case studies. With OTD, we have the first use of visible channel in RDT algorithm (VIS 0.6). Hereafter are some examples of these subjective tuning and validations. The expert subjective validation requires HRV images (that are not use in OTD).

3.5.3.1 Pre selection step

The static thresholds used for IR10.8 BT and BTD=WV6.2-IR10.8, and the morphological analysis of cloud cell top lead to identify possible overshoots for convective systems. A balance had to be found between restrictive or more tolerant values of thresholds. The first option lead to missing some overshoots, the second one implied a necessary further confirmation through additional criteria. The second option has been chosen and the step are called “pre-selection” and “confirmation”

The figure below illustrates a case study over Austrian-Slovenian border, on the 25th of May, 2009. Only pre-detected OT are plotted, superimposed on an enhanced IR image. The convective system containing several convective cells exhibits some OT signatures. The corresponding OT’s extensions vary from one to a tenth of pixels, all located on an extremum of IR10.8 BT.

A comparable approach concerning overshoots was also examined, for cross comparison. The same case study has been analysed by Bedka and al (here extracted from “Best Practice Guide” of Convection Working Group - CWG), figure below exhibits HRV channel with result of OT detection. In this case, all four OTD appear also inside the pre-selected OT set. Some more interesting points are proposed with RDT-CW code, these points need a confirmation, which is the aim of next step of the algorithm.

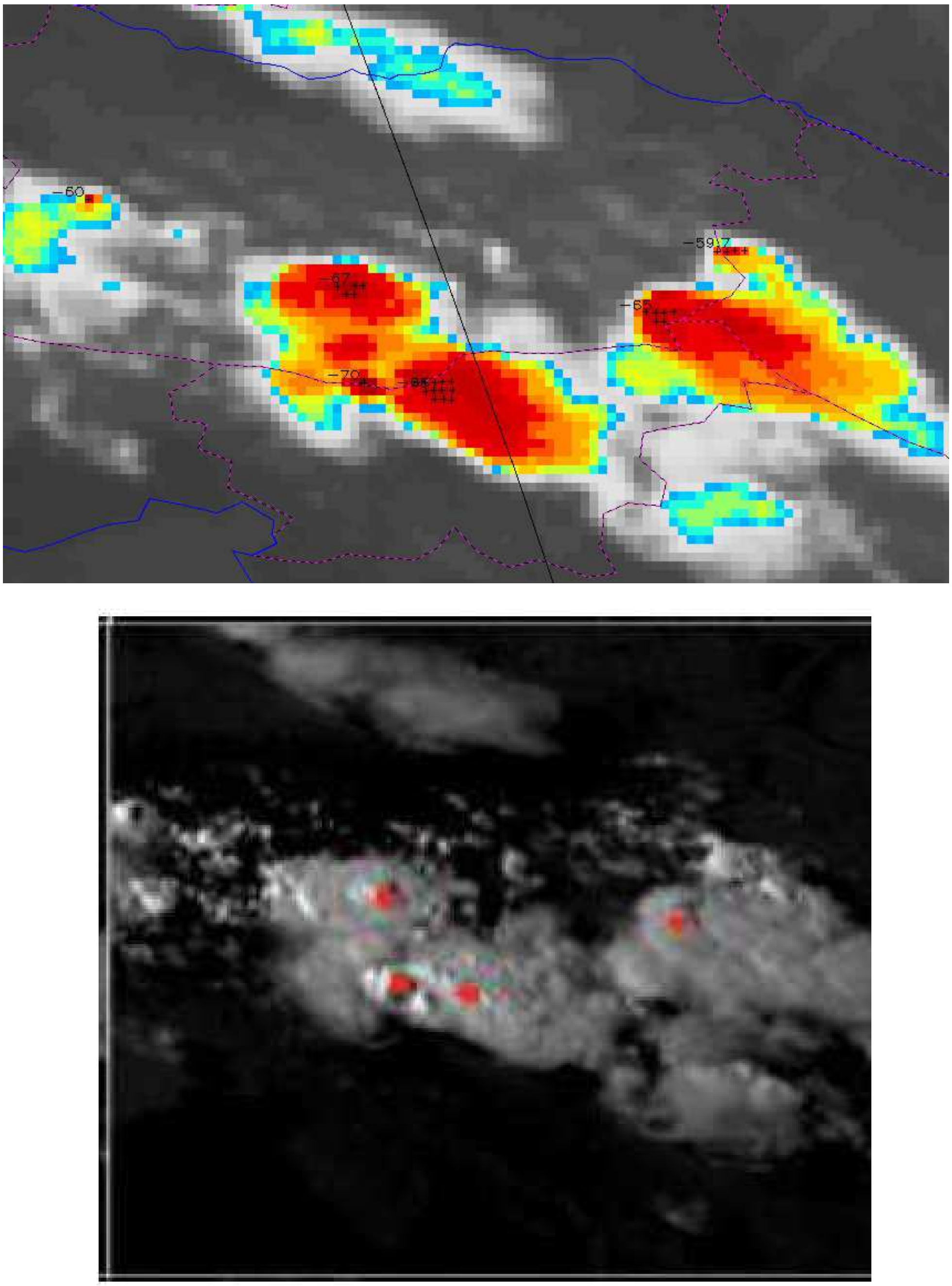


Figure 16: 25th May 2009, slot 16h00 UTC. Zoom over Austrian-Slovenian frontier. Top: Enhanced IR10.8 image with plotted pre-selected OT. Bottom: HRV image with highlighted OTD from Bedka and al

3.5.3.2 Confirmation step

NWP input is used by RDT-CW code for guidance and for a more efficient discrimination step. With OTD, NWP data have now a new role in RDT. Tropopause pressure and temperature are read or re-processed (diagnosed) during the managing phase of NWP data. This parameter is a key attribute for confirming or filtering overshooting top candidates, since a relevant gap over tropopause is generally expected and observed with overshoots.

Several attempts and case studies, based on ARPEGE NWP data over Europe, have lead to set a first threshold to a value of 5°C to define what is a significant gap over tropopause. The value of 10°C, generally admitted, would filter almost all OTs from this situation.

For pixels only slightly above tropopause level (i.e. gap between 0° and 5°), a complementary set of criteria mixing high BTD, high reflectance and large gap between average and minimum temperature of cloud cell, allows to keep some overshoots with different marked signatures

The figure below illustrates the differences between pre-selection and confirmation steps, highlighting in particular how the OTD takes advantage of tropopause diagnosis.

