# RDT-CW: TOWARD A MULTIDIMENSIONAL DESCRIPTION OF CONVECTION

**Jean-Marc Moisselin, Frederic Autonès**

Météo-France, DPREVI/PI, 42 avenue G. Coriolis 31057 Toulouse, France

Abstract

RDT-CW (Rapid Development Thunderstorm, Convection Warning) product is an object-oriented diagnostic for convective clouds or cells. RDT-CW is mainly based on satellite data. The corresponding software (PGE, Product Generation Element) has been developed in the context of Eumetsat's NWCSAF by the Nowcasting Department of Meteo-France. It tracks clouds, identifies those that are convective (discrimination), and provides some descriptive attributes about their microphysical, morphological and dynamical properties.

Input data come from satellite channels, NWCSAF processing chain, NWP data or lightning network. Year after year many attributes have been added to the convection object. These improvements offer end-users the possibility to focus on specific parameters according to their centre of interest.

- Attributes available at the first development phases of the product
  - Morphological attributes: size, vertical extension, minimum temperature, pressure of the top of the system
  - Lightning attributes
  - Tracking attributes (speed)
  - Evolution attributes (trend of various parameters).
- New recent attributes
  - v2012: main cloud phase of the cell and highest convective rain rate inside the cell, second vertical level description
  - v2013: overshooting tops
- Foreseen evolution
  - v2015: better motion vector estimate and advection scheme, new output format

The v2011 release, from which NWP data can be used for improving discrimination scheme, has been validated with lightning data over European domain and on summer and intermediate seasons. The results have fulfilled the requirements. For example the detection is superior to 70%. The product has been given the status « operational » in EUMETSAT meaning.

Main future evolution concerns: the development of a forecast (up to 1 hour), the development of a new product Convection Initiation. The MTG prospects offer interesting new possibilities for Convection Products due to the increase of channels, the increase of resolution of the FCI (Flexible Combined Imager), and the upcoming of the Lightning Imager (LI).

## 1. INTRODUCTION

Thunderstorms may cause various damages in many places of the world. Associated meteorological hazards are numerous (wind, lightning, hail, rainfall). Thunderstorms can also be seen as the most dangerous aviation weather hazard. Thunderstorms nowcasting is a major field development for many meteorological services.

Thunderstorms are well adapted to object approach as they have for example almost unambiguous spatial envelope [Moisselin et al, 2012]. The object approach makes the tracking of systems easier and allows to calculate some trend parameters.

In the framework of NWCSAF Météo-France has developed the RDT, PGE (Production Generation Element) number 11 of the NWCSAF software package. RDT detects, tracks and characterizes thunderstorms. The first paragraph describes the main characteristics of the product. The second one provides the main conclusions concerning the validation. The third one describes the future evolution of the product.

## 2. DESCRIPTION OF THE PRODUCT

### 2.1. Algorithm

The PGE of RDT combines a cloud-tracker and an algorithm to discriminate convective and non-convective cloud objects. The cloud objects defined by the RDT are cloud towers with a significant vertical extension, namely at least 6℃ colder than the warmer pixel in the surrounding [Guillou and al, 2009]. For that purpose, the 10.8 µm channel of MSG is used. The tracking algorithm allows to link an object on the previous image. Once the link is identified, some characteristics of the object can be calculated: trends (e.g. cooling rate), motion vector (considering successive positions of the gravity centre). Then the third step is a statistical scheme to define if the cell is convective or not. The statistical scheme, called discrimination, depends on historic and data available. In optimal configuration it requires following satellite channels: WV6.2, WV7.3, IR8.7, IR10.8, IR 12.0. Empirical rules help to declassify convective systems.

Finally an object (outline) associated with different attributes describes the meteorological system. The output file format of RDT is BUFR. The next figure (Figure 1) describes some RDT cells superimposed on an enhanced MSG 10.8 µm image over West Africa.

