METEOSAT CONVECTIVE INITIATION PRODUCT
WITH AND WITHOUT CLOUD TRACKING - EXPERIENCES

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Abstract

The aim of a Convective Initiation (CI) product is to identify those cumulus clouds which are likely to develop into mature cumulonimbus. Two CI algorithms developed at EUMETSAT for Meteosat Spinning Enhanced Visible and InfraRed Imager (SEVIRI) data were adapted and evaluated at the Hungarian Meteorological Service (OMSZ) in the frame of EUMETSAT Scientific Studies. Both CI algorithms are based on the Mecikalski and Bedka (2006) method. One of them uses box-averaging method instead of cloud tracking, while the other tracks the clouds.

In 2011 the box-averaging algorithm was studied at OMSZ. We adapted this algorithm from 15- to 5-minute SEVIRI data and improved it to suppress false alarms. The NWCSAF Cloud Type product was used to reduce the ‘general’ cloud mask to a narrower one, which is closer to a ‘cumulus / towering cumulus’ cloud mask. Additional filters were developed. Due to improved filtering and the reduced cloud mask the number of the false alarms decreased and the lead time (to predict the appearance of a new 35 dBZ radar echo) increased. The improved algorithm was validated against Hungarian radar data for test cases. Probability of Detection about 60% and False alarm Rate about 30% were found. The mean lead time was 23 minute.

In 2012 a cloud tracking CI algorithm for 15-minute SEVIRI data was developed at EUMETSAT. In the frame of a EUMETSAT Scientific Study, OMSZ beta tested this algorithm to evaluate its performance. CI and GII (atmospheric water vapour content and instability parameters) products are studied together in severe and non-severe storm cases. The aim is to investigate the possibility to combine the CI information with the environmental instability parameters to further improve the reliability of the product, and to study whether one can find any trace of possible later severity already at the developing stage of the thunderstorm.

The present paper summarises the results of the study on the box-averaging CI algorithm and the preliminarily results (mainly the experiences of the beta testing) of the study on the cloud tracking CI algorithm.

INTRODUCTION

The aim of the CI product is to find those already existing cumulus clouds, which show signs of rapid development, and so are likely to develop into mature cumulonimbus clouds. Its quantitative definition: CI indicates the clouds for which a new 35 dBZ radar signal is likely to appear in the next hour.

In the USA several methods have been developed to detect convective initiation on satellite imagery since 1965, more intensively since 2003 (e.g. Roberts and Rutledge, 2003; Mecikalski and Bedka, 2006; Sieglaff, 2011; Mecikalski et al., 2010a,b). Mecikalski and Bedka (2006) have defined several tests to identify growing cumulus clouds. These tests compare certain channel brightness temperatures (BT), their differences (BTD) and time trends (the so called interest fields) to prescribed thresholds (critical values). For this some methods use a convective cloud mask (Berendes et al., 2008) some others the whole cloud mask (Sieglaff et al, 2011). To calculate trends, consecutive
images have to be used. For proper trend calculation the clouds should be tracked. Some methods use cloud tracking (e.g. Mecikalski and Bedka, 2006), while some other methods use a 'box-averaging method' instead of cloud tracking (e.g. Sieglaeff et al., 2011). Box-averaging methods are computationally faster, while the cloud tracking methods are more accurate, especially for fast moving cells. The box-averaging method works with non-moving boxes, and uses average values instead of pixel based values. It supposes that the cell does not move out of the (pre-defined) box within consecutive slots (and other cells do not come in). That way the trend calculation is much faster, but the underlying assumption on cloud motion may cause errors, and so several additional filters are needed. Some cloud tracking methods work with satellite Atmospheric Motion Vector (AMV) data (Mecikalski and Bedka, 2006), while others use object-oriented cloud tracking approach (Walker et al., 2010). Recently, work began to develop a “probabilistic” CI detection algorithm (Mecikalski et al., 2012).