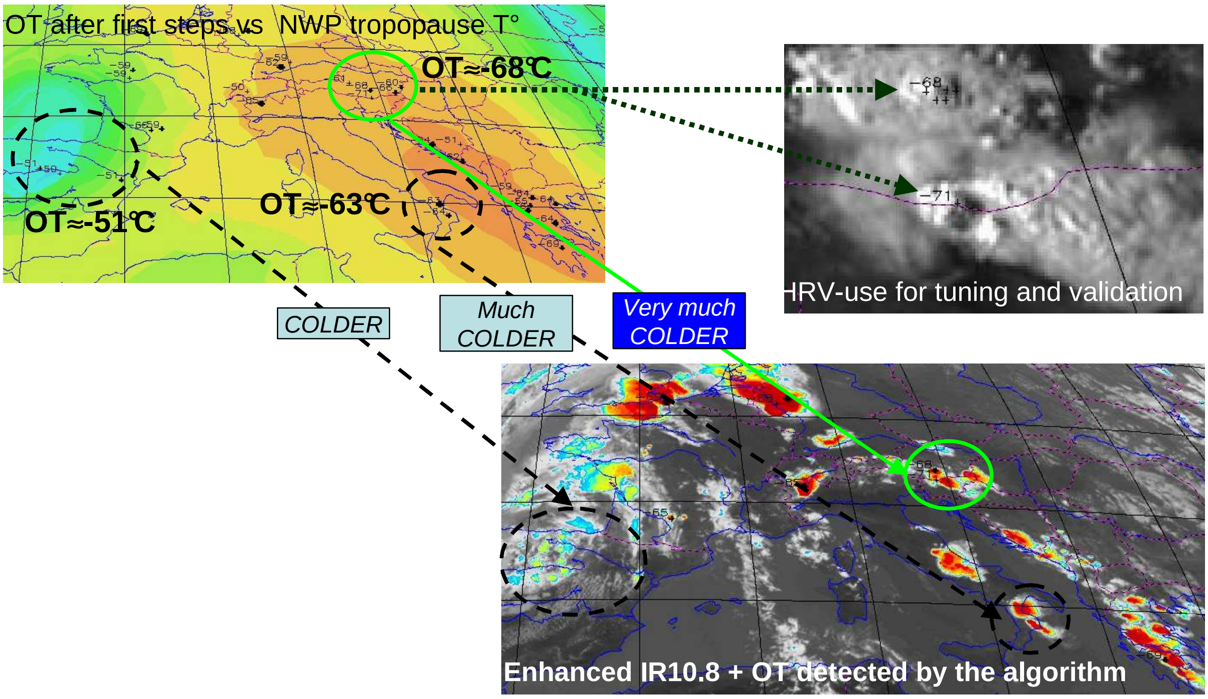


Figure 17: Left-above : OTD after first step plotted over NWP tropopause T°C (blue>-50,green[-50,-60],yellow-green[-60,-65],orange[-65,-67], dark orange<-67). Right above: HRV image confirming two OT (HRV not used by the algorithm). Below: the HRV OT are also found by the algorithm that takes into account (among other criterias) the gap between OT temperature and tropopause temperature.

3.5.3.3 Subjective validation

We only consider in this chapter the OT confirmed after the confirmation step. Only these OT are available in RDT-CW output. Mainly low resolution visible, HRV and IR10.8 enhanced images have been used to validate the OT. For most cases, overshooting top detection appears close to high reflectance spot, and can be considered as validated as in in figure hereafter

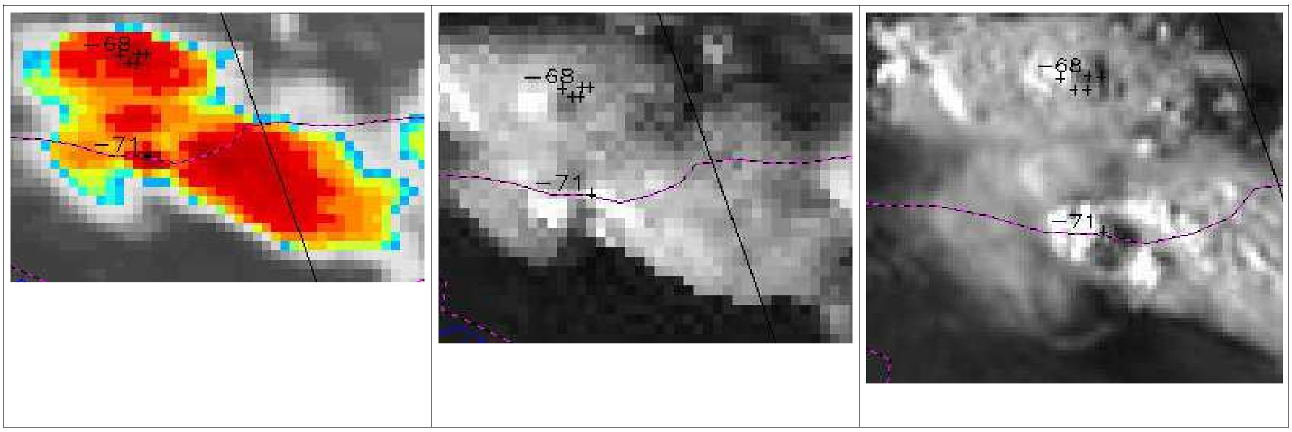


Figure 18: OTD plotted on raw IR10.8 enhanced images (left), on low resolution VIS parallax-corrected images (middle), and on raw HRV image (right).

Two OT have a temperature of 3-4°C below tropopause temperature. They are associated with high values of reflectance, even if those “spots” are not exactly colocated on paralax-corrected images. Detection can be considered as validated when looking at buddings on HRV images

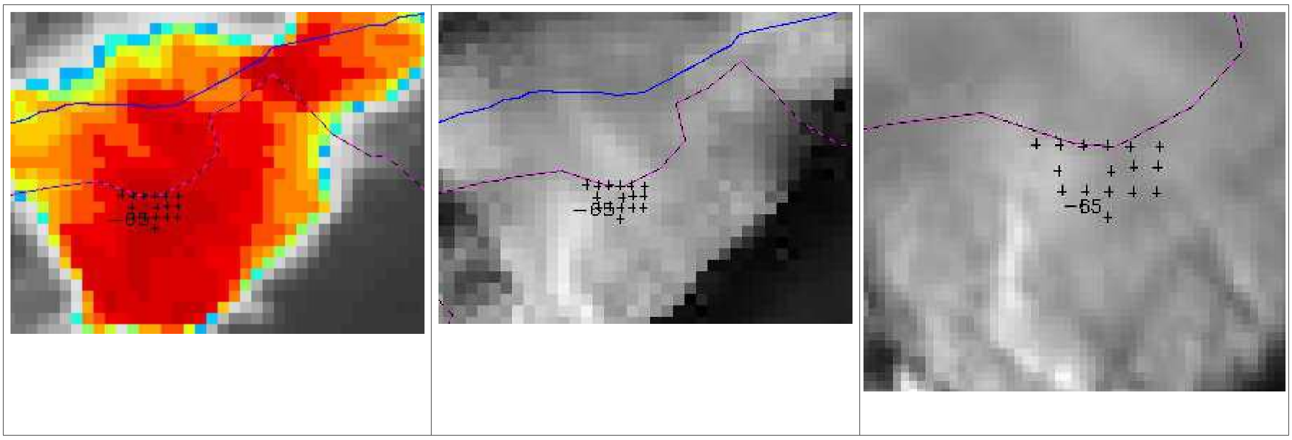


Figure 19: As in previous figure

Reflectance values are not very high on LR and HR VIS images, and located rather southward of the detected OT. This one is slightly above tropopause level but largely colder than surrounding pixels.

