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Prethodno priopćenje
Preliminary contribution

THE VALUE OF SATELLITE-DERIVED INSTABILITY INDICES IN THE ASSESSMENT OF PRE-CONVECTIVE CONDITIONS

Vrijednost indeksa nestabilnosti izvedenih iz satelitskih podataka u procjeni uvjeta za razvoj konvekcije

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Abstract: Instability indices derived from Meteosat satellite data were evaluated against radiosonde and lightning data in order to assess their applicability in estimating the potential for convective development. Satellite derived values for the K Index, the Lifted index and for Total Precipitable Water, retrieved from the EUMETSAT archive for the summer seasons 2009 and 2010, were evaluated against instability indices derived from radiosonde data, and against the lightning data, taken as the indication of convective development. Statistical analysis showed that satellite-based indices correlate very well with the same indices derived from the radiosonde data, correlation coefficients being above 0.9 and the significance tested with Monte-Carlo method. The evaluation against lightning occurrence resulted in threshold values for each instability index and the probabilities of lightning occurrence for each index value.

Key words: satellite data, instability indices, radiosonde, lightning

Sažetak: Indeksi nestabilnosti izvedeni iz Meteosat satelitskih podataka verificirani su pomoću radiosondažnih podataka i podataka o električnim pražnjenjima, u cilju određivanja njihove upotrebljivosti u procjeni potencijala za razvoj konvekcije. Vrijednosti satelitski dobivenog K indeksa, Lifted indeksa i indeksa ukupne oborive vode, preuzeti su iz EUMETSAT arhive za ljetne sezone 2009. i 2010.. Oni su uspoređeni s indeksima nestabilnosti izvedenim iz radiosondažnih podataka, te s podacima o pojavi munja, koji su uzeti kao pokazatelj razvoja konvekcije. Statistička analiza pokazala je da indeksi izvedeni iz satelitskih podataka vrlo dobro koreliraju s istim indeksima dobivenim iz radiosondažnih podataka, koeficijenti korelacije su iznad 0.9 (signifikantnost testirana Monte Carlo metodom). Usporedba s podacima munja rezultirala je određivanjem graničnih vrijednosti za svaki indeks nestabilnosti kao i vjerojatnošću za pojavu munja za svaku vrijednost indeksa.

Ključne riječi: satelitski podaci, indeksi nestabilnosti, radiosondaže, munje

1. INTRODUCTION

Thunderstorms belong to the most important elements of very short range forecasting and nowcasting, due to their high frequency of occurrence in the warm part of the year and the high impact weather they produce. Despite the guidance that numerical weather prediction models give on favorable conditions for the onset of convection, more detailed information on the exact location and severity of convective storms is needed for accurate forecasts. Forecasting for the first 12 hours requires extensive use of remote sensing data, i.e. radar, satellite and lightning data. Due to the increase in spatial and temporal resolution, satellite data have become an indispensable part of nowcasting systems and a basis for a growing number of convection-related research efforts. Satellite data can be used in all phases of convective development. In the phase of Convective Initiation, nowcasting methods rely on the use of infrared and visible satellite data and cloud-motion winds for tracking cumulus clouds and their properties (e.g. Mecikalski et al., 2008). In mature convective storms cloud-top signatures, such as U/V- or ring-shapes and overshooting tops, and the related microphysics are revealed by the infrared temperature data, as described by e.g. Caruso et al. (2000), Setvak et al. (2003), Bedka (2010), Mikuš and Strelec Mahović (2012) and many others.

Besides detecting the initiation of convection and following the development into the mature phase, satellite data can enable the assessment of pre-convective conditions. One way of achieving this is through the so-called Global Instability Indices (GII) product, which combines Meteosat Second Generation (MSG) (Schmetz et al., 2002) radiance data and NWP model fields into stability indices similar to these calculated from radiosounding data (König, 2002, 2007). These types of retrievals of instability and air mass parameters have been used operationally since 1988 using first the GOES VISSR Atmospheric Sounder instrument and later the GOES Sounder (e.g. Hayden, 1988; Huang et al., 1992; Rao and Fuelberg, 1997; Dostalek and Schmit, 2001). The biggest advantage of MSG satellite-based instability indices is the capability of the continuous monitoring insured by the 5 min repeat cycle (in satellite rapid scan) and up to 3 km pixel resolution. This provides forecasters with useful information much more frequently than the soundings available twice daily at a very limited number of radiosonde stations. The instability products help forecasters focus their attention on a particular region, which can then be monitored more closely by other means such as satellite imagery and/or radar and lightning data. The indices can only assess the likelihood of convection within the next few hours, and should be seen in combination with measures of other triggering and/or lifting mechanisms (König and de Coning, 2009).

In this paper a description is given of how the GII product derived from the MSG data can be used in order to assess the preconditions necessary for convective development. Satellite-based stability indices will be compared to cloud images later the same day. Values of the indices in the pixels closest to the sounding stations will be compared to the indices calculated from radiosounding data. Finally, probability of convection, based on satellite derived stability indices early in the morning, when the sky is cloud free as much as possible, will be evaluated statistically against the occurrence of lightning later in the same day.

2. DATA AND METHODS

2.1. MSG GII stability indices

Stability indices are a measure of the atmospheric static stability. Their values are used to quickly assess the potential of the atmosphere to produce convection and consequently severe weather. Traditionally, stability indices are calculated from a radiosonde or model derived sounding, in most cases from the temperature and humidity data at certain levels. The value of an index represents the potential for convection or a probability of convective development at a certain fixed location (either the radio sounding site, if the index is calculated from radio sounding data or a numerical model grid point, if NWP model data is used for calculation). In different regions of the world, by differentiating non-thunderstorm from thunderstorm cases, meteorologists have set typical threshold values for each stability index used in their area.

Besides calculating stability indices from radiosounding or model data the availability of several infrared channels in MSG data makes it possible to assess the air stability in pre-convective, cloud-free conditions also from the satellite data. Due to the limited spectral resolution, MSG-based temperature and moisture retrievals have rather coarse vertical resolution, which is, however, still sufficient for the derivation of stability indices, as they typically require a lower quantity of observations within a vertical profile (Peppler 1988; Fuhrhop et al., 2000).

Atmospheric stability parameters are routinely extracted from the MSG imagery within the Meteorological Products Extraction Facility (MPEF) at EUMETSAT (Morgan, 2002). Since these parameters are provided on a global scale (i.e., the entire MSG field of view), the product is known under the name Global Instability Index (GII). The GII parameters can be produced on any spatial scale ranging from a single MSG pixel to the averages over n x n pixels.

