7th European Conference on Severe Storms (ECSS2013) , 3 - 7 June 2013, Helsinki, Finland

METEOSAT CONVECTIVE INITIATION PRODUCT AND ENVIRONMENTAL PARAMETERS – IN CASE OF SEVERE AND NON-SEVERE THUNDERSTORMS

M. Putsay[1], Zs. Kocsis[1], M. König[2], A. Simon[1], I. Szenyán[1] and M. Diószeghy[1]

[1]*Hungarian Meteorological Service, Kitaibel Pál u 1, 1024 Budapest, Hungary, putsay.m@met.hu*
[2]*EUMETSAT, Eumetsat Allee 1, D-64295 Darmstadt, Germany, Marianne.Koenig@eumetsat.int*

I. INTRODUCTION

In the framework of a EUMETSAT Scientific Study, the Hungarian Meteorological Service (OMSZ) studied the Convective Initiation (CI) product and satellite derived environmental parameters (atmospheric water vapour content and instability) for a number of severe and non-severe storm cases. The aim was to investigate the possibility to combine the CI information with the environmental instability and airmass parameters to further improve the reliability of the product, and to study a possible relationship between the pre-convective environment and later storm severity.

The CI results were studied together with the environmental parameters and with other information on the severity level of the convective storm (system), like maxima of the surface measured wind gust, radar reflectivity, radar derived hail probability and vertical integrated liquid (VIL) values (characterizing the size of the hail particles), severe storm reports, etc.

An overview of CI and the convective environmental algorithms is found in ‘Best Practice’ document on the Convective Working Group homepage (Mecikalski et al., 2013).

II. CONVECTIVE INITIATION ALGORITHM

The aim of this product is the early detection of those rapid developing cumulus clouds which will produce convective precipitation in the next hour.

A cloud tracking CI algorithm for 15-minute Meteosat Spinning Enhanced Visible and InfraRed Imager (SEVIRI) data was developed at EUMETSAT (Kocsis et al., 2012). This algorithm is based on the Mecikalski and Bedka (2006) and Mecikalski et al. (2010) methods.

All pixels covered by low- or mid-level cloud are analyzed. Several tests are used comparing certain channel brightness temperatures (BT), their differences (BTD) and time trends (the so called interest fields) to prescribed thresholds (critical values). The algorithm uses products developed by the ‘Satellite Application Facility on support to Nowcasting and Very Short-Range Forecasting’ (NWC SAF). The Cloud Type (CT) product is used to select the low- and mid-level cloudy pixels and the High Resolution Wind (HRW) product to track these clouds. Five SEVIRI infrared (IR) channel data (6.2 μm, 7.3 μm, 8.7 μm, 10.8 μm and 12.0 μm channels) in three consecutive slots are analyzed. 10 different interest fields are tested. If at least 7 out of 10 interest field tests are met, the pixel is marked as a ‘CI nowcast’, showing signs of early towering cumulus cloud.

III. SATELLITE RETRIEVED CONVECTIVE ENVIRONMENTAL PARAMETERS

Two convective environmental parameter product groups retrieved from 15-minute SEVIRI data are available: the Global Instability Index (GII) products created by EUMETSAT (König, 2002) and the SEVIRI Physical Retrieval (SPhR) products (SAFNWC documentation, 2012). For the latter the software is developed by the NWC SAF. Both product groups include total and layer precipitable water (TPW, LPW) and instability indices. The LPW are the followings: boundary layer water vapour content (BL) calculated for the layer from surface to 850 hPa, mid layer water vapour content (ML) calculated for the layer from 850 to 500 hPa and high layer water vapour content (HL) calculated for the layer above 500 hPa. Both product groups derive the K-Index and the Lifted Index and other instability indices.

In both algorithms the satellite retrieved profiles are calculated by the so called `physical retrieval’ method using ‘first guess’ temperature and humidity profiles and measured IR BTs as input. In the GII algorithm the numerical weather prediction (NWP) profiles are used as ‘first guess’. In the SPhR algorithm the NWP data is `background data`. This algorithm first performs a non-linear regression with NWP profiles and the measured IR BTs and the output of this regression is used as ‘first guess’.