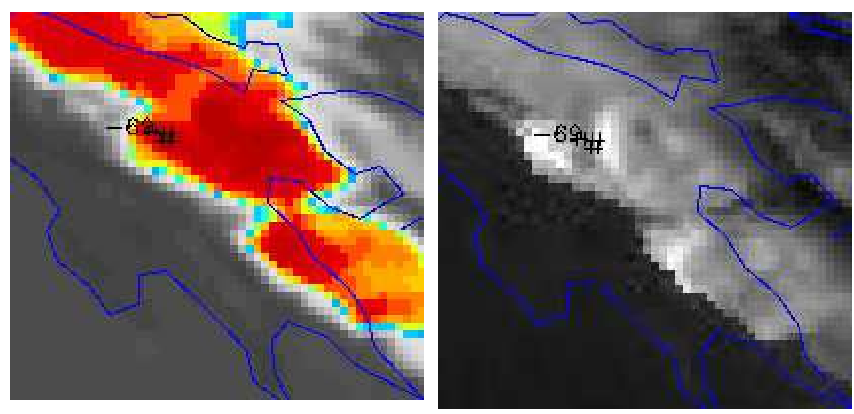


Figure 20: As in previous figure

OTD is confirmed by high VIS reflectance values in the vicinity, even if the gap between OT temperature and NWP tropopause temperature is only 1.5°C.

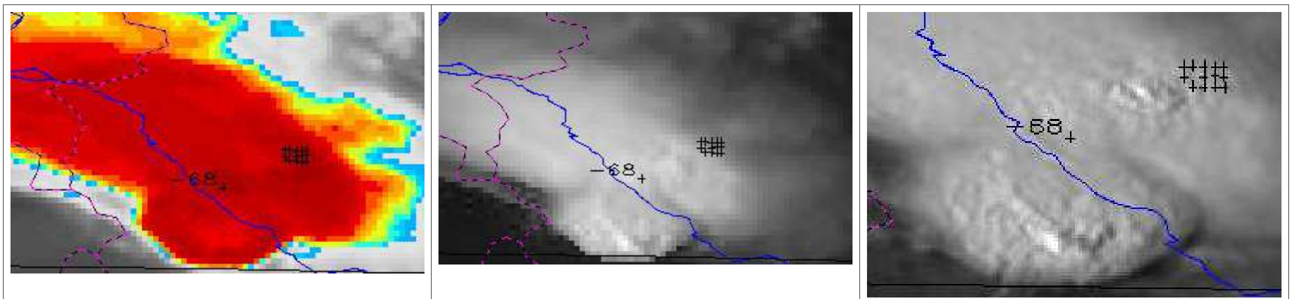


Figure 21: As in previous figure

Theses “twin” OT, both with temperature extrema and BTD maximum, don't show high co-located reflectances (except for one pixel close to the eastern one), even if the texture seem obviously above an anvil. One can suspect a secondary extremum on the southern edge of the cloud cell, where white spot in HR visible appears.

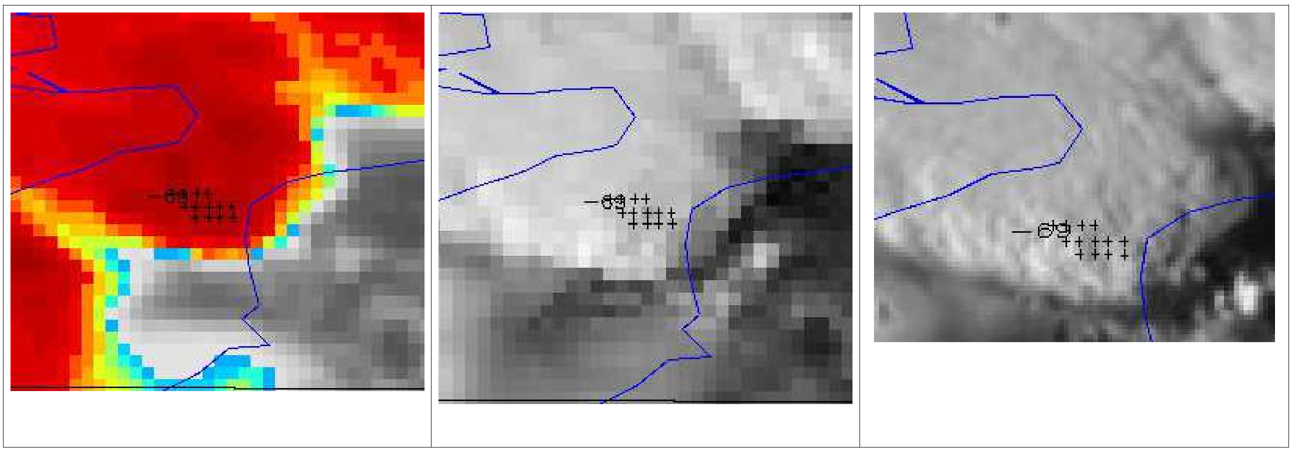


Figure 22: As in previous figure

Moderate reflectances appear here slightly south of the IR-detected OT, on the edge of the cloud system. Visible channels hardly confirm this detection. .

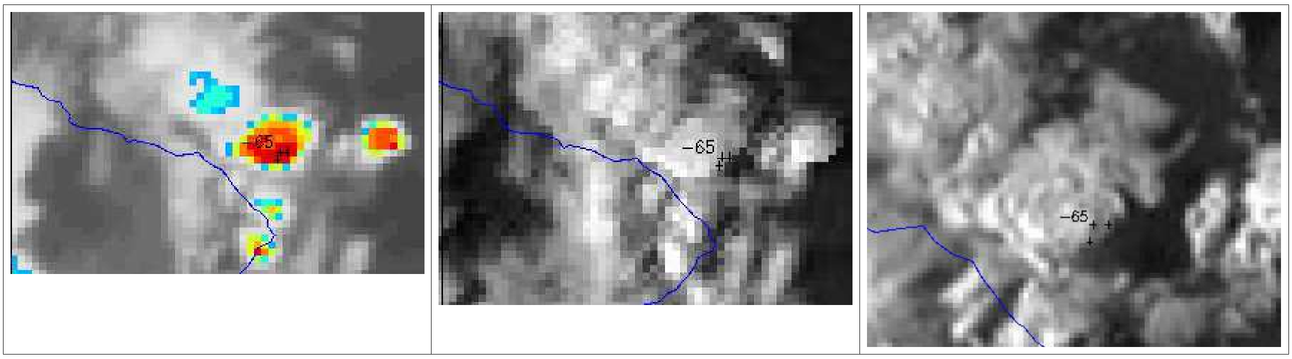


Figure 23: As in previous figure

OT is associated with high value of LR VIS reflectance. HRV signal appears more on the western edge of the cloud cell. The cell is quite small, but clearly above tropopause (gap of 5°), justifying the OT detection.