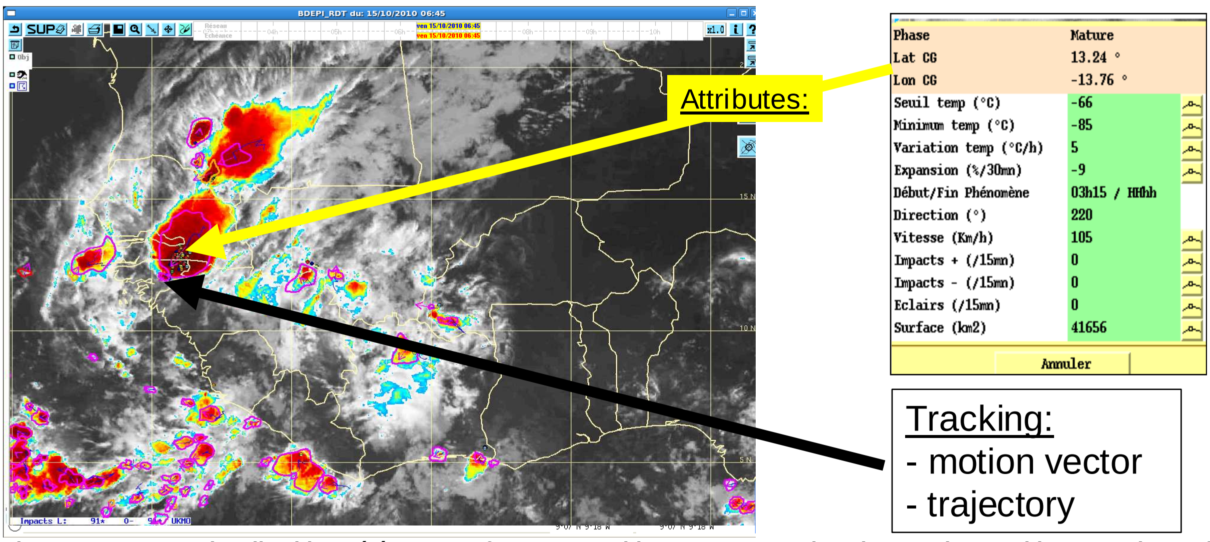


**Figure 1: RDT as visualized by Météo-France forecasters with SYNERGIE workstation. Background image: enhanced 10.8µm satellite-image. Convective cell is characterized by various attributes and its trajectory.**

Not only brightness temperature (BT) values are used for RDT processing, but also other kind of data that can be used at different steps:

- Other NWCSAF products:
  - Cloud products: to eliminate clear sky areas, to define the attribute « Cloud Top Height »
  - Precipitation Products: to define CRR associated to the cell, to set the convection diagnosis to Yes if the CRR is above a threshold

- NWP (Numerical Weather Prediction) data: to eliminate stable areas in cell-detection, to provide a predictor to the discrimination process (Lifted Index), to help the Overshooting Tops (OT) Detection (OTD).
- Lightning data. Lightning data are of course a key element to define if a cell is convective or not, even if RDT algorithm is able to detect convective cells without lightning data. The tuning or validation of RDT product is made with lightning data as ground truth (in that case lightning data are not used as input data). Lightning data help also to define the « lightning attribute ».

### 2.2. Last evolutions

Year after year many attributes have been added to the convection object. These improvements offer end-users the possibility to focus on specific parameters according to their centre of interest. Since IOP, the first attributes of RDT have been morphological attributes (size, vertical extension, minimum temperature), lightning attributes, pressure of the top of the system, tracking attributes, evolution or trend attributes.

In the v2011 release, RDT can take benefit of NWP data. This version has been proven to have reliable scores (see next chapter). Subjective validation has proven that the use of NWP helps to increase the earliness of the convection diagnosis.

- Convection indices are calculated and help to focus on area of interest. In the tuning of the RDT it helps to reduce the imbalance between convective and non-convection population. Thus the statistical process has to discriminate less extreme events: tuning is more reliable.
- In operational mode, the stable areas are not analysed: it reduces the false alarms.
- The value of Lifted index is used as predictor in statistical discrimination scheme and provides a useful estimation of the potential energy for convective development and organisation.