The GII physical retrieval scheme uses six MSG channels: WV6.2, WV7.3, IR8.7, IR10.8, IR12.0 and IR13.4 m. Radiative transfer calculations are used to find a combination of surface skin temperature, air temperature and moisture profile from the NWP models that best matches the observations in these six channels. Since there are many combinations of these three parameters that would give the same radiances at the top of the atmosphere for the MSG channels, so-called ‘first guess’ from NWP forecast is fed into the iteration scheme as an initial proposal for a solution. This original first guess is then modified until its radiative properties fit the satellite observations. A typical first-guess field is a short-term forecast. In case of the operational GII the global ECMWF forecast is used. The core of the retrieval is the standard retrieval equation that can be found in e.g. Rodgers (1976).

The MPEF GII product includes the Lifted index (LI) and the K Index (K), which will be used in this study, as well as the total precipitable water (TPW) content as a further air-mass analysis parameter. KO index was neglected in this study because of its dependence on potential temperature at 1000 hPa level.

The observed stability indices are defined as:

$$LI = T(500\ hPa) - T(\text{near surface, lifted to } 500\ hPa) \tag{1}$$

$$K = [T(850\ hPa) - T(500\ hPa)] + Td(850\ hPa) - [T(700\ hPa) - Td(700\ hPa)] \tag{2}$$

TPW - vertically integrated water vapor concentration;

where T is the air temperature at the indicated levels and Td is the observed dew-point temperature at the indicated levels.

LI indicates the likelihood of severe thunderstorms. The chances of a severe thunderstorm are the best when LI is less than or equal to -6°C (Bahorić, 2012). This is because air rising in these situations is much warmer than its surroundings and can accelerate rapidly, creating tall, violent thunderstorms. Values less than -9°C reflect extreme instability. A value of LI between 0 °C and -2°C indicates a small

Table 1. List of radiosounding stations used for the verification

Tablica 1. Radiosondažne postaje korištene za verifikaciju

Station name	Number	LAT	LON
Muenchen	10868	48,24 °N	11,55 °E
Wien	11035	48,25 °N	16,36 °E
Poprad-Ganovce	11952	49,03 °N	20,31 °E
Milano	16080	4,43 °N	9,28 °E
Udine	16044	46,03 °N	13,18 °E
Zagreb-Maksimir	14240	45,81 °N	16,03 °E
Budapest	12843	47,43 °N	19,18 °E
St Pietro Capofiume	16144	44,65 °N	11,61 °E
Zadar	14430	44,10 °N	15,35 °E
Beograd	13275	44,76 °N	20,41 °E

chance of having a severe thunderstorm. Airmass thunderstorms can occur even when the LI is slightly positive.

K Index has proved useful in indicating the probability of airmass thunderstorms. As the K Index increases, so does the probability of having an airmass thunderstorm. K Index takes into account three components important for convective instability: temperature lapse rate, lower tropospheric humidity and the vertical extent of the moist layer. Values of K Index lower than 15 °C (Bahorić, 2012) indicate very small likelihood of thunderstorms, while K Index values higher than 35 °C indicate high probability for the development of numerous and/or severe thunderstorms.

2.2. Radiosouding data

Radiosounding data from 10 radiosounding stations within the study area have been taken for the analysis. The list of stations and their coordinates are given in Table 1. Their locations can be seen in Fig. 1 (marked with blue triangles). Five cases (days) were selected for the evaluation. For the selected days atmosphere was stable in the morning hours, without any (e.g. frontal) disturbances and most importantly with minimum cloud coverage over the whole domain. Generally, the focus was on the warm part of the year, from May to September, when the frequency of convective cases over Croatian territory is much higher than during winter (e.g. Mikuš et al., 2011).

For each studied case stability indices, K Index, LI and TPW, were calculated from 00 UTC soundings on the stations listed in Table 1. This resulted in 50 values for each index. These values were compared to the values of corresponding GII indices in the pixels closest to the radiosounding stations, at the time of the sounding.

2.3. Lightning data

Lightning in the atmosphere develops due to charging processes within convective clouds; therefore lightning activity is a good indicator of deep, moist convection (Ávila et al., 2010). Lightning data used in this work were provided by the LINET system, a lightning detection network in Europe (e.g. Betz et al., 2007, 2009) comprising of ~ 100 sensors and covering the area from approximately 30°N 10°W to 65°N 35°E. These sensors can detect both cloud-to-ground and intra-cloud lightning. In the LINET system the minimum detectable signal is in the range of 1–2 kA, within a radial distance of 100 km from the sensor, and the discharge locations are detected with an accuracy of ±100 m (Betz et al., 2009). This sensitivity decreases gradually with the increasing distance of a lightning flash position from the sensor, with a threshold of 10 kA in a radial distance of 300 km (Höller et al., 2009). Within the Croatian territory, four LINET sensors are located along the coast (near Rijeka, Zadar, Split and Dubrovnik) and one in the hinterland in Zagreb. Some Croatian regions are also covered by sensors placed in the neighboring countries. The distance between adjacent sensors in the area of research is approximately 200 km.

Table 2. Contingency table

Tablica 2. Tablica kontingencije

Event forecast (GII index)	Event observed (Lightning)		
	yes	no	total
yes	a	b	a + b
no	c	d	c + d
total	a + c	b + d	a + b + c + d= n

For the geographical domain of interest, covering the region from 41°N 9°E to 49°N 21°E 5-min (rapid-scan) GII values were averaged, for 0.2°x0.2° boxes for the period between 06 and 09 UTC for 27 selected cases of convection developing in the clear air in 2009 and 13 cases in 2010. The average GII values were then compared to the occurrence of lightning in the boxes in the afternoon hours from 12 to 21 UTC. Out of many types of convection, occurring almost daily in the atmosphere of mid-latitudes, especially in the warmer part of the year, convection developing in the clear air, i.e. previously cloud-free air, is the most difficult to predict. Under convection in the clear air we consider the situations when the atmosphere is 'quiet' (cloud-free) in the morning, but a few hours later intensive development of convective clouds occurs.

Contingency table (Wilks, 2005), as shown in Table 2, was used for the assessment of statistical parameters such as Probability of Detection (POD), False Alarm Ratio (FAR) and Hanssen-Kuiper skill score (HK), calculated as:

$$POD = \frac{a}{a+c} \tag{3}$$

$$FAR = \frac{b}{a+b} \tag{4}$$

$$HK = \frac{(ad - bc)}{[(a+c)(b+d)]} \tag{5}$$

Coefficients a, b, c and d were calculated for each index value but taking into account all values greater and equal to that value (or less and equal, in case of LI). For example, for K Index value 20 °C we check all pixels where GII K Index was 20 °C or larger and compare it to the occurrence of lightning. If the index averaged over 0.2°x0.2° box (for a period between 06 and 09 UTC) was <20 °C and lightning occurred in that area between 12 and 21 UTC, we count that under event 'a' in the contingency table. If lightning did not occur the event will be counted under 'b'. If GII K Index is <20 °C and lightning occurred this is counted as event 'c' and if lightning did not occur this is 'd'. After that we calculate POD, FAR and HK for each value of index, for each index separately.