To conclude, the Overshooting Top Detection implemented in RDT-CW code seems to fit its objective for the cases studies which have been analyzed. The first step allows selecting all kind of interesting pixels and the confirmation step allow to focus on the most relevant ones.

3.5.3.4 Applicability to tropical regions

Brightness temperature, but also size and distance thresholds have been adapted when applying OT detection to tropical regions. Deep convection associated with high and cold tropopause has lead to consider rather at least double-size OT for the morphology analysis. indeed, the initial values of thresholds did not allow to fulfil the conditions for most cases.

Thus temperature threshold of -70°C and typical OT size of 100km have set for latitudes below 30°. Below is an illustration of the result, with single pixel and extended OT which are compliant with morphology and tropopause value.

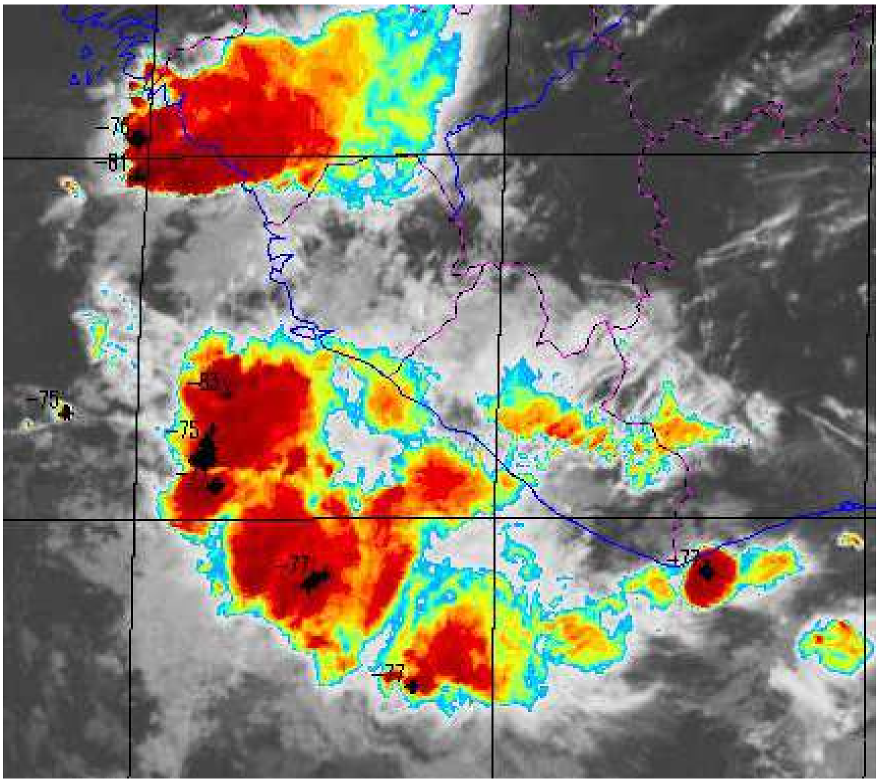


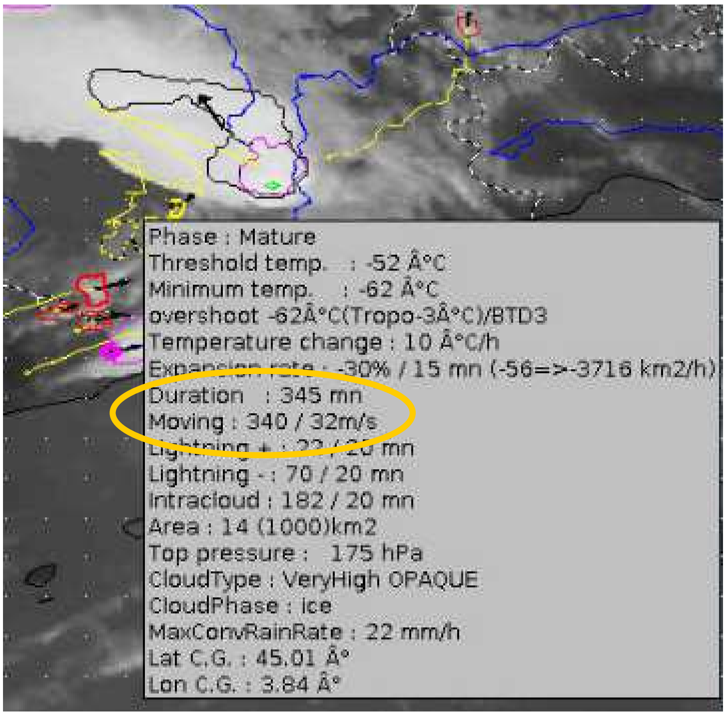
Figure 24: 06/06/2012 12h00 UTC, south-west Africa: OTD on enhanced IR image.

3.5.4 Forecast cloud systems

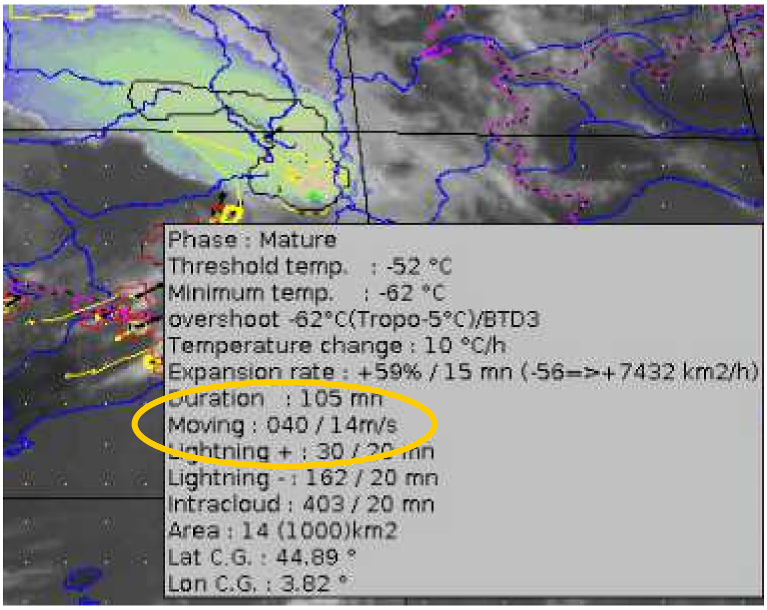
RDT-CW software provides the user the possibility to forecast cloud cell position using the diagnosed movement speed of the cloud cell.

Extrapolated cloud cells positions are obtained through Lagrangian forecast, i.e. the whole object is moved according to direction/speed of the diagnosed movement.