For the v2012 release, main cloud phase of the cell (coming from Cloud NWCSAF product) and highest convective rain rate inside the cell (coming from Convective Precipitation NWCSAF product) enrich the description of convection. The use of other PGEs is a key point for RDT PGE since the latter is placed at the end of the NWCSAF processing chain. Additionally to first level (outline depending on the base of the convective towers) a second level (outline depending on the upper levels of the towers) allows to focus on specific areas.

In the v2013 release, the OTD inside RDT cell is proposed to users. v2013 is the first release of CDOP2 [NWCSAF, 2011]. This new attribute allows to focus on potentially hazardous areas and to distinguish the most convective cells. The main steps of the algorithm are described hereafter. Parameters of Interest are adapted from [CWG, 2012]. Full algorithm described in [Autonès and Moisselin, 2013a]

- Step 1, cell conditions:
  - Temperature of the coldest pixel of the cell has to be below -50℃ (threshold for mid-latitude regions)
  - And at least one pixel with BTD WV6.2-IR10.8>0℃
- Step 2, selection of Pixel of Interest:
  - Coldest pixel
  - Other pixels of interest can be selected considering conditions on BTD WV6.2-IR10.8, BTD WV6.2-WV7.3 or VIS06
- Step 3, the OT candidates. We analyse pixels around the Pixel of Interest, using typical values of OT-size values. For each pixel of interest, the aims of this step are:
  - To define the pixels that may belong to the OT
  - To confirm that there are much warmer surrounding pixels
- Step 4, final conditions to be satisfied. At the end of step 3, some cold pixels surrounded by warm pixels are identified. But do they really correspond to an OT? Is this a domelike protrusion above the cumulonimbus anvil?
  - OT candidate at least 5℃ colder than NWP tropopaus e (wet adiabatic relaxation of the air particle)

- Or a condition using following parameters of interest:
  - Temperature difference between OT and NWP tropopause
  - BTD=WV6.3-IR10.8
  - VIS0.6 reflectance
  - Temperature difference between OT and cloud-cell

The use of NWP data is again a key point for OTD, giving significant information on the environment at a larger geographical scale, as described in next figure (Figure 2).