Besides contingency table parameters, cumulative and relative frequencies were calculated for each value of GII indices, counting the number of boxes where the lightning occurred and dividing it with the total number of boxes with a certain index value.

3. RESULTS

3.1. Visual assessment of cloud development

The example in Fig. 1 shows how the satellite-based GII indices are connected to convective cloud development. Indices are calculated only for the cloud-free pixels. For K Index (Fig. 1a) it is evident that clouds develop in the afternoon in the region where the index, calculated earlier that day, indicated instability (yellow and red colors in the image). The same can be seen in Fig. 1b, showing the values of GII LI at 07:00, 13:30 and 17:45 UTC, combined with IR 10.8 µm image. Clouds developed in the area where LI had minimum values. In the vicinity of the clouds, i.e. on their edges, instability indices have a small gradient towards more unstable values. Reason for that is that the physical retrieval method, used for deriving these indices, works under the assumption that the pixel is cloud free (where partial cloudiness may not have been detected by the prior cloud detection process). This leads to a slightly lower brightness temperature in some channels, which by the GII retrieval is interpreted as increased moisture, thus, by definition, higher instability.

What could be concluded from Figure 1c is that the values of GII TPW are not directly connected to cloud development. Besides the region of high TPW values over the Alps and North Italy, which is in the agreement with the extreme values of the other two indices, there is also a region of high TPW values over East Europe. In that area, however, clouds did not develop in the afternoon, as it can be seen at 17:45 UTC in Fig. 1c. Taking into account the fact that convection requires several factors (e.g. Doswell, 1987), not only sufficient humidity content, it is clear that TPW on it's own is not always a good indicator of the probability for convection. It should be considered in combination with atmospheric instability and lifting processes. This can be seen in Figure 1c, where the high values of TPW index observed in the morning hours, over the eastern part of domain, does not correlate well with development of the convective cloudiness.

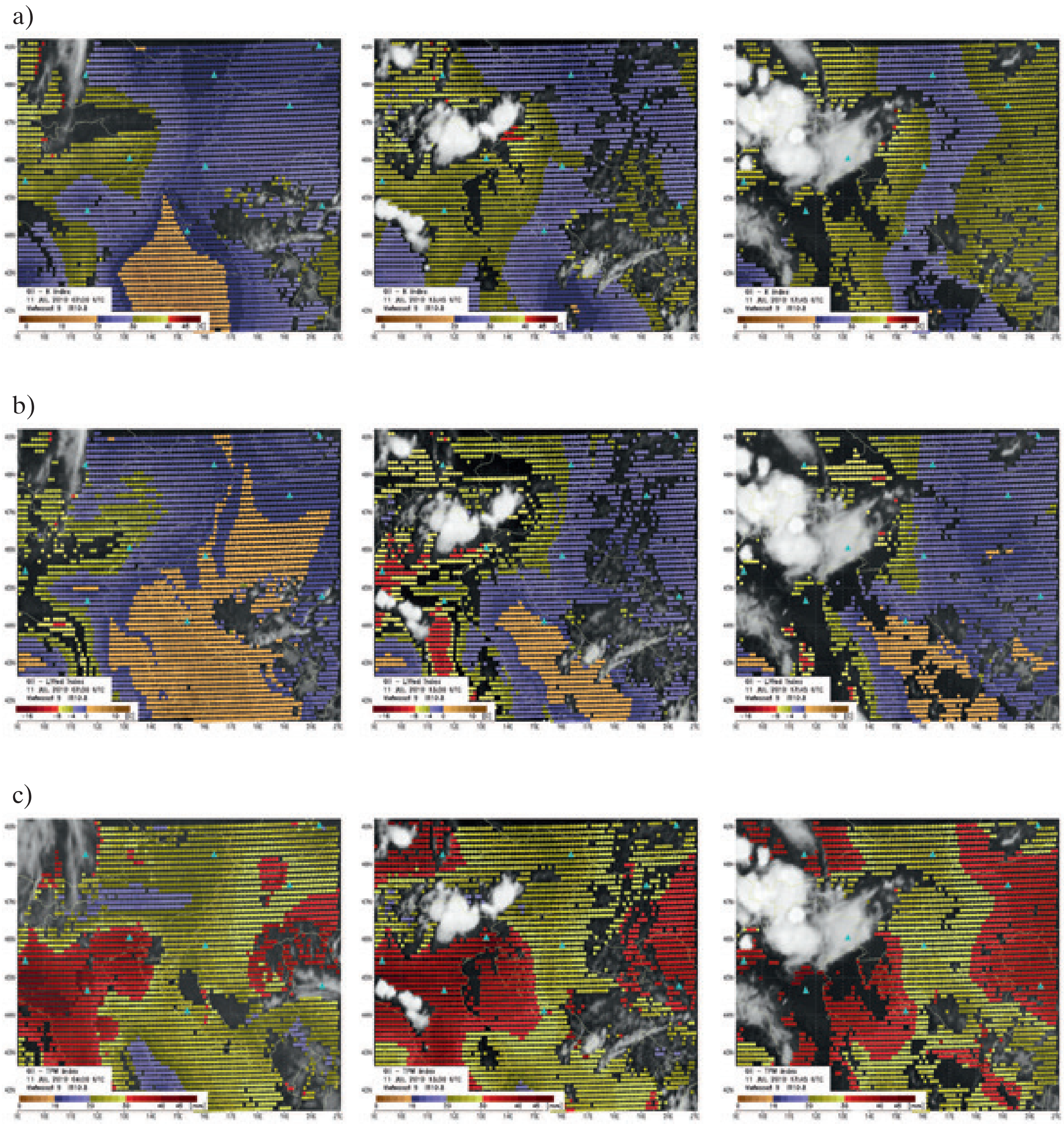

Figure 1. GII K Index (a), LI (b) and TPW (c) in the morning (left), mid-day (middle) and evening (right) on 11 July 2010. Blue triangles mark the locations of the radiosounding stations used for the evaluation.

Slika 1. GII K indeks (a), LI (b) i TPW (c) ujutro (lijevo), sredinom dana (sredina) i poslijepodne (desno) 11. srpnja 2010. Plavi trokutići označavaju radiosondažne postaje korištene za verifikaciju.