Consequently, quality of this extrapolation relies highly on the quality of movement diagnosis. The use of a pre-initialized guess of movement field from blending NWP wind data and HRW , and a final-step coherence checking has allowed to filter erratic speed and/or direction due to split/merge or to threshold temperature changes. Thus, confidence is Lagrangian extrapolation has become much higher, as illustrated in figure below.



V2013 : erratic speed and direction following numerous splits/merges along trajectory



V2016 : coherent speed and direction despite numerous splits/merges along trajectory

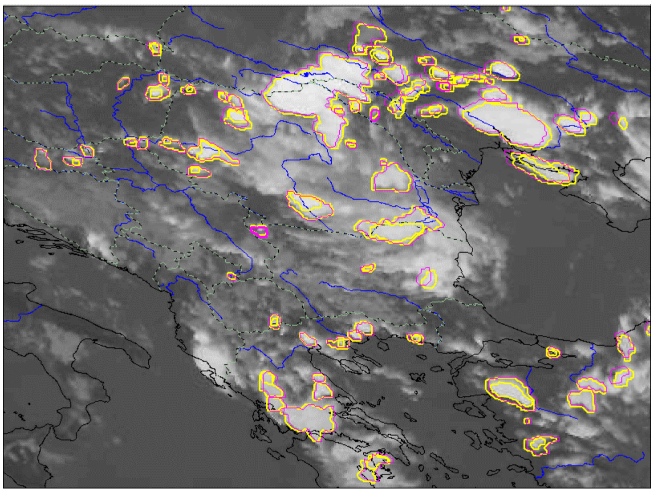
Figure 25: v2013 vs v2016 illustration of RDT motion vectors improvement

Concerning forecast positions, it must be reminded that a cloud cell definition/contour corresponds to a given threshold temperature, and that this threshold changes dynamically/automatically from one slot to the other. ***A forecast contour remains based on the same temperature threshold than the observed/analyzed object***. It will consequently be very difficult to assess the position of a forecast contour when compared to the following corresponding observed contours, because it is likely that those contours will not correspond to the same threshold temperature. Moreover, the longer the forecast ranges, the less precise the localization of forecast convective object is.

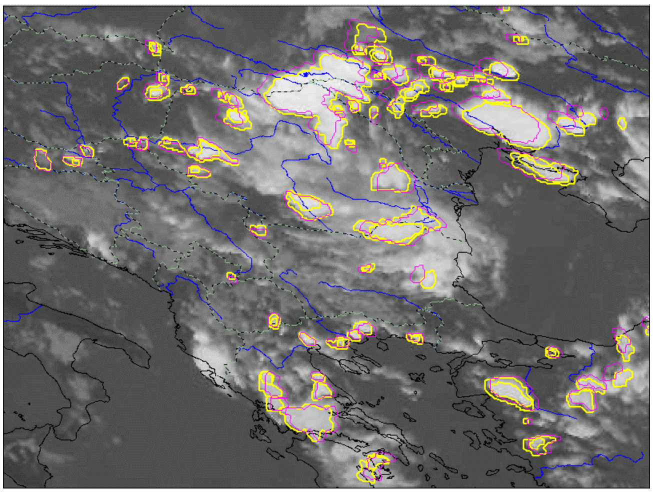
Assessment of forecast products position should ideally take into account for each cloud cell the stage of development, the morphological evolution or the expansion rate. Forecast cloud cell position can consequently only subjectively be regarded.

Trends attributes of observed cloud cells are used to give indication of possible values changes of some parameters in the first forecast ranges (trend's values used for 15min range, half values for 30min). Here again those values can only be regarded as estimation and not pure forecast:

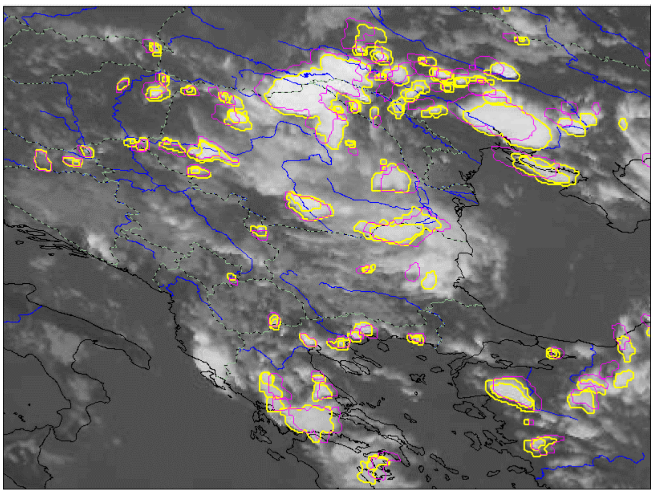
- Cooling rate for minimum temperature estimation (up to tropopause temperature limit if this value is available thanks to NWP data) and severity
- Lighting trend for lightning activity and severity
- Top pressure trend for top pressure estimation
- Expansion rate for amplification or limitation of contour dilatation



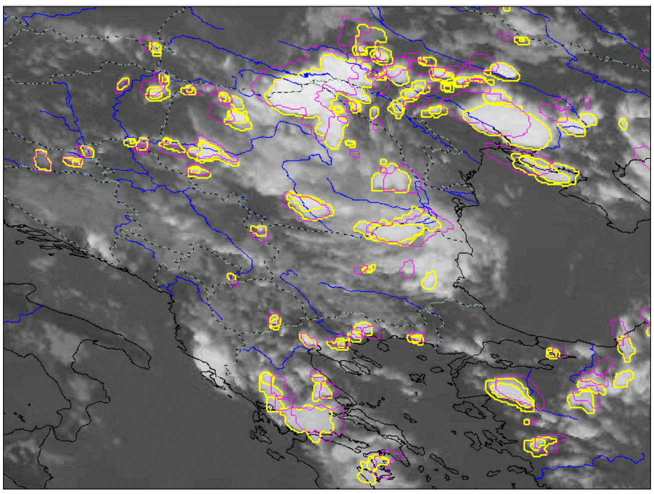
2010-06-28T15:00:00Z + **15min**



2010-06-28T15:00:00Z + **30min**



2010-06-28T15:00:00Z + **45min**



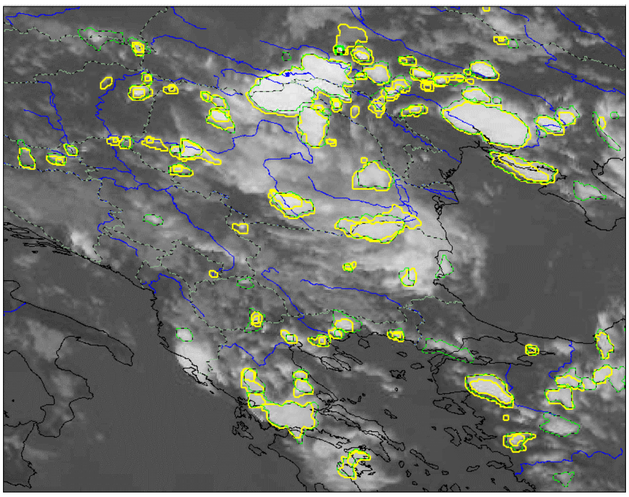
2010-06-28T15:00:00Z + **60min**

Figure 26: RDT-CW v2016 advection products (forecast contours in Magenta) from slot 2010-06-28T15:00:00Z (Observed contours in yellow).