The satellite retrieved environmental parameters are available only for cloud-free areas. It should be noted that the TPW and BL are highly topography dependent, yielding lower values over mountainous terrain.

IV. DATA AND METHODOLOGY

A test database was set up by collecting severe and non-severe storm (system) cases, mainly over Central Europe. We run the CI software for all daytime images of these days. The SAFNWC program package was run locally at OMSZ. The CT, HRW and SPhR data were calculated using 15-minute data of the SEVIRI instrument on board of the Meteosat-9 satellite and 3-hourly ECMWF data as NWP input.

Satellite image sequences were visualized and studied to find the originating cells of convective storms or storm systems. Reliable CI nowcasts were looked for (in or near the initiating cells and far from overlapping thin cirrus clouds) and their locations and the corresponding interest fields were collected in the database. Reliable environmental parameters were also collected, as close to the area and time of initiation as possible, with special attention to TPW and BL in mountainous regions. We tried to avoid areas covered by undetected thin cirrus clouds through manual inspection. If the severe systems were advected, environmental parameters were collected for their mature stage as well.

Additionally, data were collected about the mature phase of these convective events to help us to classify the storms, or storm systems according to their intensity. These data were the following:

- severe storm reports published in news, or in the European Severe Weather database (ESWD);
- 10-min surface measurements (in Hungary): maximum wind gust and maximum rain amount;
- radar data measured by the Hungarian Radar System, covering the Carpathian Basin: rain rate (calculated from the column maximum reflectivity), cloud top height (ETOPS), hail probability, vertical integrated liquid (VIL) value (the higher the VIL the higher the hail size) and the VIL/ETOPS ratio;
- minimum BT in the SEVIRI 10.8 μm channel.
- radar features, if present, like comma echo, bow echo, week echo region (WER) or bounded weak echo region (BWER) in the vertical cross sections;
- satellite features, if present, like long lived cold rings or ice plumes, and
- forecasters' assessment.

The elevation of the area where the convective storms (or storm systems) initiated was also noted.

Convective events were classified according to their intensity: severe, intensive, normal, weak, and according to the altitude at initiation: 0-150, 150-300, 300-800 and above 800 m.

For 64 (airmass and frontal) convective events both reliable CI and environmental parameters were found. For 7 additional severe convective events there was no reliable CI nowcasts. In the 'pure' environmental parameter studies (described in the next section) 71 convective events were used.

V. ANALYZING THE ENVIRONMENTAL PARAMETERS

We studied the possibility to add the convective environmental parameters as further information into the CI processing.

The environmental parameters could be used in different ways in the CI processing. Siewert et al. (2010) suggested using them as additional interest fields. We considered another way, namely to add quality flags to the CI nowcasts, depending on the environmental parameters. Two threshold sets might be useful: thresholds, below which the probability of convection is low; and thresholds, below which the probability of severe storm formation is low.

A separation of stable and unstable areas can help to filter false alarms in stable conditions. The **K-Index threshold of 20 °C** works quite well in separating stable (K-Index < 20 °C) and unstable areas (K-Index > 20 °C). However, for high mountains with a surface pressure below 850 hPa, the K-Index is not defined. For these areas only the Lifted Index is available to characterize the instability.

To calculate the Lifted Index an air parcel is theoretically lifted from the 'lowest 100hPa' to 500 hPa and there compared with the ambient temperature. In principle the Lifted Index is negative in unstable and positive in stable conditions. However, we have found (slightly) positive Lifted Indices over mountainous terrain also in cases when convective clouds developed. This can happen because of the errors in the retrieval processing due to different topographies (real topography, topography used in NWP model and in the satellite retrieval), or due to the errors in the NWP data used in the retrieval. It can also happen that the Lifted Index is indeed positive, but thunderstorms are developing. The thunderstorm might originate from a valley (from below the 'lowest 100 hPa over the surface'), or the mountains may lift the parcel above the 'lowest 100 hPa layer' where the atmosphere may be more unstable.