It has to be stressed that the thresholds for each index are not fixed in time and space, but can vary from season to season and from place to place around the globe, depending on climate and topography characteristic of a particular area. As mentioned before, besides atmospheric instability, additional conditions, such as lifting mechanisms, must be fulfilled for strong convective development.

3.2. Verification of GII indices against radiosonding data

Verification of the satellite derived indices was done comparing two sets of data for a particular index, as explained in paragraph 2.2. It has been assumed that the reference sample for the verification were the radiosounding indices, which are seen as the observed state of the atmosphere. Other assumptions are that

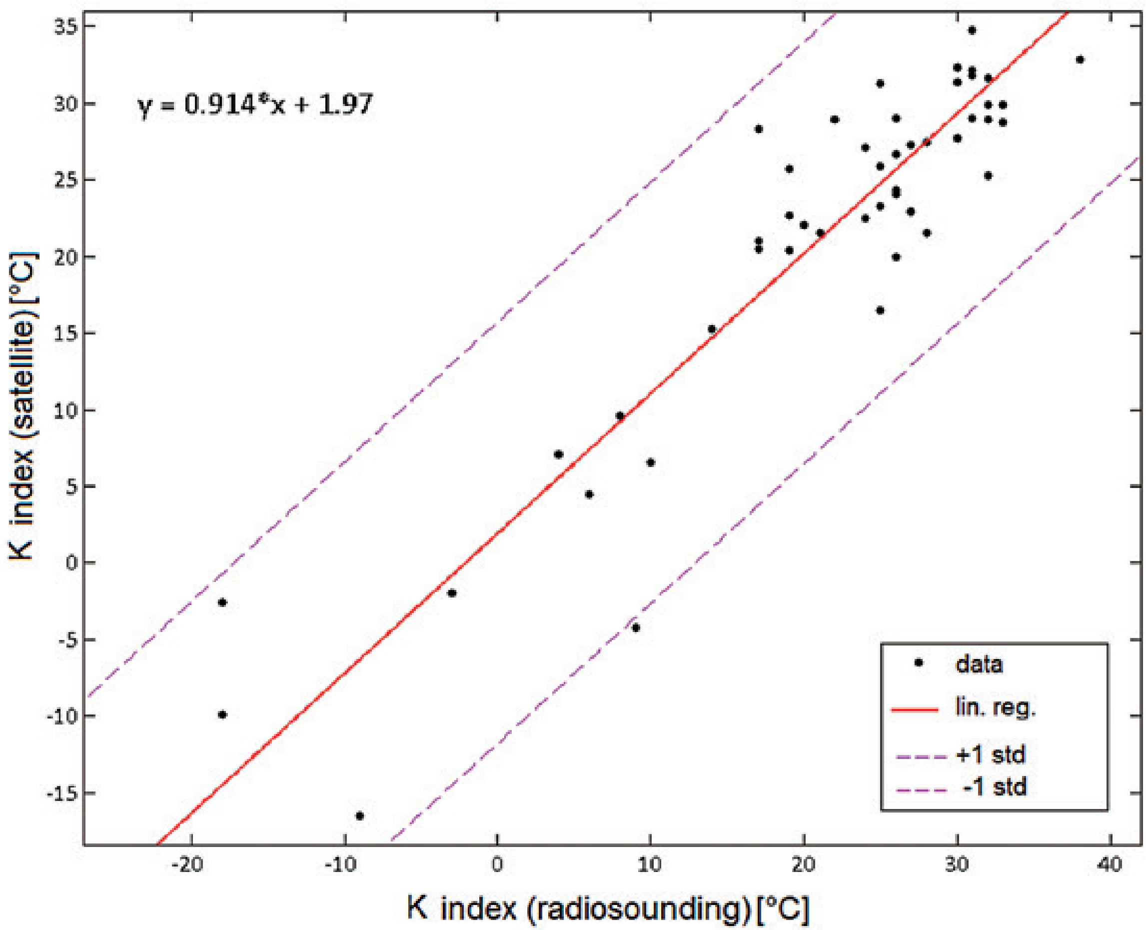

Figure 2. Scatter plot of radiosounding-derived and satellite-derived K Index

Slika 2. Dijagram raspršenja K indeksa izvedenog pomoću radiosondažnih i satelitskih podataka

the accuracy of the satellite derived indices does not depend on the location and that there are no temporal and spatial correlations between the values of indices in neighboring pixels. That means that radiosunding stations are sufficiently far from each other and that the period between two soundings of amosphere is big enough. Thus, a set of 50 realizations of independent random variables (radiosounding indices) and 50 realizations of dependent random variables (satellite-derived indices) is obtained, among which the degree of correlation is tested. Final assumption is that the satellite-derived indices were sampled at the exact locations of the radiosounding stations. For that reason, value of satellite derived index in the closest available (not overcasted) pixel was used.

The scatter-plot for the K Index, along with the associated linear regression line, shown in Fig. 2, reveals good correlation between the two datasets. All the points of scatter plot are closely concentrated along the regression line, with only one point exceeding one standard deviation. Coefficient of correlation for this example is 0.934 (significance was proved by Monte Carlo test) and this value is large enough to ensure adequacy of this satellite-derived index. Same facts are also clearly seen in Fig. 3, where the histogram of the difference of two differently derived index values is approximately showing normal distribution around 0 °C.

Same procedure was done for LI and TPW indices, the scatter-plots in Figs. 4 and 5 showing similar results, again with high values of correlation coefficients: 0.942 and 0.963, respectively. The fact that the correlation coefficient for TPW index is slightly bigger than the one for K Index and LI can lead to the conclusion that

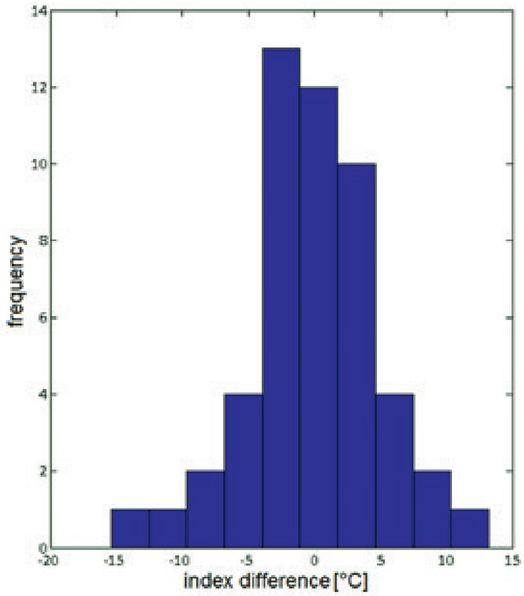

Figure 3. Histogram of differences between radiosounding-derived and satellite-derived K Index

Slika 3. Histogram razlika K indeksa izvedenog pomoću radiosondažnih i satelitskih podataka

the retrieval method works better for the moisture profile than for the temperature profile, which can be expected regarding the information content of the MSG channels. But it must be stressed that used data sample is generally too small to draw concrete conclusions. Histograms of LI and TPW indices (not shown here) are also having similar pattern as the one for the K Index.