At EUMETSAT the CI algorithm was adapted to Meteosat SEVIRI data. The first version (Siewert, 2010) was based on the Mecikalski and Bedka (2006) method in the sense that it tested several interest fields, but the trend calculation was based on the box-averaging method. In this algorithm 17 different interest fields were tested. Six IR channel data in 3 consecutive time slots (15-min SEVIRI data) were analyzed. For each pixel a box (7x7 pixels for the 15-minute data) was defined and the averaged BTs of the six IR channel were calculated in this box. The averaging was made over all cloudy pixels. Using the average BTs, BTD differences and trends were calculated and tested. If at least 14 interest field tests were fulfilled from 17, then the pixel centered in the box was marked as a CI hit. This box-averaging algorithm was adapted to 5-minute SEVIRI data and further developed by Putsay et al. (2011) using the NWCSAF Cloud Type (CT) product to reduce the cloud mask and including several additional filters to reduce the false alarms. The results of this work are described in the first part of the Results chapter. Kocsis et al. (2012) developed a cloud tracking CI algorithm for 15-minute SEVIRI data using the NWCSAF High Resolution Wind (HRW) product to track the clouds. They also used the NWCSAF CT product to reduce the cloud mask, a reduced number of interest fields and modified critical values. At OMSZ this cloud tracking CI algorithm was beta tested. The results are presented in the second part of the Results chapter.

DATA AND METHODOLOGY

The CI product was created locally at OMSZ. 5-min Meteosat-8 and 15-min Meteosat-9 SEVIRI images were used. The NWCSAF products needed by the CI algorithms were created also locally through the version 2012 of the SAFNWC/MSG program package: the CT product to create a reduced cloud mask (containing only low- and mid-level opaque clouds) and the HRW product to track the clouds.

The performance of the product was evaluated and validated visually. Several daytime test cases were studied with the help of the Hungarian Advanced Weather workstation (HAWK) visualisation system (Kertész, 2000). CI products were visualized together with satellite single channels and RGB images, radar data and the EUMETSAT created Global Instability Index (GII) products. The EUMETSAT recommended standard RGB images (Kerkmann et al., 2006) were created locally. In some cases the NWCSAF SEVIRI Physical Retrieval (SPhR) products were used instead of GII. SPhR has similar parameters as GII, both characterizing atmospheric instability and water vapour content. The data of the Hungarian radar network was used to check whether a new 35 dBZ radar signal appear in the next hour. Note, that 10 minutes are added to the nominal satellite slot time and indicated as 'European time' in the figures, better representing the local time.

RESULTS

We worked with two different CI algorithms in the frame of two EUMETSAT Scientific Studies. In this chapter the (preliminary) results and experiences are summarised.
Convective initiation product without cloud tracking

In the frame of a EUMETSAT Scientific Study in 2011 EUMETSAT provided the 15-minute box averaging CI software for OMSZ. We adapted this algorithm from 15- to 5-minute data and improved it to suppress false alarms (Putsay et al., 2011).

The NWCSAF Cloud Type product was used to reduce the general cloud mask to a narrower one, which is closer to a cumulus/towering cumulus cloud mask (which would be optimal for the CI algorithm). The first version of the reduced cloud mask contained the following cloud type classes: very low opaque clouds, low opaque clouds, mid-level opaque clouds and semitransparent clouds over lower level clouds. Later we excluded the ‘semitransparent clouds over lower level clouds’ class from the reduced cloud mask. Unfortunately, the separation between cumuliform and stratiform clouds is not yet performed within the SAF product processing. With this separation we could create a more appropriate cloud mask for CI algorithm. Additional filters were developed and implemented to reduce the number of false alarms: a filter to eliminate areas of false cooling due to cloud motion, and another filter to eliminate huge mid-level clouds (the aim was to filter the stratiform mid-level clouds).

