NEFODINA: A TOOL FOR AUTOMATIC DETECTION OF SEVERE CONVECTIVE PHENOMENA

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Abstract

The NEFODINA (DYNAmic NEFOanalisys) product has been developed by Italian Air Force Met Service (IAFMS) to estimate thunderstorms presence and intensity using only geostationary satellite data. More precisely using a multichannel approach it provides information on convective nuclei inside cloudy systems (from mesoscale down to single cell thunderstorm) This is an important information for the forecasters to diagnose the convective activity, evaluate its severity and its potential development. Moreover, NEFODINA determines also the Convective Objects' (COs) life phase (developing/dissolving phase).

During its life, a cell passes different phases: in particular we can speak about a cumulus stage, a growing or mature phase and finally a dissipating stage. During the growing phase, when the lightning density shows a maximum, the most intensive weather activities, heavy rainfall, thunderstorms and hail showers occurs and frequently cause significant damage.

NEFODINA software runs at IAFMS since 1990 and every day its performance and reliability is tested by Italian forecaster. Initially based only on 10.8 μm IR channel, studies on the correlation between the electric activity measured by the Lightning Network (LN) of the IAFMS and convective systems features detectable by MSG pointed out the necessity to use both infrared (IR) window and water vapor absorption bands to achieve a good operational detection and tracking of convective objects. The use of MSG water vapor (WV) channels appears very efficient not only for separating high level cloudiness from clear sky and low clouds but also for estimating the horizontal distribution of the WV amount in the middle-high troposphere.

1. Introduction

The convective phenomena are a combination of buoyancy force and advection of vorticity from general circulation with local surface and orographic forcing. To understand the potential scale increasing of the clusters and theirs development, one of the main information required is the detection and distribution of the main convective nuclei inside the cloudy cluster.

Several analysis (Puca, 2002-2005) suggested that deep convective clusters are associated with a substantial WV horizontal discontinuity and that (Melfi, 2004) their life phase also are characterized by the correlation between IR and WV channel data.

NEFODINA, a satellite multi-channels tool able to detect and track the COs using MSG data only, has been designed on the base of these results. Obviously we define and consider COs those main convective nucleus embedded into convective systems, as detectable by resolution of the SEVIRI radiometer.

2. NEFODINA algorithm

NEFODINA works with the MSG IR and WV data processing, in real time, the last two available imagery (i.e. 15 minutes), giving as output the detection of the CCs with a top BT lower than 236 K and their evolution.

The NEFODINA algorithm includes three steps:

- detection of cloud system
- the discrimination of convective cloud objects
- evaluation of Cos' life phase

A NEFODINA scheme is reported in figure 1.