In summary: for high terrain we could use only the Lifted Index to separate stable and unstable regions. However, as Lifted-Index values can exhibit large errors over these regions we recommend to either completely disregard the environmental data as quality information, or to use a **Lifted Index threshold of +2 K.**

The other potentially useful environmental parameter thresholds for a CI 'quality flag' could be the thresholds, below which the probability of severe storm formation is low. To define such a threshold set, the environmental parameters of different storm intensities were studied. We have to emphasize that in the present study we worked only with satellite retrieved instability and water vapour content values. We did not study the wind field, e.g. wind shear, although it is very important in the severe storm formation and developing processes.

We studied 71 convective events. We calculated the ML/TPW ratio, where ML is the water vapour content of the mid-layer and TPW is the total water vapour content. This ratio is a measure of the relative dryness of the mid-layer. Dry mid-layer often cause strong downdraft what is a criteria of storm severity. Figs. 1, 2 and 3 show the ML/TPW ratio against K-Index, TPW and Lifted Index, respectively. The symbols indicate the intensity class of the convective events. For the severe class we have two sub-classes: 'severe' and 'advected severe'. In the latter case the severe storm (system) travelled a long way between its initiation and mature phase. For the 'advected severe' symbols the parameters reflect the environment of the mature storms (or systems).

In Figs. 1 and 2 the symbols of the severe storms are grouped in the lower right corner of the graph. In our cases the severe storms formed in an environment of **K-Index higher than 28 °C, TPW higher than 23 mm and ML/TPW lower than 0.55.** These thresholds could be used in a CI quality flag. We note that these thresholds are valid only for relatively low altitudes. Over mountainous terrain, TPW decreases with altitude and as a consequence ML/TPW increases. We did not include the Lifted Index in this threshold set, as the results (shown in Fig. 3) do not suggest a good correspondence here.

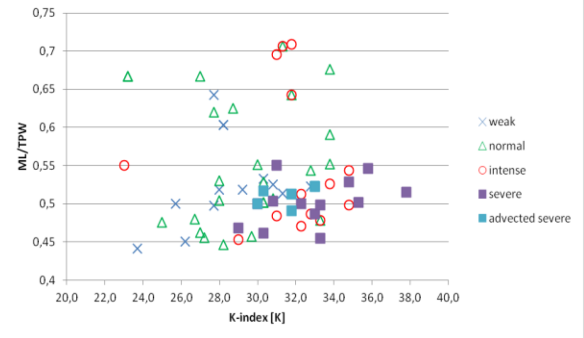

FIG. 1: ML/TPW ratio against K-Index for the convective events of different intensity classes. ML is the water vapour content of the medium layer, while TPW is the total water vapour content.

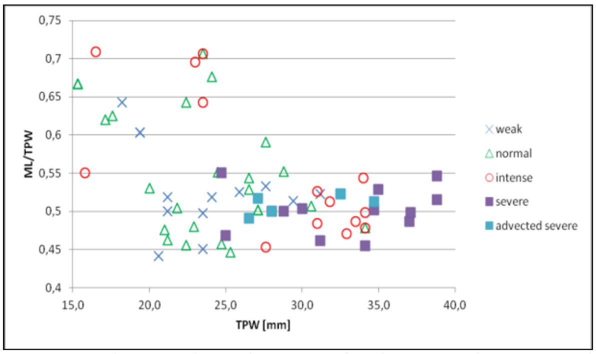

FIG. 2: ML/TPW ratio against TPW for the convective events of different intensity classes.

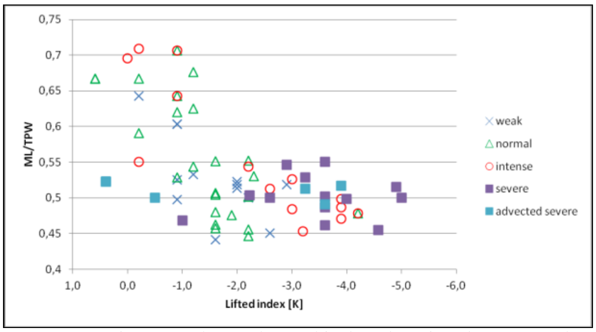

FIG. 3: ML/TPW ratio against Lifted Index for the convective events of different storm intensity classes.