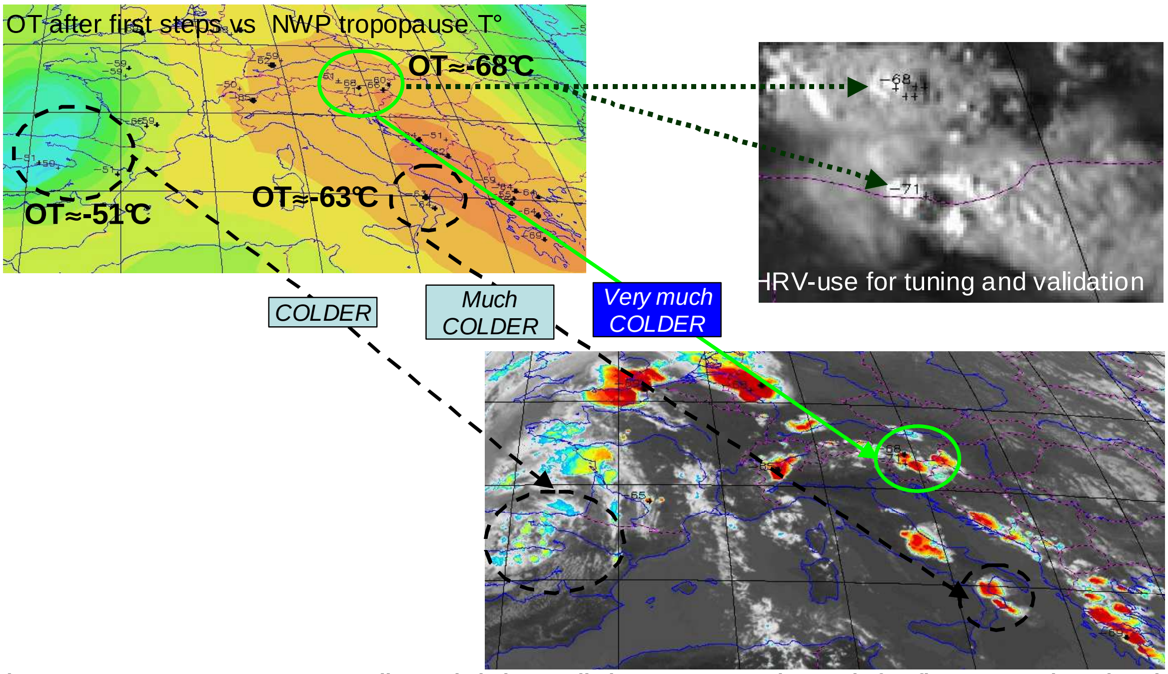


**Figure 2: Tropopause-temperature-diagnosis helps to eliminate wrong OT detected after first steps, rejected OT have a temperature not cold enough compared tropopause. High Resolution visible Image confirms the OT.**

### 2.3. Product-use

RDT offers now a complete description of convection, using many sources of data as input and providing different characteristics (Figure 3).

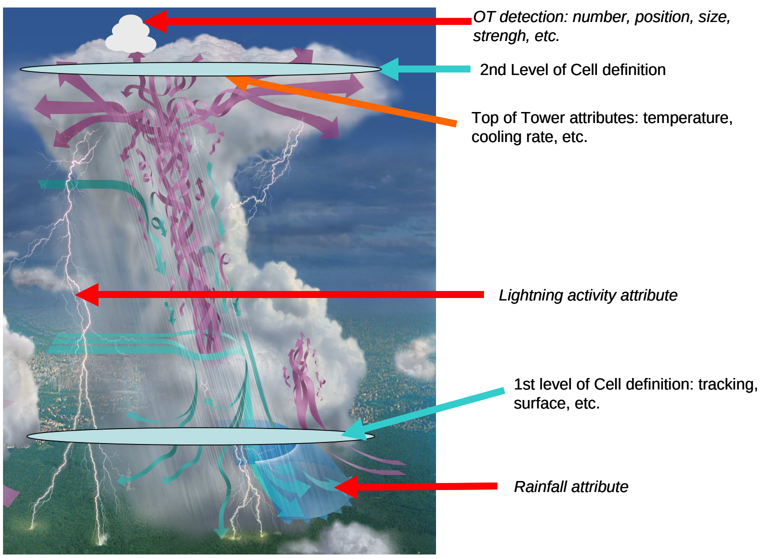


**Figure 3: RDT mature cell with description of main attributes. In red, attributes related to some meteorological hazards. In blue the vertical levels describing the cell**

The product is used both by research and operations, as proven by a NWCSAF survey distributed to NWCSAF users. The judgment of overall quality of RDT product is very satisfying: 6 High, 4 Medium, 1 Low [NWCSAF, 2010]. RDT has been proposed or used is used in various international and European projects: AMMA, FlySafe, Hymex, HAIC, TOPMET (SESAR).

# 3. VALIDATION OF THE PRODUCT

## 3.1. DATA

EUCLID data over Europe have been used as Ground Truth. EUCLID data concern stroke returns of Cloud-to-Ground flashes, collected from several interconnected national lightning detection networks over Europe (time of the event, impact point coordinates, current intensity and polarity). The validation domain is the intersection between domains of local MSG archive and EUCLID data availability. The period covers summer 2008 and April-October 2009

The most recent available PGE11-RDT discrimination tuning has been undertaken over France for version 2011. It is widely applicable to v2012 and v2013 releases, which benefit from the same discrimination scheme. Thus, the validation is made on v2011 and is applicable to v2012 and v2013. The validation report of the last release (v2013) provides more detailed scores and results [Autonès and Moisselin, 2013b].