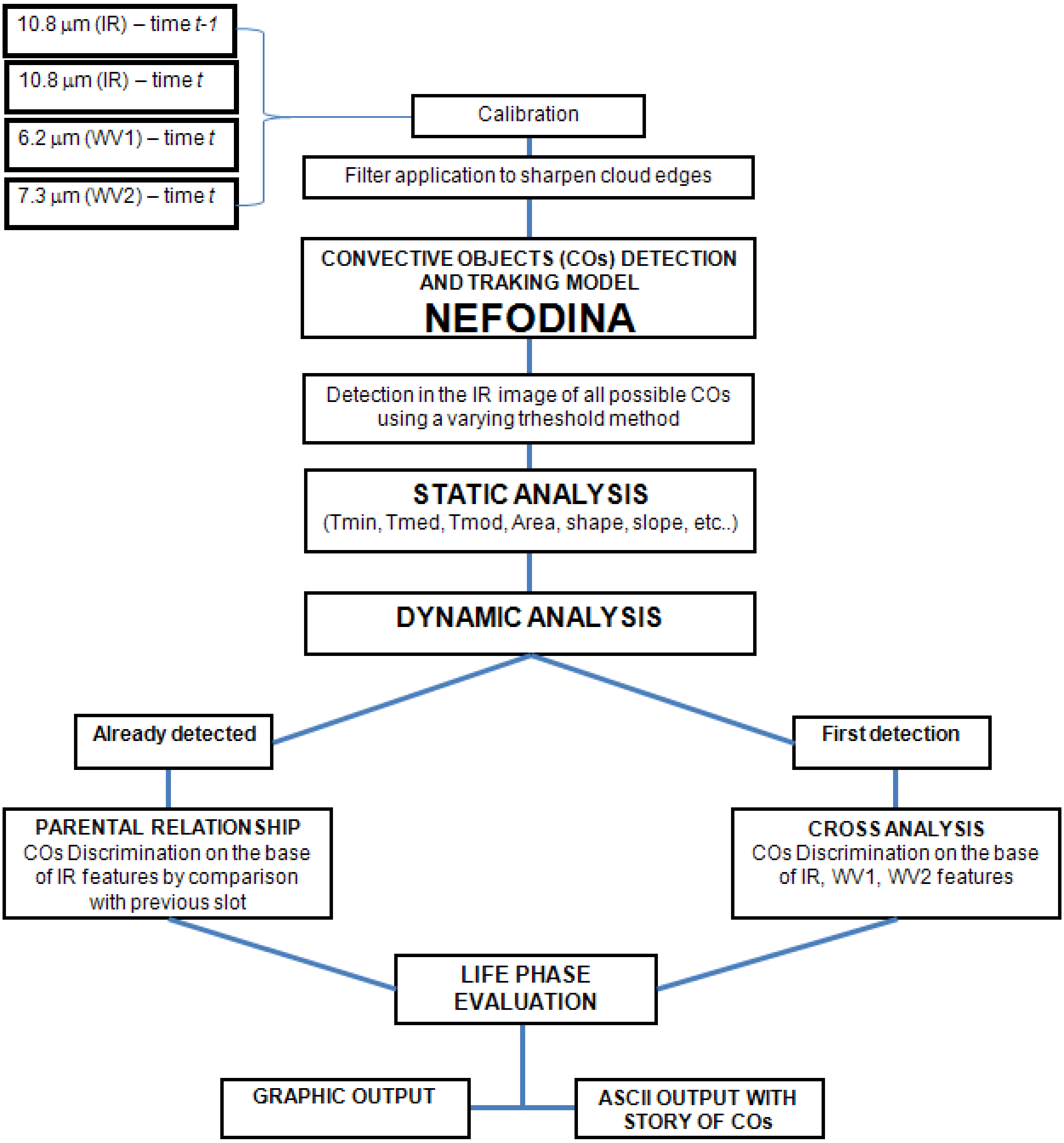

Figure 1. Scheme of the main phases of NEFODINA.

The detection phase

The spatial distribution study of the IR window (IR1=10.8 µm) and absorption bands (WV1=6.2 µm and WV2=7.3 µm) brightness temperature (BT) has pointed out that the cloud structure with an high top and limited oval shape in the IR window channel has to be confirmed by the detection of the same limited area in the WV absorption band, to be classified as convective. The requirement of meaningful water vapor content in the middle troposphere with an oval shape, characterized by an environment humidity discontinuity, is a basic information to obtain a satisfactory efficiency of the COs detection.
So a variable temperature threshold method is applied on IR1 and WV1 on the cloudy clusters with a BT lower than 236 °K. Varying the threshold inside a defined temperature range [Twarm =236°K - Tcold=200°K] with step of 1 °K, we detect every cell presents in the clouds (Rosci (2000), Puca (2003)).

Some static parameters are so calculated for each object:

- minima temperature (value and position) in IR,WV1, WV2 ;
- average temperature in IR, WV1, WV2;
- modal temperature in IR, WV1, WV2;
- total area in IR, WV1, WV2;
- modal temperature area in IR, WV1, WV2;
- position of the centre of gravity in IR, WV1, WV2;
- ellipticity (ratio of max. semi dispersion and min. semi dispersion) in IR only;
- slope index in IR only;

On the base of the static parameters it is so done a first discrimination of the COs at time *t*.

The discrimination of convective cloud objects (Dynamic analysis)

Two kinds of "dynamic analysis" are computed:

- Parental relationship:
  a cross correlation between the cloud cells detected at time *t* and the COs detected at time *(t-1)*, is so evaluated minimizing the distance function based on the position of the centre of gravity, minima temperature and modal temperature. The COs with a distance *d* major than a maximum radius R_{max} is classified as first detection. On the contrary it is important to underline that "already detected" means whether that an object continue to be convective or another cell (daughter) was formed adjacent the old one (the mother)(see Figure below).