Due to improved filtering and the reduced cloud mask the number of false alarms decreased significantly and the lead time (to predict the appearance of a new 35 dBZ radar echo) increased. The improved algorithm was validated against Hungarian radar data for test cases. Probability of Detection (POD) about 60% and False Alarm Rate (FAR) about 30% were found. The mean lead time was 23 minutes.

Convective Initiation product with cloud tracking

We run the cloud tracking CI algorithm (Kocsis et al., 2012) pre-operationally for the 2012 summer period and evaluated its performance. Our task was to evaluate the CI product together with the GII product for severe and non-severe cases. The aim of this is to investigate the possibility to combine the CI information with the environmental instability parameters to further improve the reliability of the product, and to study whether one can find any trace of possible later severity already in the developing phase of the thunderstorm. In this paper we report about the preliminary results, first of all about the experiences of the beta testing. The questions were the following. Have we CI hits in cases when they should be? Have the CI hits considerable lead time? Which typical circumstances cause misses and false alarms?

![Figure 1: Meteosat-9 images from 05 August 2012 14:10 UTC (upper row) and 17:40 UTC (bottom row). Left: HRV cloud RGB image overlaid by the CI product (red) and 35 dBZ radar contours (black lines), right: IR10.8 images overlaid by CI product (red).](image-url)
The algorithm works the best in “fair weather” condition, when only isolated (towering) cumulus clouds are present in a mostly cloud-free environment without overlapping cirrus clouds. Two examples are presented for CI detection in fair weather condition.

On 05 August 2012 there were cumulus clouds over an extended area of Hungary (Fig. 1). Only one thunderstorm developed on this area causing severe weather on the surface. Doppler radar data confirmed the rotation of the storm in one slot (not shown). At a later stage an ice plume developed over the anvil (bottom right panel of Fig. 1). The CI algorithm detected the initiation of this severe thunderstorm: two pixels were detected as CI event in the correct location. In these two pixels the interest field values confirm rapid development. The 15-minute cooling was less than -12 K, while the 30-minute cooling was about -16 to -20 K. The trend of the brightness temperature difference of the two water vapour channels (BTD (WV6.2-WV7.3)) was higher than 7 K. Note that these values considerably exceed the corresponding critical values. The satellite retrieved GII K-index was about 31-32 K, while the total precipitable water (TPW) was about 31-32 mm.

Figure 2: Meteosat-9 images from 04 June 2012 11:10 UTC (upper row) and 12:55 UTC (bottom row). Left: HRV cloud RGB image overlaid by the CI product (red), right: day microphysical RGB images.

The other fair weather example is from 04 June 2012 (Fig. 2). Isolated (towering) cumulus clouds are seen over the hills of Bosnia (upper panels). Several of these cumulus clouds developed later into thunderstorms forming a severe convective system. The bottom panels show the system over Croatia at 12:55 UTC. The orange colour over the cloud top at 12:55 UTC in the day microphysics RGB (bottom right panel of Fig. 2) refers to small particles on the cloud top, which indicate high probability of intense, strong updraft (e.g. Lensky and Rosenfeld, 2006). Over the studied area several pixels were detected by the CI algorithm. For some pixels the 15-minute cooling was less than -14 K, while the 30-minute cooling was about -17, -26 K. The trend of BTD (WV6.2-WV7.3) was higher than 7 K. The satellite retrieved GII K-index was about 27 K and the TPW was about 23 mm over the Bosnian hills at the time of the initiation of the original cells. At the mature stage of the system (over the Hungarian Croatian border) the K-index was about 31-33 K and TPW was about 29-31 mm.

Although the method works the best for isolated (towering) cumulus clouds developing in mostly clear sky conditions it can give useful information in other situations as well. However, if the cumulus cloud develops under a higher cloud layer then the algorithm can either not detect this event at all or with a considerably delay. Fig. 3 is an example of such a complex situation. The big system on the east side of Fig. 3 is a severe storm. On its flank site several pixels are detected as rapidly growing (towering) cumulus clouds, for example along the line in the middle of the image. 30 minutes later one can see
that from this line a cumulonimbus developed (right panel of Fig. 3). Note that on the south of the image an outflow boundary is seen.