## 3.2. METHOD

A RDT trajectory aggregates all RDT objects linked in time. For each RDT trajectory an electric trajectory is built using:

- RDT successive geographical position of the gravity centre
- Lightning data

The strokes associated to the path help to define the time steps that are electric or not. This electric trajectory defines the ground truth for RDT validation. For each time-step, the RDT Yes/No convection diagnosis is compared to the electrical trajectories. That process defines the first approach, the *time-step validation approach*. In a second approach, the *section validation approach*, we focus on several continuous time-steps, having the same electrical activity (Figure 4). The difficulty in that case is to consider a RDT Yes-convection-diagnosis before or after electrical section. Is a RDT Yes convection diagnosis before an electrical section a False Alarm or an earliness diagnosis? The question is open for example for the first green section in Figure 4. Different options are envisaged to take this issue into account.

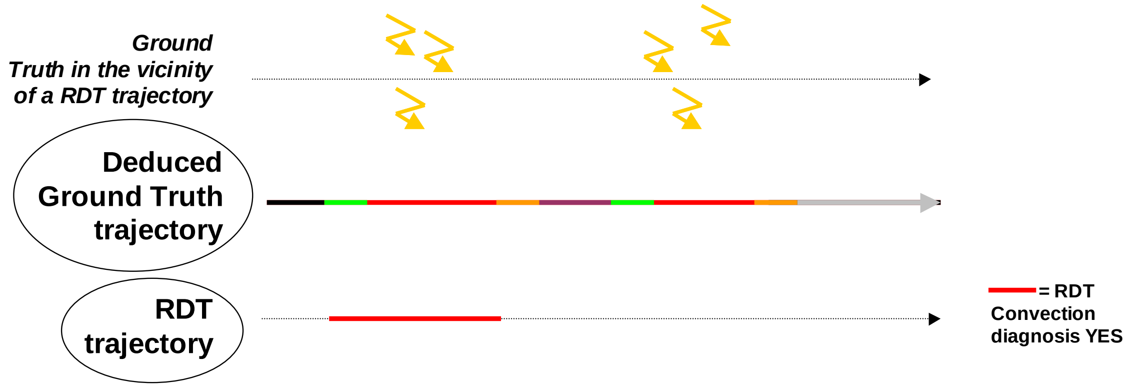


**Figure 4: Validation outline. The electrical-trajectory (ground truth trajectory) is built with the strokes in the vicinity of a RDT trajectory (upper part of the figure). Some sections are then defined for deduced ground truth trajectory (middle part). The RDT convection diagnosis (lower part) is compared to electrical observed ground truth.**

In the third full trajectory validation approach, the principle is simply to verify that a Yes convection RDT-trajectory (at least one time step having a Yes convection diagnosis) corresponds to an electrical trajectory with at least a time step with strokes in the vicinity of the trajectory.

Contingency tables are produced for each approach, and classical categorical statistics are used: POD (Probability Of Detection, hit rate), FAR (False Alarm Ratio), POFD (Probability Of False Detection) and TS (Threat Score).

For these different approaches there are several control parameters

- The distance between the strokes and non-electrical trajectories, called proximity tolerance. A tolerance of 10km is already taken into account to pair RDT cells and lightning strokes defining electrical trajectories. Thus, non-electrical trajectories are always distant of at least 10km from strokes. The proximity tolerance is defined beyond this value of 10 km, to identify non-electrical trajectories with flashes in the vicinity. It is used to eliminate some potential ambiguous cases (leading to false alarms) from the contingency table, without change of observed electrical population. In next chapter results for values of proximity tolerance of 0 and 35 km are presented.
- The way to consider electrical trajectories with low or moderate lightning activity. If the trajectories with low activity are rejected from the verification sample, the scores are higher and more interpretable, some spurious trajectories are rejected. In next chapter results for moderate activity are presented. In that case a trajectory is assumed convective if it matches with 5 flashes strokes at least. Trajectories with strictly more than 0 and less than 5 strokes are rejected from the sample.