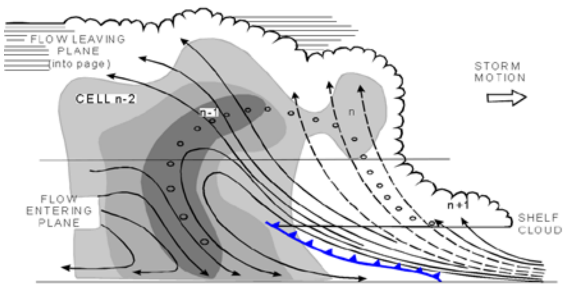

Figure 2. An ordinary single cell produces a gust front which may lift the surrounding air along the periphery of the cell to its level of free convection. Now new secondary cells, called "daughter cells", can form adjacent to the old cell. The develop, very rapidly and after a short time, become the new centre of the Multi-Cell Storm (mother cell).

- Cross Analysis:
  an analysis of the WV1 BT and the WV2 BT spatial distribution in order to check if the convective features detected in the IR image are supported in the WV1 and WV2 channels.

- Another check is made to individuate the "cold objects" (objects near the limit of the troposphere and therefore near the thermal inversion, that shows a top more crushed and cold) this is a new implementation to avoid that they couldn't be identified like convective from the algorithm and discarded for their low value of the slope index

The evaluation of Cos' life phase

The life cycle of a Cumulonimbus (Cb) can be separated into three stages: developing, mature and dissipating stage (Manual of Synoptic Satellite Meteorology Conceptual Models and Case Studies developed by DHMZ, FMI, KNMI and ZAMG). The developing stage is characterised by a distinct single updraft. The process of entrainment at the cloud edges is essential for the further development of the Cb. The entrainment results in a smaller water vapour content at the cloud edge compared to the centre of the Cb and, consequently, in the evaporation of water droplets. The supply of sufficient humidity from surface levels will support further growth of the developing cell. The mature stage of the single cell body (which of course can be embedded within a group of cells) typically lasts between 25 and 30 minutes. The end of the mature stage is reached when the outflowing dry air completely cuts off the incoming supply of moist air. The dissipating stage, of a Cb is reached when the updraft weakens and increasing downdrafts of dry cold air spread at lower levels. The supply of warm moist air from the lower levels is then interrupted and the Cb dissipates.

Taking in account the above conceptual model we characterize the CO life cycle in two phases: growing and dissolving phase. The CO growing phase happens when most of its Cbs are in developing/mature stage whereas the dissolving phase when the Cbs are in dissipating stage. It is clear that the phases duration of the CO life cycle are in general longer than the Cb one.
The most intensive weather activities occur during the growing phase. During this phase a pulsating movement of the CO top can be observed in MSG High Resolution Visible imagery. The CO's top increases and decreases for an unknown time interval dependent by the WV content of the environment and the CO updraft velocity. For this reason information of IR1 channel temperature only is not enough to evaluate the start of dissolving phase. A small decrease of the cloud top temperature (detected in the IR1 channel) is not a satisfactory indication for the beginning of the dissolving phase, it has to be associated with a decrease of the water vapor content in the middle troposphere.
So the dissolving phase of the CO starts really only when the cloud top descent is simultaneous to a WV decrease (see Fig. below).

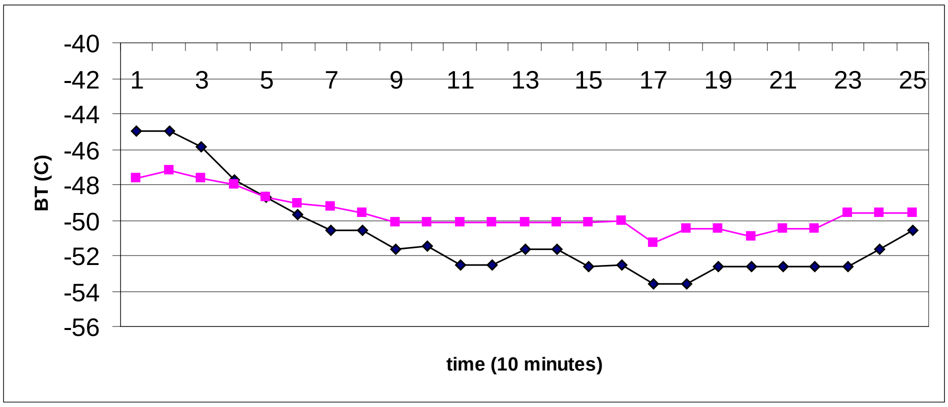

Figure 3. BT minima in the WV channel (squares) and in IR channel of the Meteosat-6 rapid scan as function of time.