In all scatter plots a small cluster of data can be seen (most obviously in Fig. 4), shifted towards the values of indices that are connected to a more stable atmosphere. These are the values related to one day in winter season when the humidity is much lower and the instability weaker than in warm periods of the year. This is the normal periodic index change pattern, following the changes of temperature and moisture of the atmosphere throughout

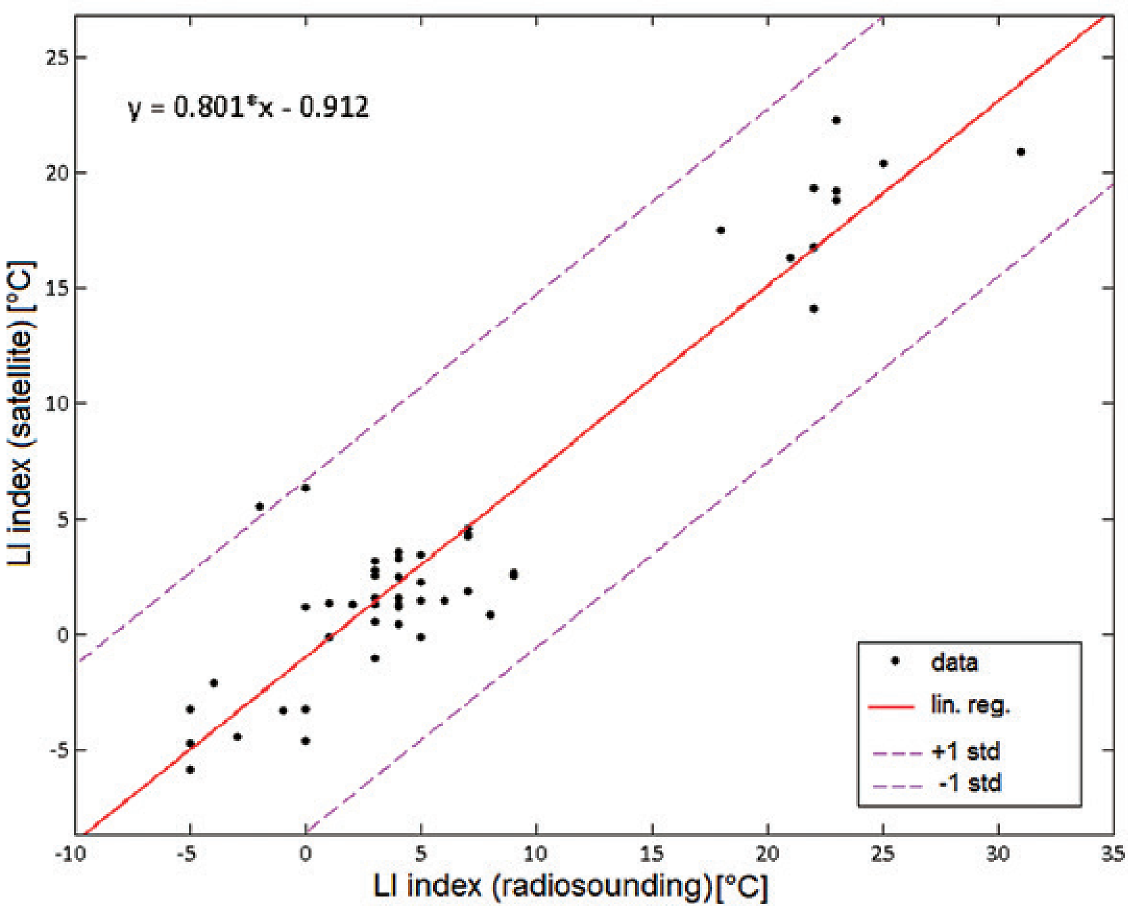

Figure 4. Scatter plot of radiosounding-derived and satellite-derived LI index

Slika 4. Dijagram raspršenja LI indeksa izvedenog pomoću radiosondažnih i satelitskih podataka