### 3.3. MAIN RESULTS

Different approaches are compared in Figure 5.

| | | POD | POFD | FAR | TS | |
|---|---|---|---|---|---|---|
| ❶ | *Trajectory Approach, France, Summer 2005, Meteorage data, RDT v2009* | 66 | 2 | 44 | 43 | |
| | Trajectory Approach Europe, Summer 2008 + summer 2009, EUCLID data, RDT v2011 | 75 | 3.5 | 31 | 56 | ❷ |
| ❸ | Trajectory Approach Europe, Full period, EUCLID data, RDT v2011 | 74 | 3.5 | 34 | 53 | |
| | *Idem with flashes proximity tolerance of 35km* | 74 | 2 | 22 | 61 | |
| ❹ | Section approach Europe, Full period, EUCLID data, RDT v2011 | 77 | 4 | 28 | 59 | |
| | *Idem with flashes proximity tolerance of 35km* | 77 | 3 | 21 | 64 | |
| ❺ | Time steps approach Europe, Full period, EUCLID data, RDT v2011 | 65 | 1.5 | 20 | 56 | |
| | *Idem with flashes proximity tolerance of 35km* | 65 | 1 | 14 | 59 | |

**Figure 5: Main results of validation. Column: the values of scores. Lines: different configurations that have been tested. Scores in percentage**

The table above points out the sensitivity of score values on the assumption used. Some line-to-line comparisons provides following analysis:

❶: 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 (2005 / 2008 and 2009)

Considering the results above and our experience of RDT behaviour, we consider that the main impacts come from differences of version of RDT. Thus we can conclude that results for this validation are better than those of the previous one. For example the TS reaches from 43% to 56%.

❷: Scores remain good when non-summer months are added. The impact is mainly on FAR but remains light (34% to compare with 31%)

❸: Flash proximity tolerance lowers the FAR (from 34% with a tolerance of 0 km to the value of 22% with a tolerance of 35 km)

❹: Best results concern the Section Approach (due to time-tolerance given to sections before and after lightning activity in the hypothesis chosen here). The TS reaches the value of 64% with a 35-km proximity tolerance

❺: Time-step approach is very disadvantageous but scores are correct (POD=65%)

The version v2011 has been validated with lightning data over European domain and on summer and intermediate seasons. The results has fulfilled the requirements and the product has been given the status « operational » in EUMETSAT meaning

### 3.4. The precocity skill

One of the goals of RDT is to detect as early as possible convective systems evolving in thunderstorms. The precocity of this diagnostic is measured against the age of first lightning flash paired with a cloud cell of a convective trajectory. More than 50% of good detection are already classified at the time of the first lightning occurrence, 80% thirty minutes after, and 25% are classified before the first flashes stroke (15 minutes before).

## 4. FUTURE PLANS

### 4.1. RDT-CW v2015 release

Up to now RDT is a diagnosis tool product. For the next release we plan to introduce a forecast, up to one hour. This Lagrangian forecast will be based on RDT motion vector estimate. But sometimes this estimation can be uncertain or inexistent: new cell (without father), uncertainty on father-cell, fusion or fission of cells, change of base of tower characteristics between two consecutive slots (surface, temperature), incoherence between neighbouring cells.

The link between two NWCSAF products, RDT and HRW-AMV (High Resolution Wind, Atmospheric Motion vector) has been analysed over the period 1-7/6/2013. HRW is taken at the level closest to the base of each convective tower. Results are encouraging since biases between two values are reasonable (Figure 6)

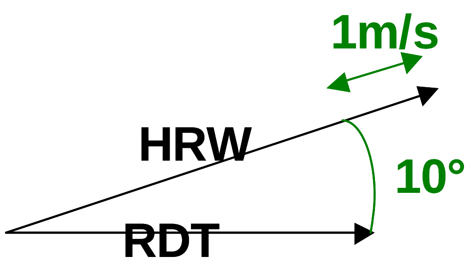


**Figure 6: Average differences between HRW and RDT motion vector**

Thus, the use of HRW-AMV could:

- Be an interesting alternative of estimation of motion vector for RDT
- Help to quantify the uncertainty on motion vector estimate
- Have a positive impact expected on advection scheme (foreseen for v2015)

In the future releases the description of convective cells will be enriched, giving a high priority to the use of other NWCSAF products: the identification of aeronautical hazardous areas using CRR over a threshold, the estimation of motion vector using both cell speed estimation and NWCSAF AMV product. RDT name will change in the v2015 release becoming RDT-CW, a component of convection products.