A CO is considered in a growing phase if its top temperature is decreasing in both IR1and WV1 channels or if it has a substantial change in the water vapor temperature:

$$\left[\left(\Delta T_{IR1} \leq -1\right) \wedge \left(\Delta T_{WV1} \leq 0\right)\right] \vee \left(\Delta T_{WV1} \leq -0.7\right)$$

it is considered in a dissolving phase if its top temperature is increasing in both IR1and WV1 channels or if it has a substantial change in the water vapor temperature

$$\left[\left(\Delta T_{IR1} \geq 1\right) \wedge \left(\Delta T_{WV1} \geq 0\right)\right] \vee \left(\Delta T_{WV1} \geq 0.7\right)$$

in all the other cases the CO keeps the previous stage detected.

3. The final output

The model output consists of the last infrared image (ch10.8) over the European area where the convective cells and their stage are represented (see Figure 4 and 5).
Blue shades are used to show the cloud to which we are interested. Dark blue is used for lowest cloud and light blue/yellow for highest clouds. With red shades are indicated the cloud top of the detected convective cell evaluated in growing phase With pink shades are indicated the cloud top of the detected convective cell evaluated in decreasing phase.The dark red and dark pink colors are used to indicate the most intensive convective regions.
This output image is associated to an ASCII file where the minimum, medium and modal BT of the IR1, WV1, WV2 channels are reported with shape, slope area and other information.