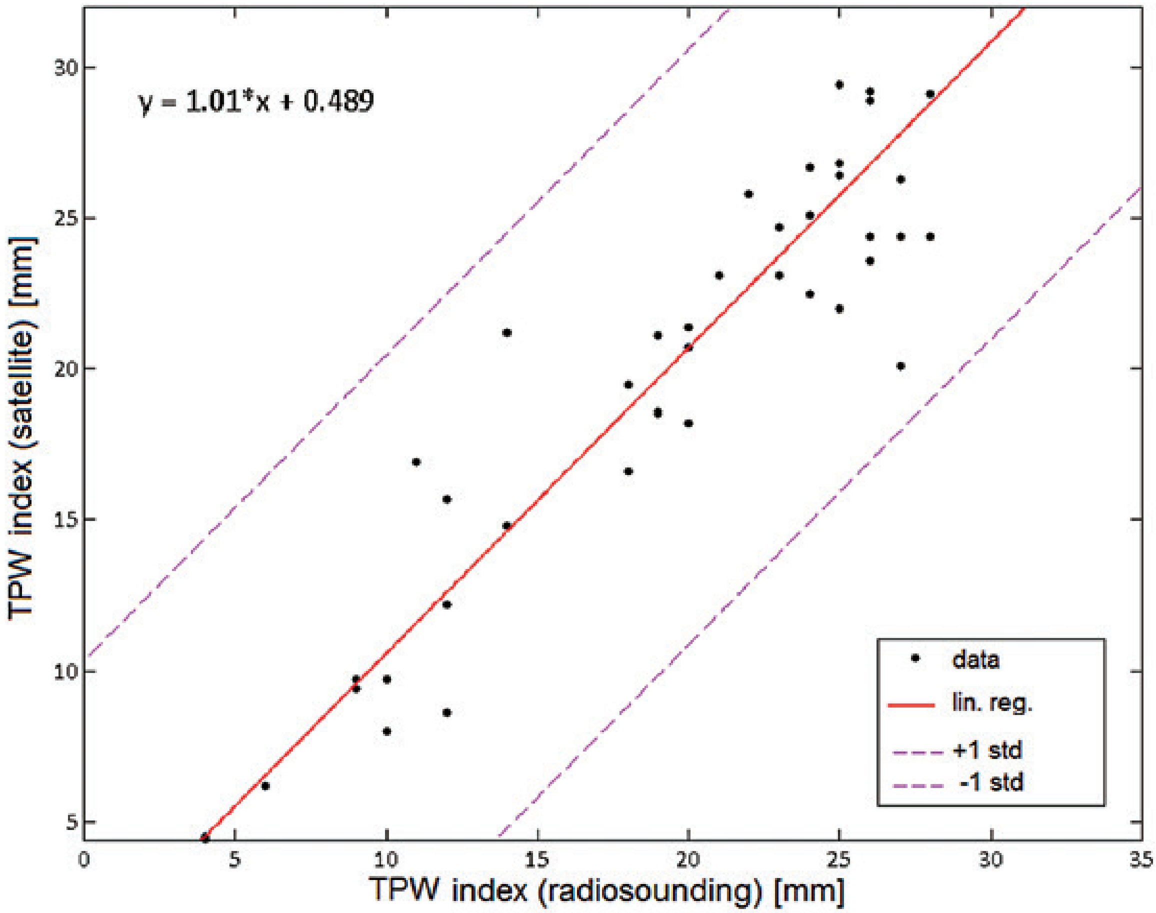

Figure 5. Scatter plot of radiosounding-derived and satellite-derived TPW index

Slika 5. Dijagram raspršenja TPW indeksa izvedenog pomoću radiosondažnih i satelitskih podataka

the year. All index values are generally smaller than the ones seen in the verification against lightning data because, as mentioned before, these are taken at 00 UTC, when the atmosphere is relatively colder, containing smaller amount of water vapor that later in the morning.

3.3. Verification of GII indices against lightning data

The temporal analyses of lightning data over Croatia (Mikuš et al,. 2012) revealed that in summer months daytime convective activity starts on average between 11 and 12 CET and ends between 17 and 20 CET. This is also seen in the time sequence of lightning frequency for 11 July 2010 (Fig. 6), where the lightning started after 10 UTC, with abrupt strong increase of frequency between 12 and 13 UTC. This distribution was the reason why the GII values were then compared to the occurrence of lightning in the afternoon hours from 12 to 21 UTC, as mentioned in paragraph 2.3.

Statistical parameters of the relation between the GII K Index and lightning occurrence are graphically presented in Fig. 7. As evident from the figure POD is almost 1 for a K Index larger than 15 °C, therefore K Index value of 15 °C was considered to be the threshold for the onset of convective development. FAR for K≥15 °C is about 0.4, dropping down to 0.1 for K≥36 °C and slightly rising after that value. Higher values of FAR for K Index >36 °C and higher is caused by a rather small number of the events with such high K Index values.

Similar values of POD, FAR and HK were found by examining these parameters for LI and TPW indices (Figs. 8 and 9). The x-coordinate of the graph showing the distribution of