Figure 3: Meteosat-9 HRV cloud RGB image overlaid by the CI product (red) from 18 June 2010 11:25 UTC (left) and 11:55 UTC (right)

On 25 May 2010 a very interesting convective system developed in Central-Europe. Between 11 and 12 UTC several cells initiated over south of the Czech Republic (Fig 4). These cells formed an MCS, and the system entered northwestern Hungary at about 15:10 UTC. Here the western most cell started to develop extremely fast, much faster than the others, and formed an extensive, highly symmetric, roundish, cold ring thunderstorm, covering almost two-thirds of Western Hungary (Fig 5). The environmental parameters were different on the Czech hills (TPW~ 20 mm, K-index~ 26 K), where the first cell initiated than in western Hungary, where the environment was more moist and unstable (TPW~ 26-27 mm, K-index ~ 32-33 K). According to the TEMP measurements (at Poprad, Budapest and in Prostejov, not shown) the mid layer was very dry and the wind shear in the 0-6 km layer was from moderate to strong. ECMWF forecasted wind convergence at low levels over Western Hungary, and very high instability: high Supercell Composite Parameter and Thompson index. The system arrived just at the time for which ECMWF forecasted the most unstable atmosphere. All these parameters explain the accelerated development of the storm. Note, that the NWCSAF SPhR Mid-layer water vapour content (ML, between 850 and 500 hPa) product shows even dryer mid layer than the ECMWF model forecasted (see the bright blue area on the bottom right panel of Figs. 4 and 5, showing the difference between the satellite retrieved and the ECMWF forecasted ML values). So the situation might be even more favourable for severe storms.

Figure 4: Meteosat-9 images and NWCSAF SPhR products from 25 May 2010 11:25 UTC. Upper left: HRV cloud RGB image overlaid by the CI product (red), middle panel upper row: NWCSAF SPhR product boundary layer water vapour content (surface-850 hPa), upper right: NWCSAF SPhR product mid-layer water vapour content (850-500 hPa), bottom left: IR10.8 image, middle panel in the bottom row: NWCSAF SPhR product K-index and bottom right: NWCSAF SPhR product difference between the satellite retrieved and the ECMWF modeled mid-layer water vapour content.
Missed cases, false alarms

Missed detections can be caused by:

- If the cumulus cloud develops under thick clouds then the method cannot detect it. For example, the satellite cannot see the initiation of an embedded storm in a frontal system.
- Not only opaque clouds can ‘shelter’ the convective initiation. Even the presence of semitransparent clouds could cause missed detection. The reason of this is the following: thickening cirrus clouds over low/mid level clouds may cause a similar signal as developing towering cumulus clouds. To avoid such CI misdetections, the pixels contaminated by cirrus clouds are excluding from the processing, and so the convective initiation under ‘detected’ cirrus clouds will be missed in the present algorithm. ‘Detected cirrus clouds’ means detected by the NWCSAF Cloud Type product. Cirrus clouds are excluded from the processing if they are detected as cirrus clouds by CT. However, very thin cirrus clouds are hard to detect.
- Missed detection could be caused by ‘too rapid’ developing. This is a 15-minute method analysing development in three consecutive images. If the storm develops from minimum 1 opaque pixel to mature stage within 30 minutes, then it could be missed. A method based on 5-minute SEVIRI data would help not to lose these cases.
- If the retrieved wind has some problem or it is not retrieved then the CI can be missed.

False alarms can be caused by:

- In some situations (thickening) stratiform clouds might be misdetected as CI events. The used cloud mask is not optimal. It contains all low and mid level clouds, not only the cumulus and towering cumulus clouds.
- ‘Environment’. Some convective clouds begin to develop, but then they are blocked (because of thermal inversion, unfavorable wind profile, cut-off from the source of buoyancy, etc…)
- Non-detected cirrus clouds (misdetected by NWCSAF CT as low of medium level clouds) are not excluded from the cloud mask and they often cause false alarms.