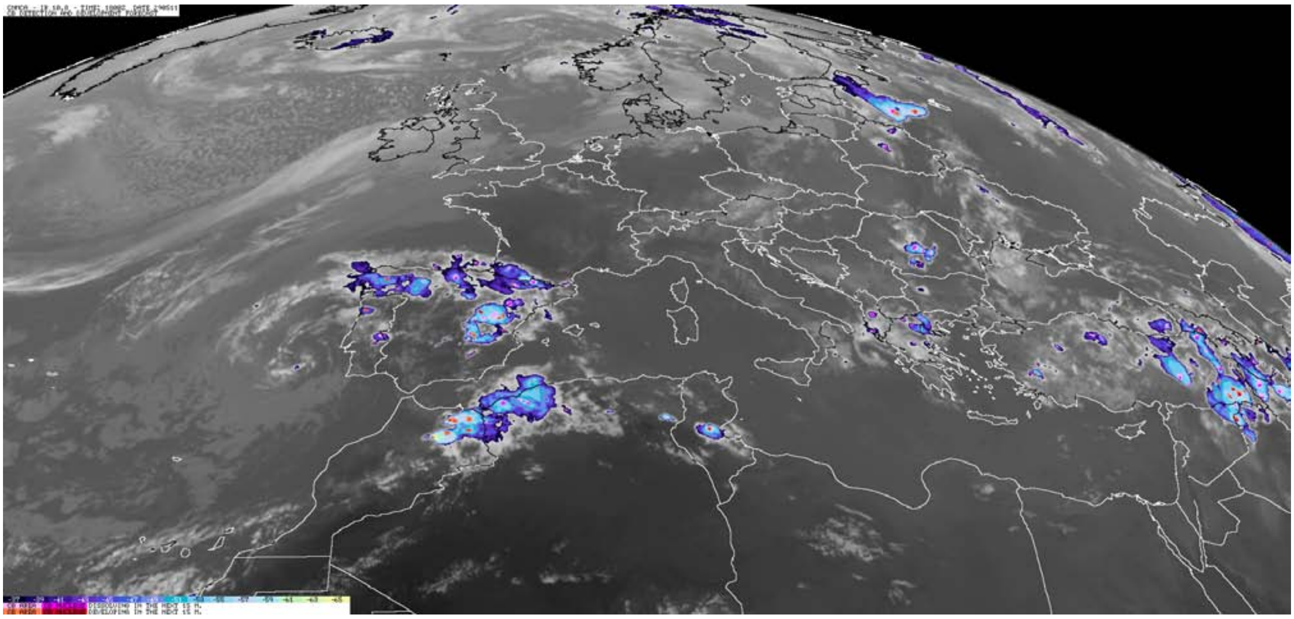

Figure 4. Graphic output of NEFODINA

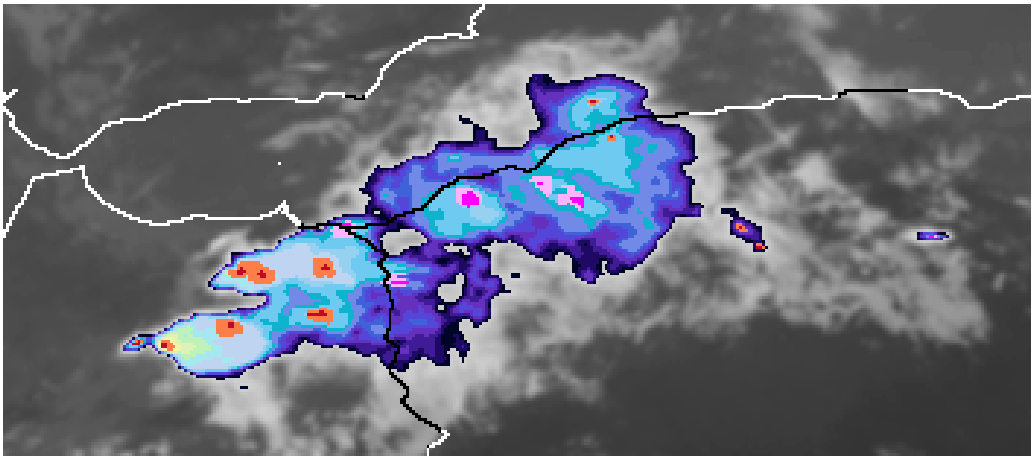

Figure 5. A detail

4. Verification Against Lightning Data

It was conducted a validation work on the detection efficiency of NEFODINA, following the idea that a CO during its life has an electric activity specially during the mature stage. The validation has been based indeed on the observation of lightning measured by the LN of the IAFMS during the life of the CO and it is conducted on a set of 12000 data uniformly selected along one year of MSG data. In this way it was obtained a correlation equal to 0.84 (see figure 8).

5. Strong points

The strong points of NEFODINA are its high geographic scalability and its easy configuration (scene size, position, threshold, colors, additional information (CTH)). Figure 6 and 7 show two uses of Nefodina in support of air and maritime military operations.

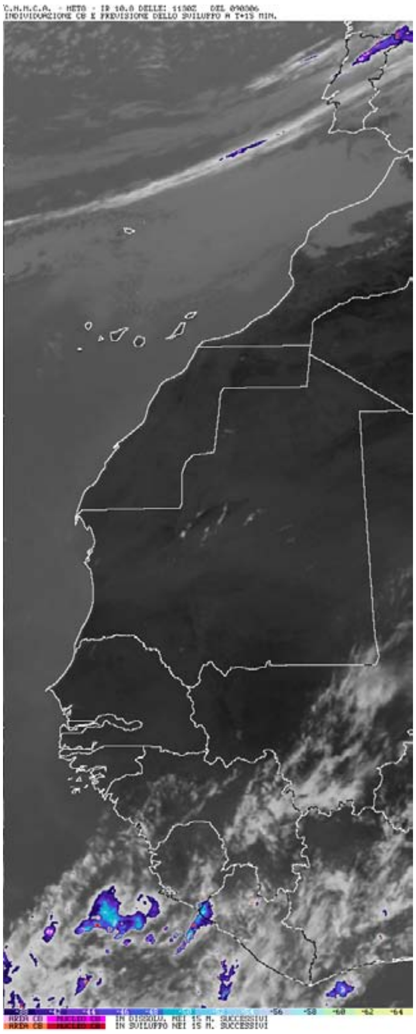

Figure 6. Nefodina in support of air and maritime military operations in Western Africa