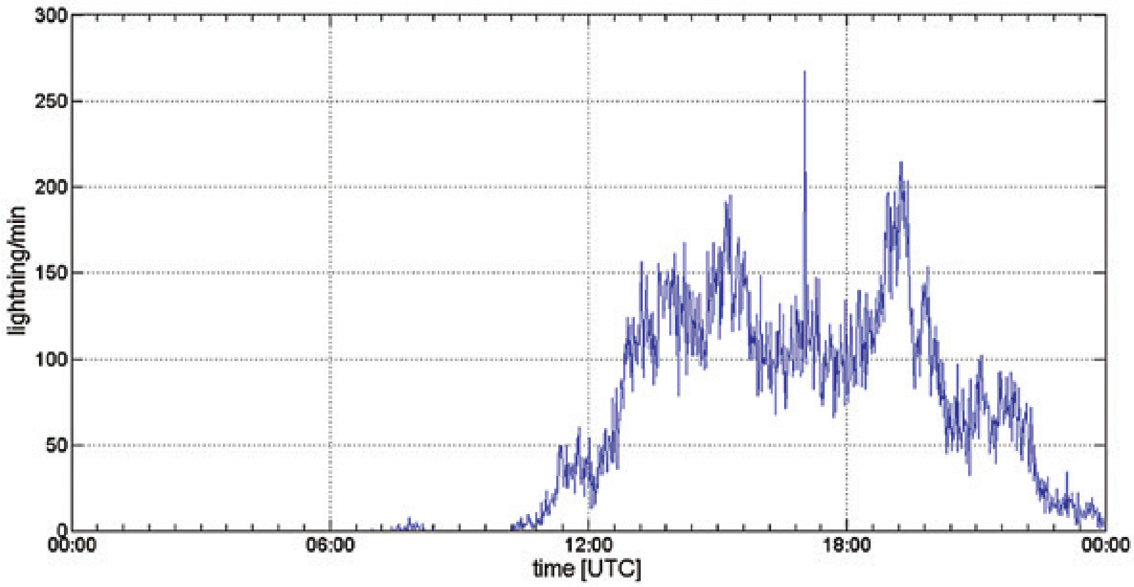

Figure 6. Lightning occurrence on 11 July 2010, 08:00-18:00UTC

Slika 6. Pojavljivanje munja 11. srpnja 2010, 08:00-18:00 UTC

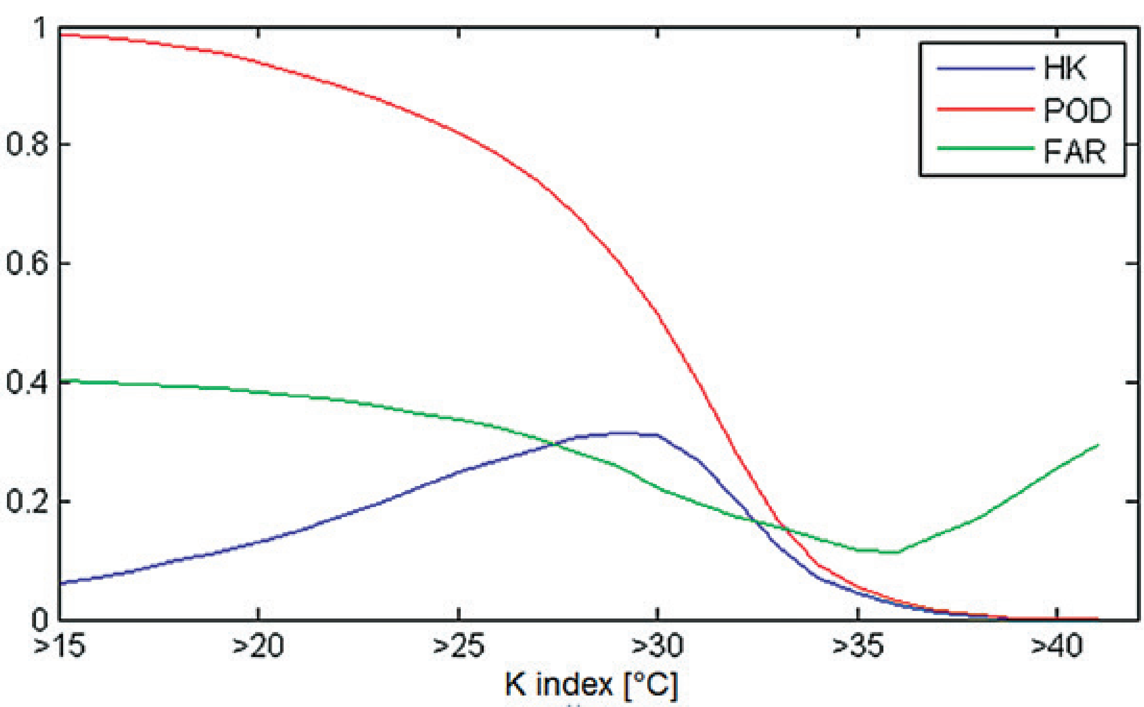

Figure 7. Statistical parameters for K Index for 40 cases in 2009 and 2010

Slika 7. Statistički parametri za K indeks za 40 događaja u 2009. i 2010. godini

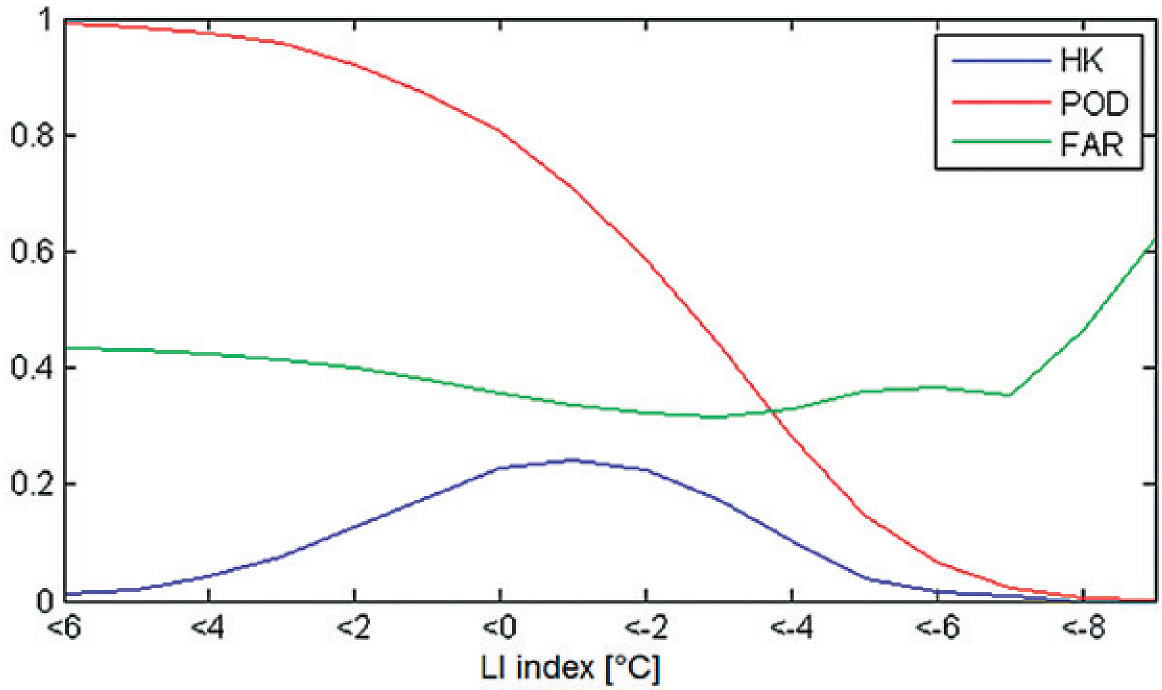

Figure 8. Statistical parameters for LI index for 40 cases in 2009 and 2010

Slika 8. Statistički parametri za LI indeks za 40 događaja u 2009. i 2010. godini

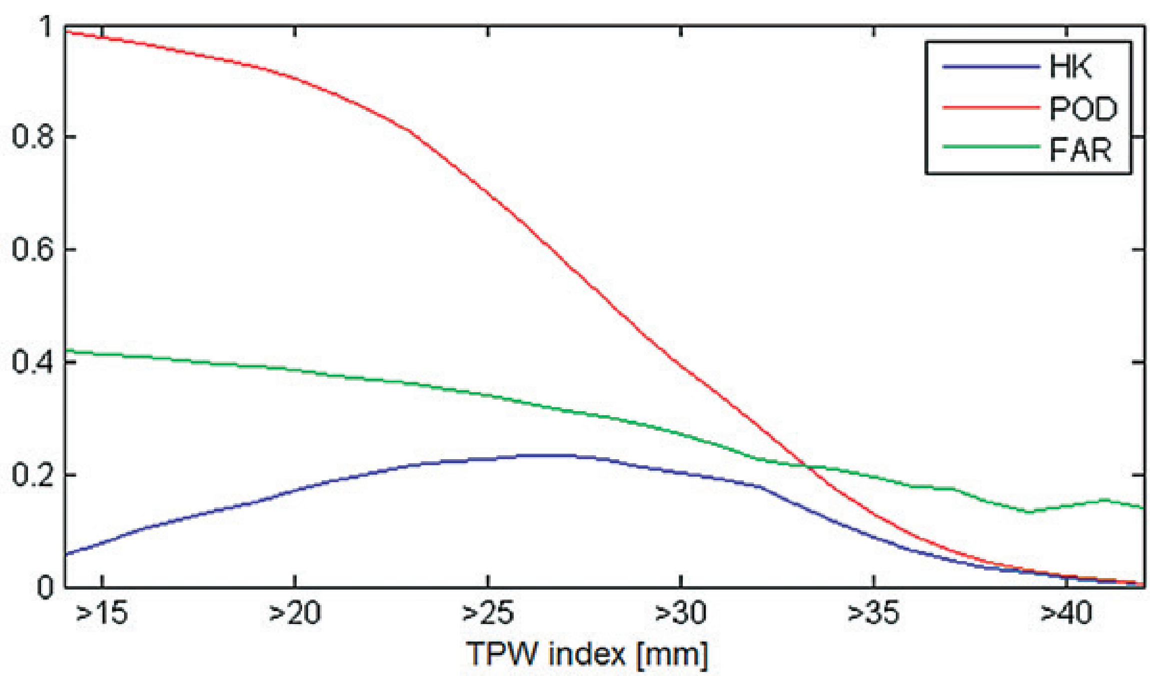

Figure 9. Statistical parameters for TPW index for 40 cases in 2009 and 2010

Slika 9. Statistički parametri za TPW indeks za 40 događaja u 2009. i 2010. godini statistical parameters for the correlation between LI index and lightning occurrence (Fig. 8) is reversed, since the more negative LI index is pointing to more unstable atmosphere, i.e. more lightning.