According to our experiences the majority of the false alarms are caused by the non-detected cirrus clouds (by edge of the anvils or other cirrus clouds), as seen on an example in Fig. 6. A cirrus cloud is moving from southwest over the low clouds behind the Carpathian Mountains. On the very edges of this overlapping cirrus clouds several false alarms appear. In the CT image one can see that these pixels are not classified as cirrus clouds (cirrus clouds are indicated by bluish colours in the CT colour scale), although in the RGBs one can see that these pixels do belong to the cirrus clouds.
Comparison of the two methods

Both algorithms can work with 15- or 5-minute SEVIRI data. However, as we have experiences only with 5-minute box-averaging algorithm and with 15-minute cloud tracking algorithms, so we can compare the performance of these algorithms. As the inputs are different and the details of the algorithms are also strongly different, so it is not easy to find the reasons of their different behaviour. The statistical results (POD and FAR) were about the same for the 15-minute cloud tracking algorithm and for the 5-minute box-averaging algorithm (Putsay et al., 2011 and Kocsis et al., 2012). (Note, that the verifications were done by different people on partly different database, and visually, which is rather subjective.)

We would expect better results from a cloud tracking algorithm than from a non-tracking algorithm. However, the frequency of the data has also strong effect. For the box-averaging method we made some comparison between the 5- and 15-minute versions. We had better results with 5-minute data: more and earlier hits. So we suppose that a 5-minute cloud tracking algorithm would be better than the 15-minute algorithm. The positive effect of cloud tracking could be partially destroyed by the effect of less frequent data. The best would be to use cloud tracking algorithm with 5-minute data. To present the advantages of the proper cloud tracking, we run both algorithms in a situation when fast moving cloud streets were present over half of Europe, and the atmosphere were stable. Shallow convection was present, but no deep convection occurred the whole day. In such a situation, we should have no CI detection. The box-averaging method had much more false alarms, while the cloud tracking method had practically no false alarms.

Note that the cloud tracking CI works best when the HRV channel data are available, i.e. at daytime, while the box-averaging CI algorithm is a full day algorithm. The cloud tracking CI algorithm is computationally more expensive.

SUMMARY

Two different CI algorithms were evaluated. Our main conclusions are:

- Cloud tracking method works better than the box-averaging for fast moving cells.
- Cloud tracking CI method works quite well, first of all in fair weather condition without overlapping cirrus clouds (Note, that most of the situations are different.)
- At the cloud tracking CI algorithm the majority of the false alarms are due to non-detected cirrus clouds, (non-detected by the CT software).
• Missed detections happen due to detected cirrus clouds (or because of the fact that the new cell developed under high clouds)

• Low or mid level clouds in the surrounding area can delay the detection.

Possible improvements:
• Adaptation of the cloud tracking method to 5-minute SEVIRI data (maybe with using more than 3 images). Note, that for this, calculation speed should be improved.

• Efforts should be made in order to reduce false alarms. The most important step for this would be a cloud mask improvement to create a cloud mask closer to cumulus / towering cumulus cloud mask. The cumuliform-stratiform separation in the NWCSAF Cloud Type product could help, when it will be available. The improvement of the thin cirrus detection is also very important.

• Improvement of the algorithm to detect convective initiation below thin cirrus.

With the Meteosat Third Generation (MTG) data the CI detection is expected to be much more reliable with fewer false alarms due to the higher spatial and temporal resolution of the satellite data and the new NIR1.3 channel, which is designed specifically to improve the detection of the thin cirrus clouds.

ACKNOWLEDGEMENTS

This work was done in frame of EUMETSAT studies under contracts: EUM/CO/11/460000934/MK and EUM/CO/12/460001090/MK

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