Figs. 4, 5 and 6 show the ML/TPW ratio against K-Index, TPW and Lifted Index, respectively. The symbols indicate the altitude range where the initiation took place. The symbols belonging to different altitude ranges are more or less separated from each other. The class 'above 800 m' altitude is most clearly separated.

In Fig. 5 the symbols belonging to the 'above 800 m' class are grouped in the upper left corner of the graph, showing that over high terrain TPW is low and ML/TPW is high.

The arrangement of the symbols in Fig. 6 is like in Fig. 5, showing that over high terrain the Lifted Index is around zero. It can be slightly positive, as we already discussed, or it can be negative. However, in this altitude range we have not found any Lifted Index value below -1.2 K.

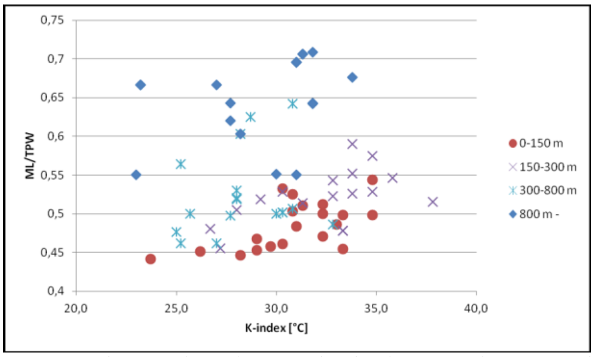

FIG. 4: ML/TPW ratio against K-Index for the convective events of different altitude ranges at the initiation area.

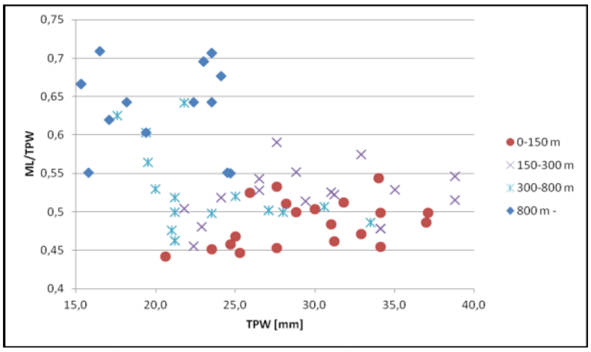

FIG. 5: ML/TPW ratio against TPW for the convective events of different altitude ranges at the initiation area.

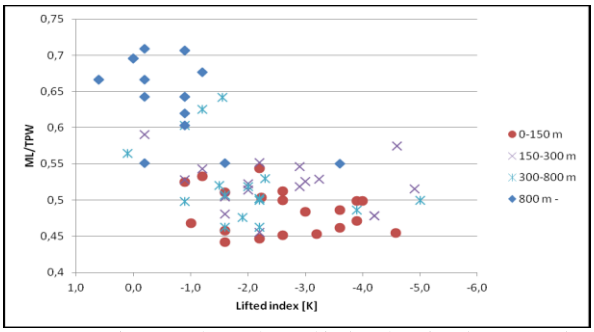

FIG. 6: ML/TPW ratio against Lifted Index for the convective events of different altitude ranges at the initiation area

We succeeded to find environmental parameter thresholds to separate stable from unstable areas and also to separate areas with higher and lower probability of severe storm occurrence. However, application of these threshold sets to define a CI quality flag poses other problems.

We have to find the environmental parameters belonging to the cloudy CI pixels. However, the satellite retrieved environmental parameters are available only for cloud-free areas. Doing the task the parameters were manually collected as close to the location and time of initiation as possible, (with special attention to TPW in high terrain, because TPW depend on the altitude). However, we tried to avoid pixels covered by undetected cirrus clouds, by looking at the RGB images.