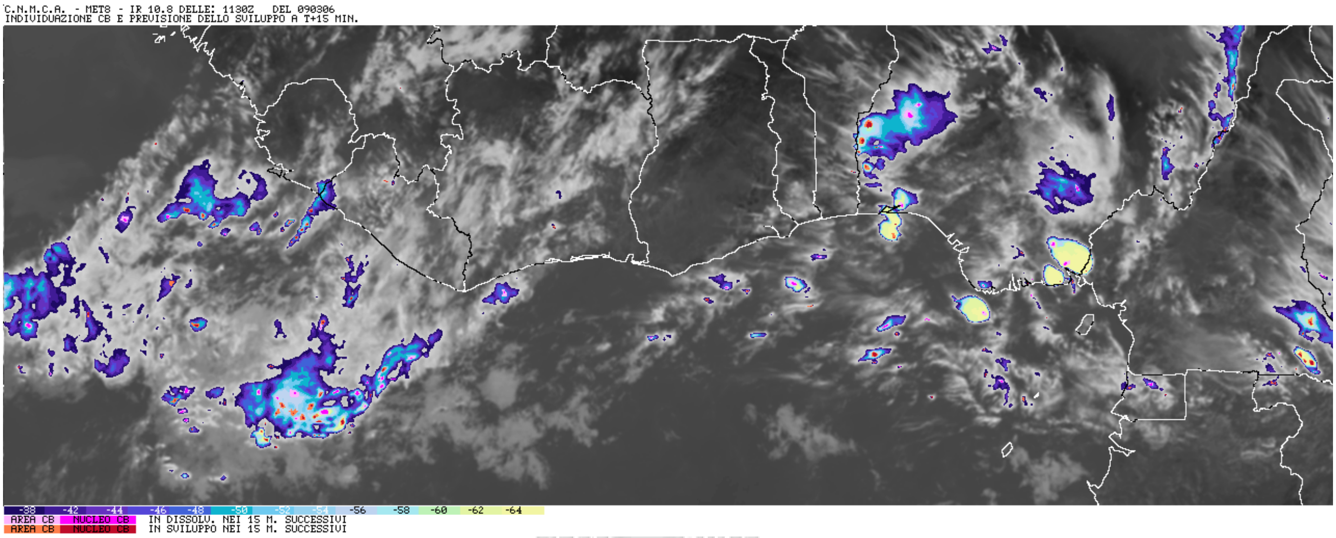

Figure 7. Nefodina in support of air and maritime military operations in Guinea gulf

Nefodina was born to be a satellite data based software but there is also the possibility to associate a grib file with model fields to increase the information (i.e. the height, the pressure of the top or the of the base, the relative humidity, vertical velocity) about the convective cell.

6. Case studies

The figures below show some NEFODINA applications on different situations in terms of convective storm regime and atmospheric character.