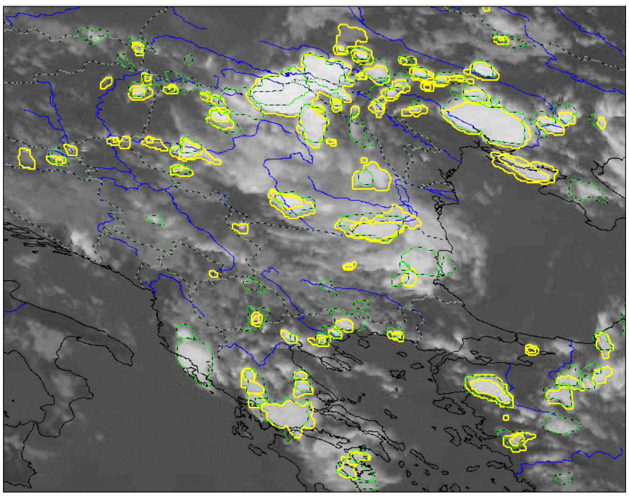
Figure above displays forecast products (magenta contours) issued from a given slot 1500Z on the 28-06-2010. Yellow contours are observed at 1500Z. One can note very few overlap between forecast cells at various ranges, which assess a good spatial coherence of the movement speed of each cloud system.

The cyclonic movement field is very well taken into account with the forecast cloud systems.

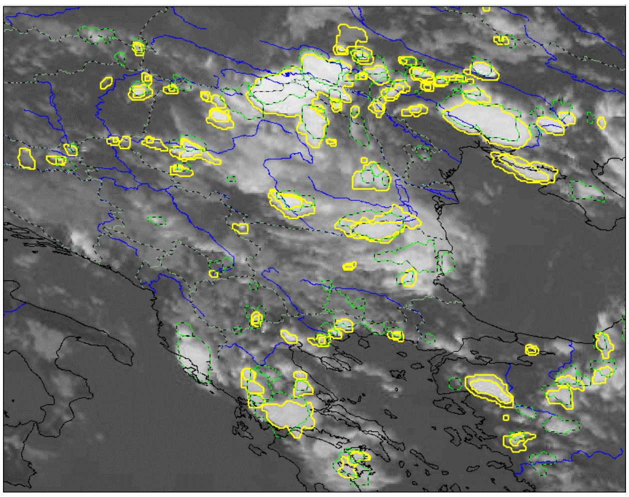
This forecast set has been produced without smoothing neither dilation of the contours.



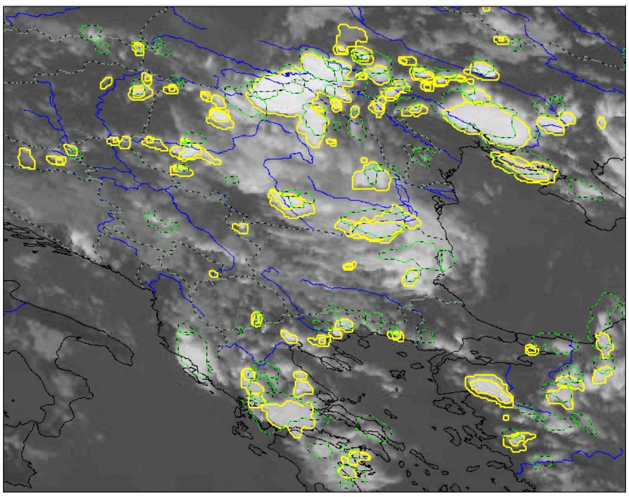
2010-06-28T**14:45:00Z + 15min**



2010-06-28T**14:30:00Z + range 30min**



2010-06-28T**14:15:00Z + range 45min**



2010-06-28T**14:00:00Z + range 60min**

Figure 27: RDT-CW v2016 advection products (green forecast contours) from previous slots valid for slot 2010-06-28T15:00:00Z (yellow observed contours).

Figure above displays forecast products (green contours) valid for a same slot 1500Z on the 28-06-2010. Yellow contours are observed at 1500Z. The first ranges (15 and 30min) show a pretty good correspondence between previous forecast and current observation. For larger ranges, mainly large cloud systems, with longer duration, find a correspondence in the observed set.

One can note that some forecast green contours are no more valid in the analyzed set, probably after declassification of the cloud system (no observed yellow contour).

On the other hand, some new cloud cells (yellow contours) appear only on the analyzed set, and can not be anticipated from the previous slots.

3.6 END-USERS FEEDBACKS

RDT, a very satisfying product widely used for Research and Operations, by Météo-France and its partners.

The use of RDT concerns for example

- Forecasters of Météo-France, in France and overseas territories (La Réunion, Antilles, Polynésie, Wallis et Futuna). RDT provides a significant help for regions not covered by radars.
- Hymex project (http://www.hymex.org/RDT/)
- HAIC project and successive experiments (2014 and 2016 Australia, 2015 French Guyana)
- Air France within an online cockpit visualisation and assistance tool
- SESAR project and TOPMET/TOPLINK experiments

Collaboration has previously concerned

- 2006 AMMA experiments (http://aoc.amma-international.org/observation/mcstracking/)
- European FlySafe Project with RDT software adapted to radar data
- NOAA for a RDT GOES (Operation + Research)
- ACMAD for a RDT-Africa
- BEA for meteorological analysis of aeronautical crashes

From 2008, 2010 and 2015 Surveys distributed to SAF/NWC users , it appeared that RDT is mainly used for Research activities and operations for forecasting. The judgment of overall quality of RDT product is very satisfying.

3.7 CONCLUSION

From a subjective point of view, the use of NWP data with RDT has allowed an improving gap of the discrimination efficiency. False alarms are lowered thanks to a “NWP convective mask” used as a guidance for the diagnosis, and precocity is increased with early diagnosis in warmest categories, thanks to a new tuning with NWP data and mask.

The objective validation over a wide region thanks to EUCLID data detailed in this report has confirmed this first analysis. It has been undertaken through various approaches from time step cell to the full life cycle of a cloud system, and taking into account the limitations of the ground truth.

With a moderate ground truth (defined by 5 flash impacts at least during a trajectory) and non convective trajectories defined by being away from flashes of more than about 35km, satisfying skills are reached for full-trajectory approach: POD of 74% together with 2% POFD, FAR 22% and a TS of 61%. Scores are even better when considering sections of trajectories or cloud cells individually.

RDT keeps good performances when taking into account intermediate season period (Spring, Autumn). Of course RDT scores are better for summer.

Moreover, the skills obtained with EUCLID data over Europe are better in all configurations and for all approaches than for the previous validation.