### 4.2. CI v2015 release

For the v2015 release, a new product will be developed, Convection Initiation product that will describe the probability for a given pixel to develop into a thunderstorm (Figure 7). The convection probability for each pixel is based on:

- BT or BTD values or trends, e.g. BDT 6.2-10.8µm, some relevant parameters of interest can be found in [CWG, 2012]
- NWCSAF products: Clear Air Products, Cloud Products, Wind Products

- NWP data (instability indices)
- Past positions and characteristics of pixel

The new CI product will complete the description of convection. It will be a predictor for RDT statistical scheme and CI will be validated by RDT.

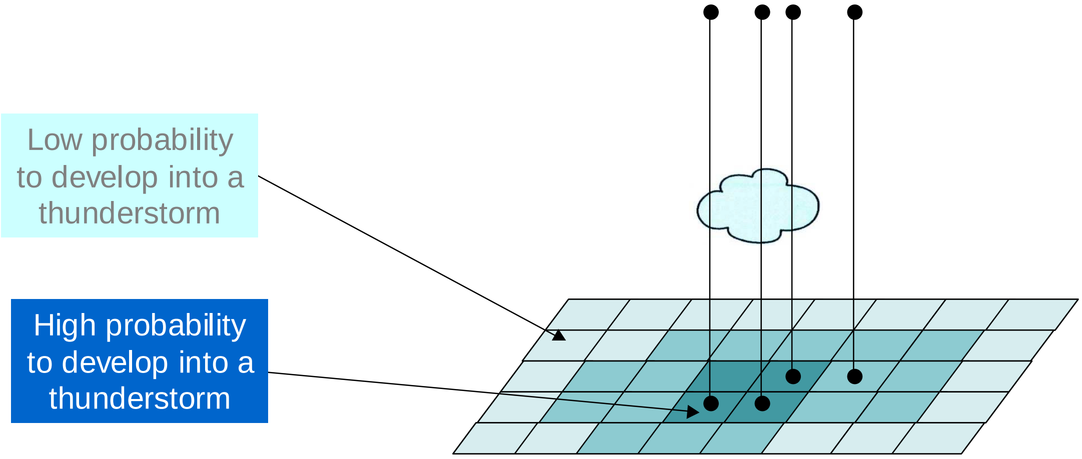


**Figure 7: Convection Initiation Product**

### 4.3. MTG context

A NWCSAF scientific report [Moisselin, 2011] describes the expected impact of MTG on convection products. Hereafter a description of some expected improvements.

Concerning the move from SEVIRI to FCI, one can note than in previous years, RDT software algorithm has always taken a lot of advantages from the increase of the number of channels. This type of change echoes the change from Meteosat first generation to MSG. New channels will help to capture some new physical characteristics or to improve current diagnosis, for example new 0.91µm channel is linked to total column precipitable water. The increase in resolution will provide a better estimate of morphological parameters and small-scale phenomena (Figure 8)