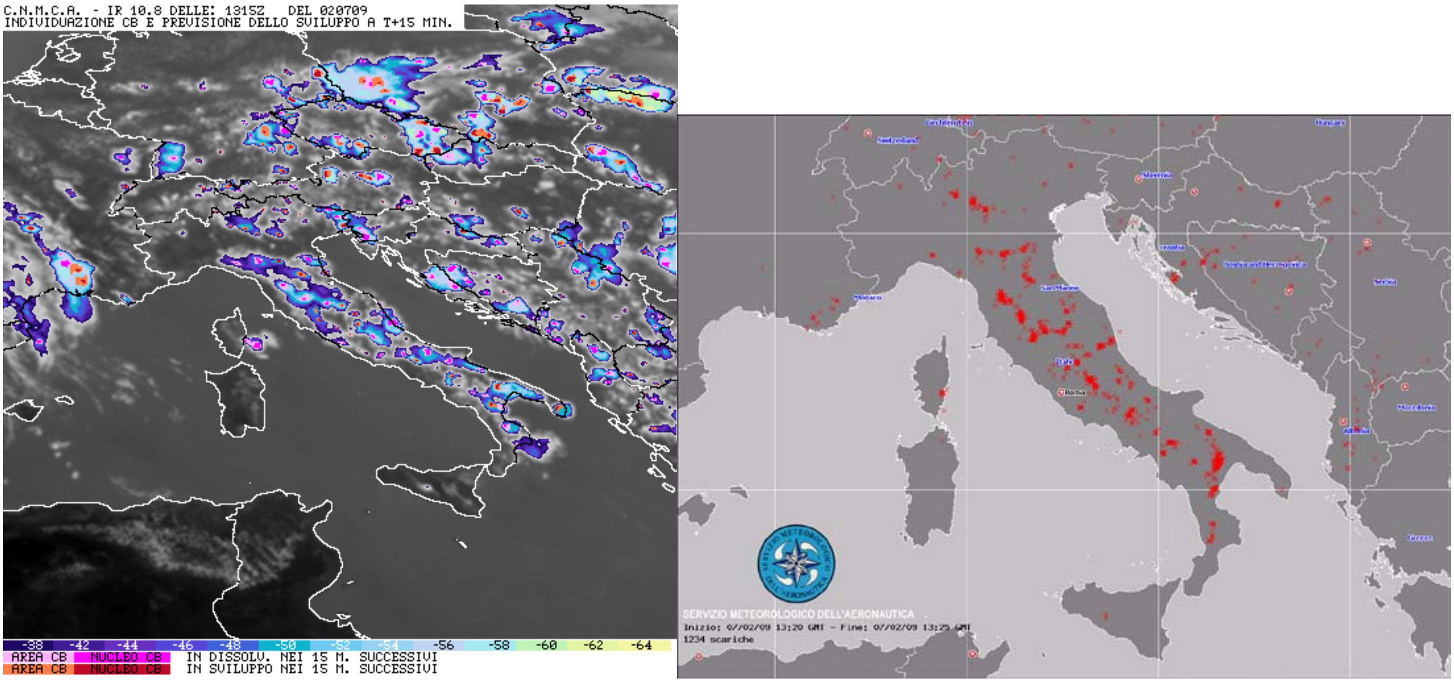

Figure 8. 2 February 2009: several single cell storms along the Appenninian area and their electric activity