This improvement does not appear so clearly concerning the precocity of RDT discrimination. It is limited to systems which are able to be early discriminated, i.e. with isolated convective system depicted from low levels.

Finally, those results fulfil the target accuracy requirements (see 1.2) over a large domain and for an extended period, i.e. 70% of detection and 25% of convective systems diagnosed before lightning activity.

We consider nevertheless that progress can still be made to lower the false alarm and the number of misses cases, and to still improve the precocity.

RDT provides an accurate depiction of convective phenomena, from triggering phase to mature stage. The RDT object allows pointing out some areas of interest of a satellite image. It provides relevant information on triggering and development clouds and on mature systems. Even if the precocity on the first lightning occurrence remains to be improved, the subjective evaluation confirmed the precocity usefulness on moderate lightning activity.

Thanks to these good results the status of RDT had been set up to “operational” by EUMETSAT (since v2011).

Since discrimination scheme of RDT-CW v2016 software is unchanged, the results mentioned above can apply also to this version

Subjective validation exhibits very good results of the algorithm concerning OTD. It is a major point to improve RDT by focusing on the areas of more severe and intense convection. Now, depending on cloud system morphology, RDT is able to present a kind of multidimensional description of convective systems, thanks to second level identification and overshooting top detection. It completes the data fusion approach with other PGEs of SAFNWC. This part is unchanged in v2016 software, which consequently benefits from the same subjective validation.

4 CONCLUSION

CI and RDT-CW help to follow convection in different stage.

CI v2016 is the first delivery of the product: CI is a very new product for which the scope for progress is high. CI-validation is still fragmentary as the product will improve and users' feedback on this first delivery will also help for a better tuning. Nevertheless this first release provides promising output.

RDT-CW v2016, as a continuation of RDT, is now a mature product with several years of continuous development and improvement and several version "operational". The forecast scheme implemented in the v2016 delivery remedies to a huge limitation of the product that was up to the v2016 only a diagnostic product. Results of the forecast scheme are correct and confirm the nowcasting dimension of the RDT-CW.

ANNEX I: EUCLID DATA

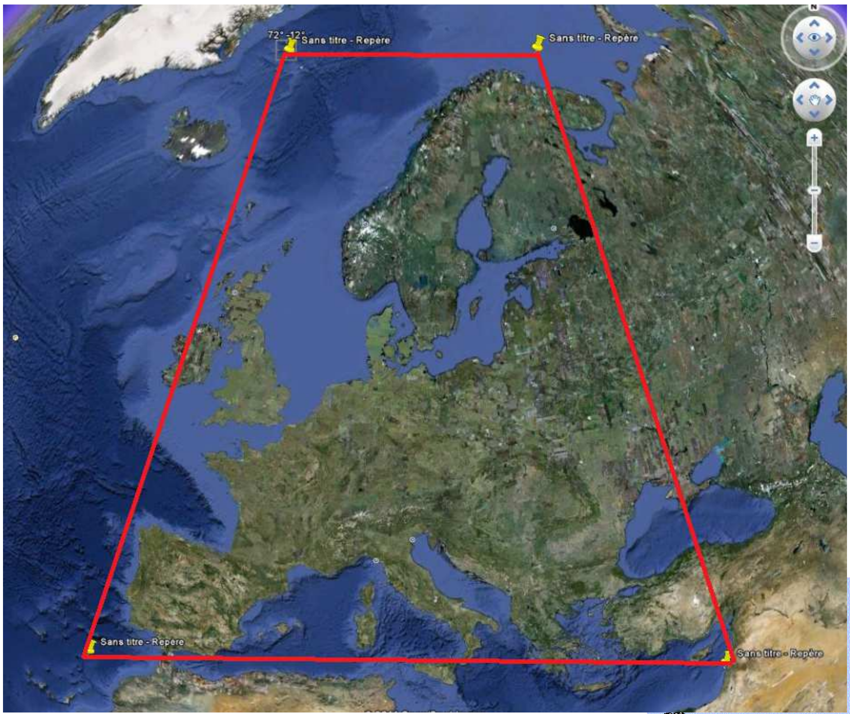


Figure 28: initial area of EUCLID data

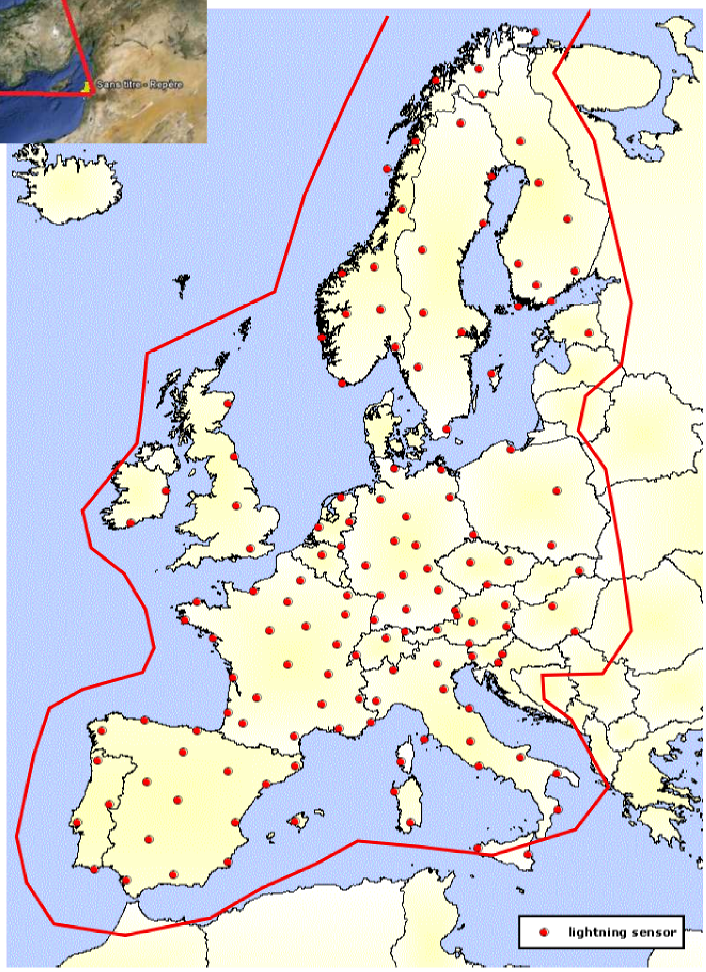


Figure 29: Detection zone of EUCLID network for 2008-2009 period

ANNEXE II: EXAMPLE OF ELECTRIC RDT TRAJECTORY ANALYSIS

The figure below illustrates the validation methodology described in the present report. An electric trajectory, considered as convective whatever the ground truth intensity (about hundred flashes paired), is analyzed against its RDT diagnosis.

Top figure points electric activity at each time step (black histogram), section and time step « colours » (maroon cf ***correspondance***), and discrimination result of RDT (magenta cf ***correspondance***).