If we want to do the same procedure automatically than we might start with the environmental parameters derived from ECMWF forecast, and overwrite it with satellite derived environment parameters if available (maybe not only with simultaneous parameters, but also with parameters derived in the vicinity and at a slightly different time). However, the undetected thin cirrus clouds can cause serious problems. The undetected thin cirrus clouds over low- or mid-level clouds often cause CI false alarms, while the undetected thin cirrus clouds over surface cause too high TPW and K-Index values. These two effects together would cause CI false alarms with good quality flags.

This problem shows how important is the improvement of the accuracy of the cloud mask, namely the improved detection of the thin cirrus clouds (both over cloud-free surface and lower level clouds).

VI. ANALYZING THE CI INTEREST FIELDS AND THE ENVIRONMENTAL PARAMETERS

We studied the relationship between atmospheric instability and updraft strength. Our plan was to study it for each storm intensity classes, to see if we find different behaviour for different storm intensity classes. We supposed that the updraft strength is higher in a more unstable environment.

To characterize the updraft strength we used the 'updraft strength indicator' CI interest field values: the 30- and 15-minute trends of brightness temperature difference (BTD) of the 6.2 µm and 7.3 µm channels; and the 30- and 15-min trends of the 10.8 µm channel BT values.

Scatter plots of environmental parameters (K-Index, Lifted Index, TPW, BL, ML) against updraft strength indicators were created and studied. For each convective event the averaged value of the updraft strength indicators was calculated, and the value related to the strongest updraft was looked for. Separate scatter plots were created using the updraft strength indicator of all CI nowcasts, the averaged updraft strength indicators and the values related to the strongest updraft. Scatter plots were created for the intensity and altitude classes separately and also for all convective events.

Numerous scatter plots were studied, but no correlation was found between environmental parameters and CI updraft strength indicators. To find a reasonable explanation of the negative results three questions should be considered:

1) Does the relation between instability and updraft strength really exist in the atmosphere?

2) Is K-Index a good measure of the instability?

3) Are the CI updraft strength indicators accurate enough?

(1) The relation between instability and updraft strength should exist. However, it might be a rather loose relation, as the updraft strength depends not only on instability, but also on many local effects.

(2) The K-Index is not the best index to describe mesoscale processes. The K-Index contains moisture information in two pressure levels and temperature information in tree pressure levels. It has mainly information on the instability of the airmass, thus the local or low level instability might not be well represented. Local effects, e.g. the vertical distribution of the instability, are not considered. The forecasters suggest using the Convective Available Potential Energy (CAPE) parameter. CAPE is an integrated value reflecting information on several levels. Presently CAPE is not retrieved from SEVIRI data. One should consider if CAPE could be retrieved from SEVIRI data with sufficient accuracy.

(3) The trend CI interest fields are often noisy. If we have more CI nowcasts for the same cell (which seem to be reliable: they are close to a developing cell and far from overlapping cirrus clouds), the updraft strength indicator values are often rather different for neighbouring pixels.

We are looking for a reasonable explanation, *why are the CI updraft strength indicators noisy.* It might be caused by the **coarse spatial resolution**. IR pixels are big compared to the developing cumulus clouds. The large IR pixels may cover different parts of (more) cumulus clouds in the successive slots causing random error (effect of sampling). The wind retrieval (for low/mid level small size clouds) is also difficult, more uncertain, often missing. Errors in wind cause errors in the trend interest fields.

The noise in the updraft strength indicators might be caused by the **coarse temporal resolution** as well. The 15-minute time step might be too large, first of all for severe cases. Another question whether the real updraft strength varies in the early developing phase. If it varies considerably and we have several CI nowcasts for the same cell (neighbouring pixels in several successive slots) than the averaged updraft strength might be characteristic. However, in many convective events we do not have many CI nowcasts. The average or strongest values were often calculated only from one (or two, tree) values, which can cause errors. The updraft strength indicator might be not characteristic.

VII. CONCLUSIONS

The present study had two aims. The first aim was to investigate the possibility to combine the CI information with the environmental instability parameters to further improve the reliability of the CI product. Our idea was to find convective environmental parameter thresholds, which could be used in a hypothetical CI quality flag to indicate if the CI nowcast is in stable or unstable area, and if it is in unstable area then the probability of severe storm formation is low or not. We have to emphasize that in this study we worked only with satellite retrieved instability and water vapour content. We did not study the wind field, although the wind shear is very important in the severe storm formation and developing processes.