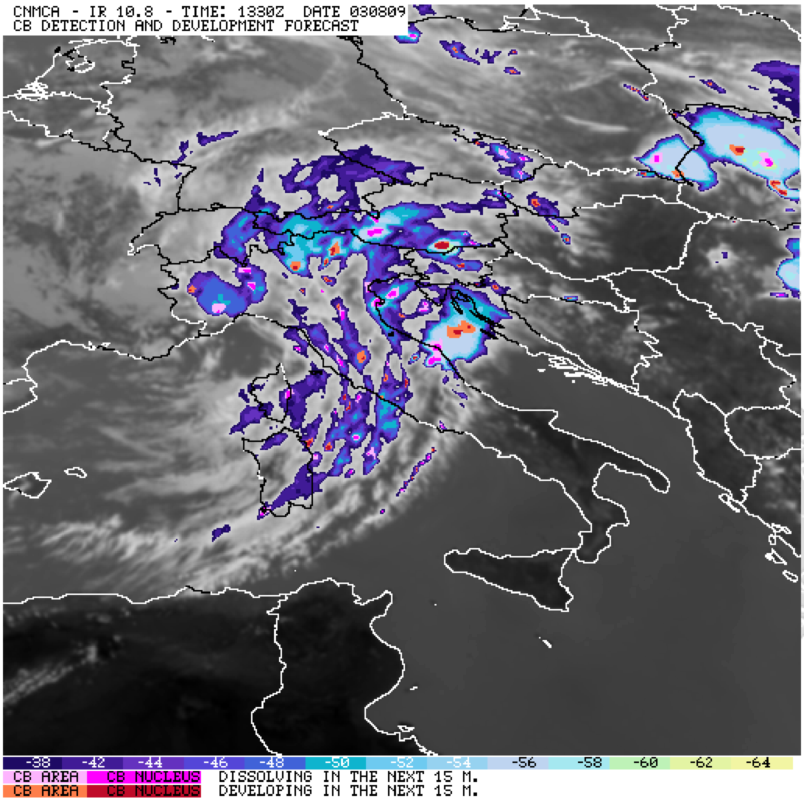

Figure 9. 3 August 2009: a multicell storm over central Adriatic sea

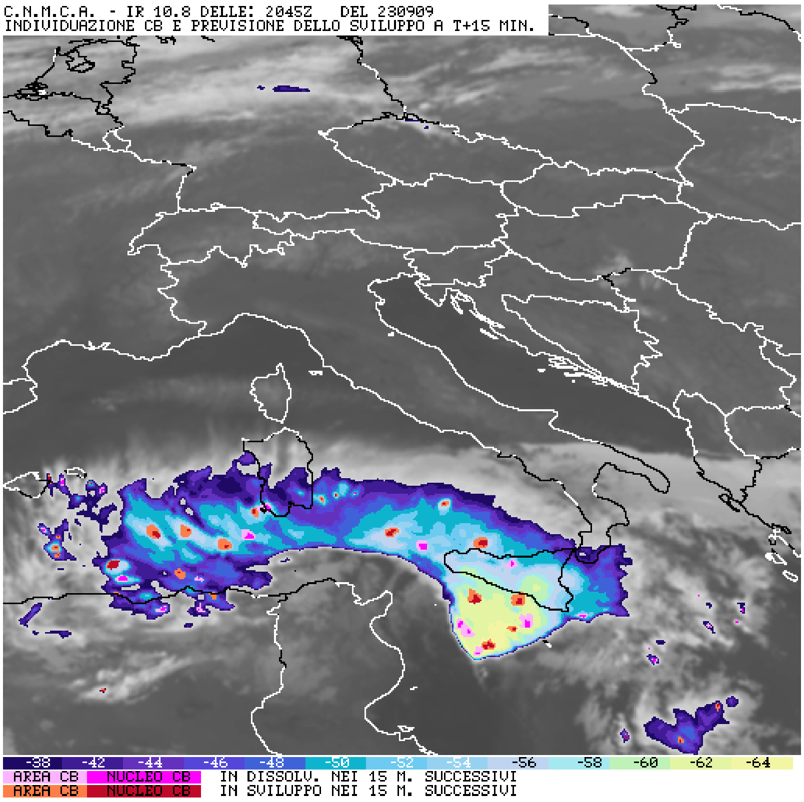

Figure 10. 23 September 2009: a supercell storm in southern of Sicily island; Nefodina highlight the V-shape of the embedded convective cells

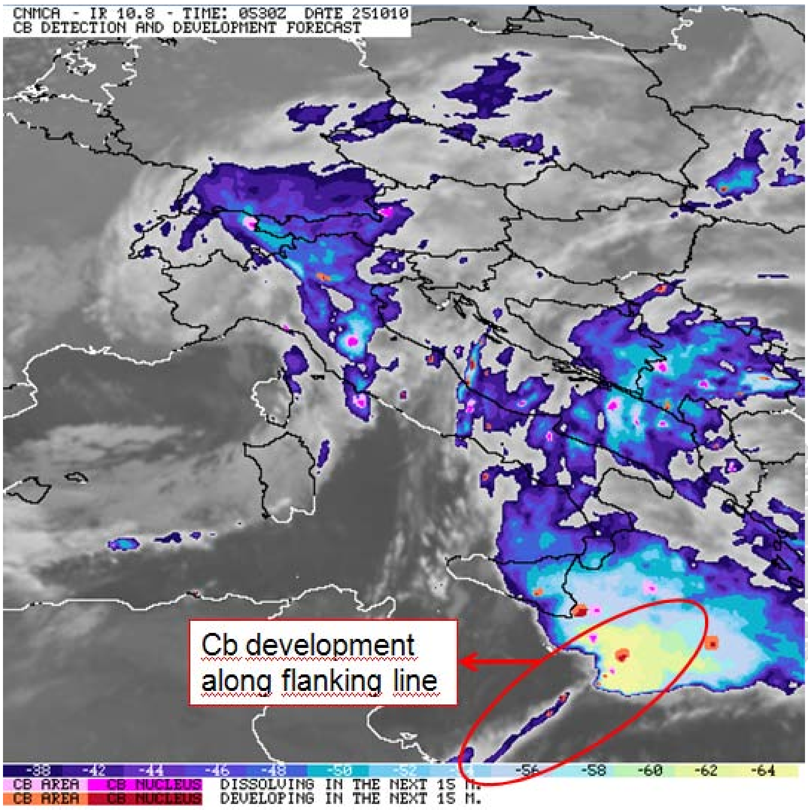

Figure 11. 25 October 2010 In a V-shaped cloud system NEFODINA shows the perfect alignment of the cumuli congesti along the Flanking Line created between the synoptic warm advection from SW and the cold downdraft of the system itself

7. Summary and Outlook

NEFODINA software has been developed to detect and evaluate the severe convective systems present on the scene. This model, processing the last two IR 10.8 μm and water vapor data of the MSG, is able to diagnose not only the whole convective system but all the convective cells inside these system.
This software runs in operational mode at the Italian Meteorological Service since 1990. It is an important support for forecaster of the IAFMS who test every day the performance and the reliability of this product. With its current setting (easily configurable), its correlation with lightning data, measured by the Italian Lightning Network, is 84%.
In addition, NEFODINA was implemented for Rapidscan service; managing the rapidscan data we are testing also the use of second derivative, so the "convection's acceleration", to estimate the life phase of the convection nuclei instead of the "velocity" (temperature variation).

8. References

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See also nefodina.meteoam.it