Bottom figure illustrates the temporal evolution of temperatures (threshold and minimum)

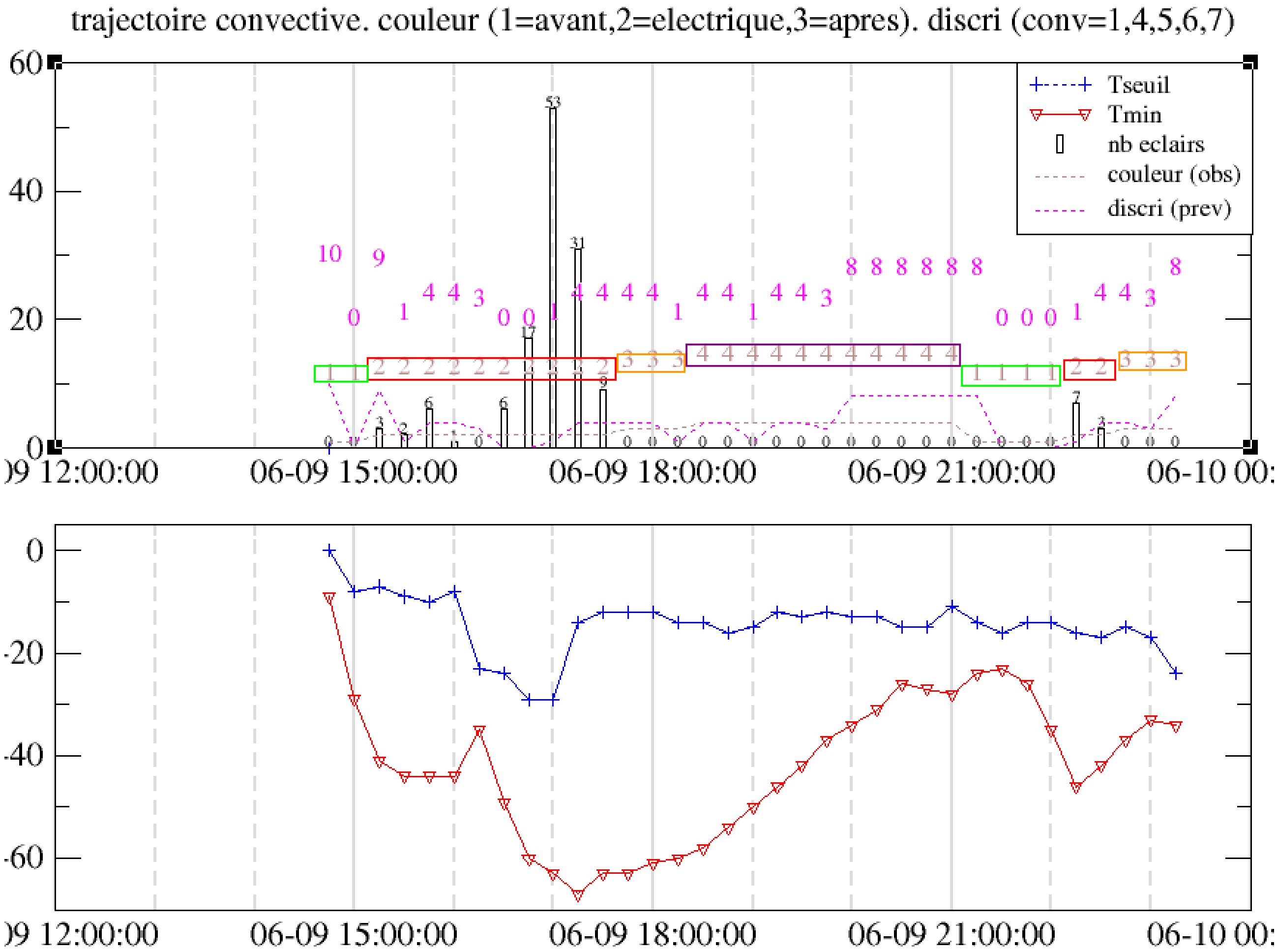


Figure 30: Evolution of a convective / electric trajectory

« **Trajectory** »: good detection: convective observation, and convective discrimination at forth time step (not a good precocity here).

« **Sections** »: trajectory cut in 7 sections, among which 2 electric (code 2 red), with respective precocity (code 1 green) and decaying (code 3 orange) sections, and a transition section (code 4 violet).

Hypothesis 1:

2 « red » sections, each one with at least one convective discrimination: 2 good detections

Hypothesis 2:

2 « green » sections with non-convective diagnosis: 2 correct rejections.

2 « red » sections, each one with at least one convective discrimination: 2 good detections

2 « orange » sections, each one with at least one convective discrimination: 2 good detections (persistence of diagnosis, late declassification)

1 « violet » section with some convective discrimination: 1 false alarm

4GD + 2CR + 1FA => **POD=100%** **FAR=20%** **POFD=33%** **TS=80%**

Hypothesis 3:

2 « green » sections with non-convective diagnosis: 2 misses.

2 « red » sections, each one with at least one convective discrimination: 2 good detections

2 « orange » sections, each one with at least one convective discrimination: 2 good detections (persistence of diagnosis, late declassification)

1 « violet » section with some convective discrimination: 1 false alarm

4GD + 2MI + 1FA => **POD=67%** **FAR=20%** **POFD=100%** **TS=57%**

« Time steps »: 36 time steps for 9h duration:

12 «red» time steps, among which 8 discriminated as convective and 4 non convective (2 non convective, 1 undefined et 1 declassified)

6 «green» time steps, among which 4 discriminated as non convective and 2 non convective (undefined)

6 «orange» time steps, among which 4 discriminated as convective, and 2 non convective (1 declassified and 1 undefined)

11 « violet » time steps, among which 5 discriminated as convective, and 6 non convective (1 declassified and 5 undefined)

Hypothesis 1: 8GD+4MI => **POD=67%, FAR=0%, POFD=0%, TS=67%**

Hypothesis 2: 12GD+4MI+14CR+5FA => **POD=75%, FAR=29%, POFD=26%, TS=57%**

Hypothesis 3: 12GD+12MI+6CR+5FA => **POD=50%, FAR=29%, POFD=45%, TS=41%**

« Color » classes of sections :

- *0 =black = non electric cell preceding first flash of more than 1h*
- *1 =green= non electric cell preceding first flash*
- *2 =red= electric cell or cell in electric section*
- *3 =orange= non electric cell following electric section*
- *4 =violet= non electric cell between 2 electric sections*
- *5 =grey= non electric cell following last electric period*

- *6 = yellow = no activity*

RDT diagnosis classes :

- ***1 = diagnosis convective from statistical model***
- ***4 = diagnosis convective inherited from main link***
- ***5 = diagnosis convective inherited ascending***
- ***6 = diagnosis convective split inherited***
- ***7 = diagnosis convective split inherited ascending***
- *0 = diagnosis non convective from statistical model*
- *3 = de-classification of previous convective system*
- *8 = statistical model not applied, previously de classified*
- *9 = statistical model not applied, previously non convective*
- *10 = statistical model never applied*