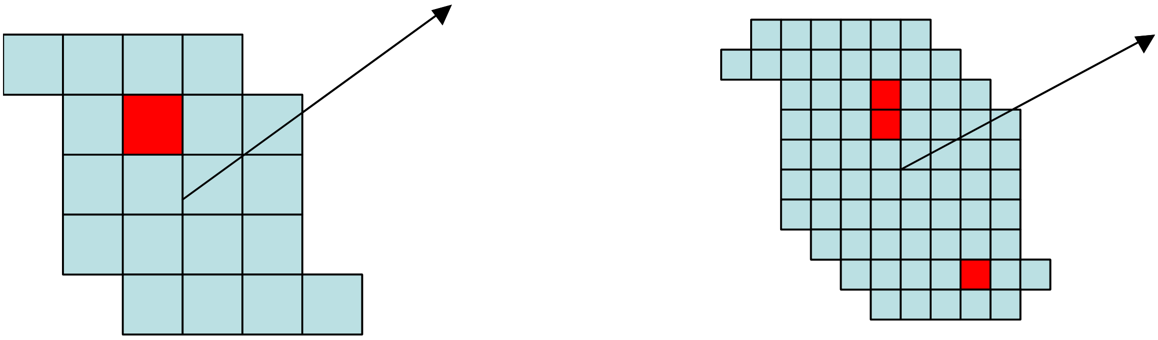

**Figure 8: Impact of an increase of resolution on cell definition and small-scale phenomena detection (example for OT)**

The improvement of Spectral accuracy will offer a better estimate of BT input data of RDT.

When two satellites with FCI will be launched, the use of future 2.5' Rapid Scan Service (RSS) will be very challenging because the lack of channels in RSS would mean for RDT a lack of predictors. Solution could be to use RSS output to update a part of RDT characteristics

The use of IRS (Infra Red Sounder) is more uncertain but some ways of improvement can be identified: use of clear-sky instability indices, use of clear-sky AMV, and indirect benefit via the improvement of NWP data for models assimilating IRS data.

LI instrument (Figure 9) is eagerly expected to improve many components of RDT:

- Statistical scheme
- Real time mode
- Enhancement of characteristics for a more complete description of convection
- Monitoring

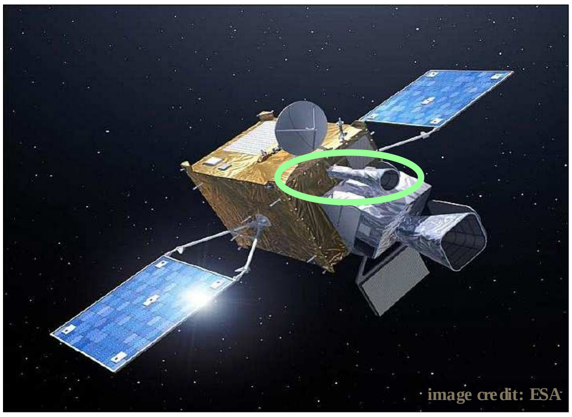


**Figure 9: MTG artist view, with LI outlined**

## 5. CONCLUSION

RDT product takes benefit of many types of input data, including output from other NWCSAF PGEs. It is now a mature product. RDT product could be integrated inside operational applications to thunderstorms monitor and automatic alarm process. RDT brings complementary information to radar and lightning network. It could improve detection precocity and achieve data fusion into object characterization. Without ground observation network, RDT allows to dispose of a description of convective phenomena. With a maximum of input data RDT offers a detailed depiction of convective systems.

The RDT software is constantly improving and some improvements are planed for next years: forecast of the product, new output format, and benefit of future MTG instruments. A new product strongly linked to RDT will be developed: convection initiation, which will provide the probability of a satellite pixel to become a thunderstorm.

## 6. GLOSSARY

AMMA: African Monsoon Multi Analysis
AMV: Atmospheric Motion Vector
BUFR: Binary Universal Form for the Representation of meteorological data
CI: Convection Initiation
CRR: Convective Rain Rate
CWG: Convection Working Group
EUCLID: European Cooperation for LIghtning Detection
FAR (False Alarm Ratio),
FCI: Flexible Combined Imager
GT: Ground Truth
HAIC: High Altitude Ice Crystals
IOP: Initial Operation Phase
LI: Lightning Imager
MSG: Meteosat Second Generation
MTG: Meteosat Third Generation
NWCSAF: Satellite Application Facility for Nowcasting
NWP: Numerical Weather Prediction

OT: Overshooting Tops
OTD: Overshooting Tops Detection
PGE: Product Generation Element
POD: Probability Of Detection, hit rate
POFD: Probability Of False Detection
RDT-CW: Rapid Development Thunderstorm Convection warning
RSS: Rapid Scan Service
SESAR: Single European Sky Air traffic management Research
SEVIRI: Spinning Enhanced Visible and InfraRed Imager
TS: Threat Score

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