The K-Index equal to 20 °C threshold separates well the **stable from unstable areas**. However, if the surface pressure is less than 850 hPa, then the K-Index is not defined. For such mountainous areas the 'stable – unstable' threshold could be either not defined or a Lifted Index threshold of +2 K might be used.

In our test days we found minimum Lifted Indices only around zero over mountains.

To separate areas where **severe storms have higher and lower probabilities** we defined thresholds using the K-Index, TPW and the ratio of ML/TPW. This threshold set is valid only for relatively low altitudes.

The forecasters suggest completing the satellite retrieved instability indices by CAPE. According to their experiences for the 'possible severe storm thresholds' CAPE (or Supercell Composite parameter) is better than the K-Index. One has to consider whether CAPE could be retrieved from SEVIRI data with sufficient accuracy.

We would like to emphasize that before applying these thresholds to automatically define a CI quality flag, one has to solve the problem caused by undetected thin cirrus clouds. The undetected thin cirrus clouds over low or mid level clouds often cause CI false alarms and over surface too high environmental parameters. This combination may results in CI false alarms with good quality flags.

The second aim of the present study was to study whether one can find any trace of possible later severity already at the developing stage of the thunderstorm.

We tried to study the **relation between instability and updraft strength** using satellite retrieved environmental parameters and CI updraft strength indicators, but we did not find any correlation. Many reasons can cause this; the most important might be that the CI trend interest fields are noisy mainly due **to the coarse spatial (and temporal) resolution**.

It might be interesting to repeat this study with better data (rapid scan data, better spatial resolution of the future third generation Meteosat (MTG) data); an improved CI algorithm (object tracking, probability CI algorithm); better thin cirrus detection ability due to new channels on MTG; including more instability indices; including satellite retrieved wind fields derived from the future MTG Infrared Sounding (IRS) data and more convective events.

VIII. ACKNOWLEDGMENTS

This study was supported by EUMETSAT (contract number EUM/CO/12/4600001090/MK). We thank our colleagues, István Sebők and Csaba Szegedi for the radar data, and Márk Rajnai and Dávid Tajti, the developers of our visualization system (Hungarian Advanced Weather Workstation, HAWK) for their valuable work and help.

IX. REFERENCES

Kocsis, Zs., Koenig, M., Mecikalski, J.R., 2012: Improvement of Convective Initiation product for Meteosat Satellites using NWC SAF High Resolution Wind and Cloud Type retrievals. *Proceedings of the 2012 EUMETSAT Meteorological Satellite Conference*, 3-7 September 2012, Sopot, Poland. http://www.eumetsat.int/

König, M., 2002: Atmospheric Instability Parameters Derived from MSG SEVIRI Observations. *EUMETSAT Technical Memorandum*, No. 9. http://www.eumetsat.int/

Mecikalski, J.R., Bedka, K.M., 2006: Forecasting Convective Initiation by Monitoring the Evolution of Moving Cumulus in Daytime GOES Imagery. *Monthly Weather Review*, 134, pp 49-78.

Mecikalski, J. R., Mackenzie, W.M., Koenig, M., and Muller, S., 2010: Use of Meteosat Second Generation Infrared Data in 0-1 hour Convective Initiation Nowcasting. Part 1. Infrared Fields. *J. Appl. Meteor. Climate*., 49, pp 521-534.

Mecikalski J.R., Bedka K.M., König M., (editors) 2013: Best Practice Document for EUMETSAT Convection Working Group. http://www.essl.org/cwg/res/pdf/bp-eumetsat_20130408.pdf

SAFNWC/MSG program package documentation, 2012. http://www.nwcsaf.org.

Siewert, C.W., Koenig, M., Mecikalski, J.R., 2010: Application of Meteosat Second Generation data towards improving the nowcasting of convective initiation. *Meteorol. Appl.* 17**,** pp 442–451.