It can be concluded that statistical relations between each of the three examined indices and lightning occurrence are similar, with the threshold for onset of convection for the K Index being 15 °C, for the LI index around 5 °C and for TPW to be around 13 mm. It has to be stressed that these thresholds are not the ones for which heavy thunderstorms would be forecasted. Thunderstorm events would rather be connected with the values of indices corresponding to the maximum of HK curve. The reason for that lies in a fact that HK parameter discriminates how well the 'yes' events are distinguished from the 'no' events. In other

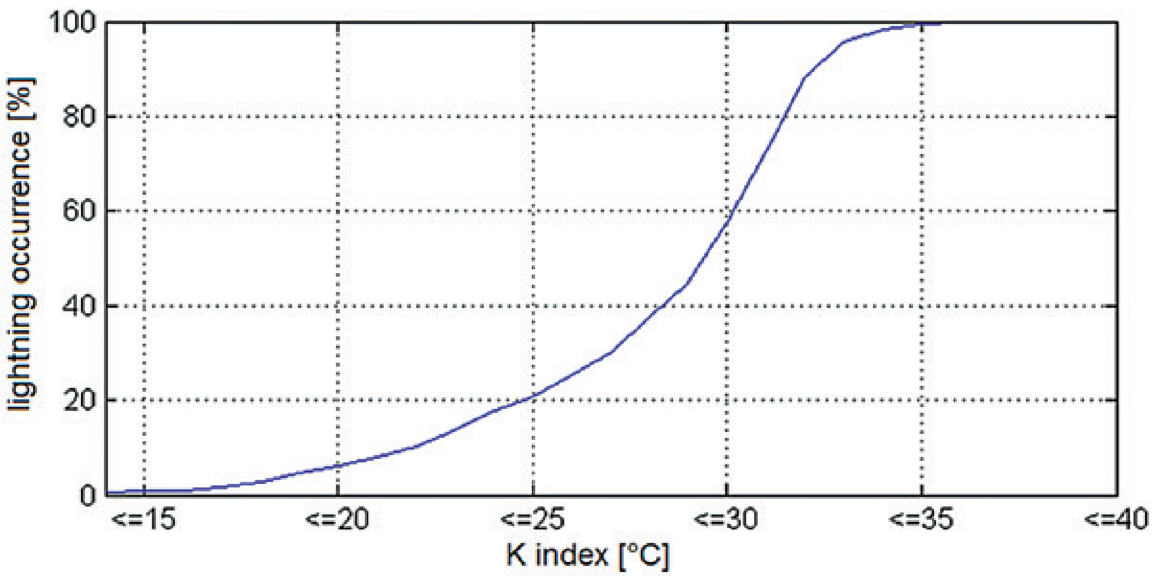

Figure 10a. Cumulative frequency of lightning occurrence against K Index values for 27 cases in 2009

Slika 10a. Kumulativna frekvencija pojave munja u ovisnosti o vrijednostima K indeksa za 27 događaja u 2009. godini

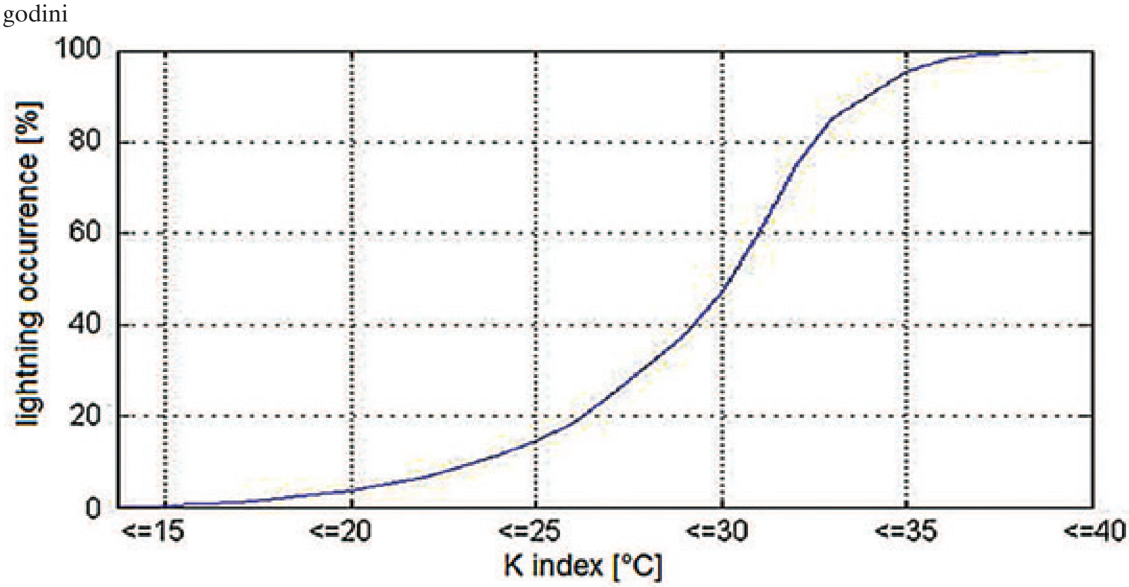

Figure 10b. Cumulative frequency of lightning occurrence against K Index values for 40 cases in 2009

Slika 10b. Kumulativna frekvencija pojave munja u ovisnosti o vrijednostima K indeksa za 40 događaja u 2009. godini words, from Figures 7 to 9 we can say that thunderstorms are more likely to occur in case of the following threshold values: 29 °C for K, 1°C for LI and 27 mm for TPW. These values are close to those shown in other similar papers dealing with this subject (e.g de Coning, 2010).

Probabilities of lightning occurrence for certain intervals of K Index values can be found in Fig. 10a (i.e. Fig. 10b. for 40 cases). For instance, for K Index values ranging from 20 - 25°C lightning is expected to occur in 10-20% of the cases, whereas for the index value around 30 °C, the probability for lightning occurrence is 60%.

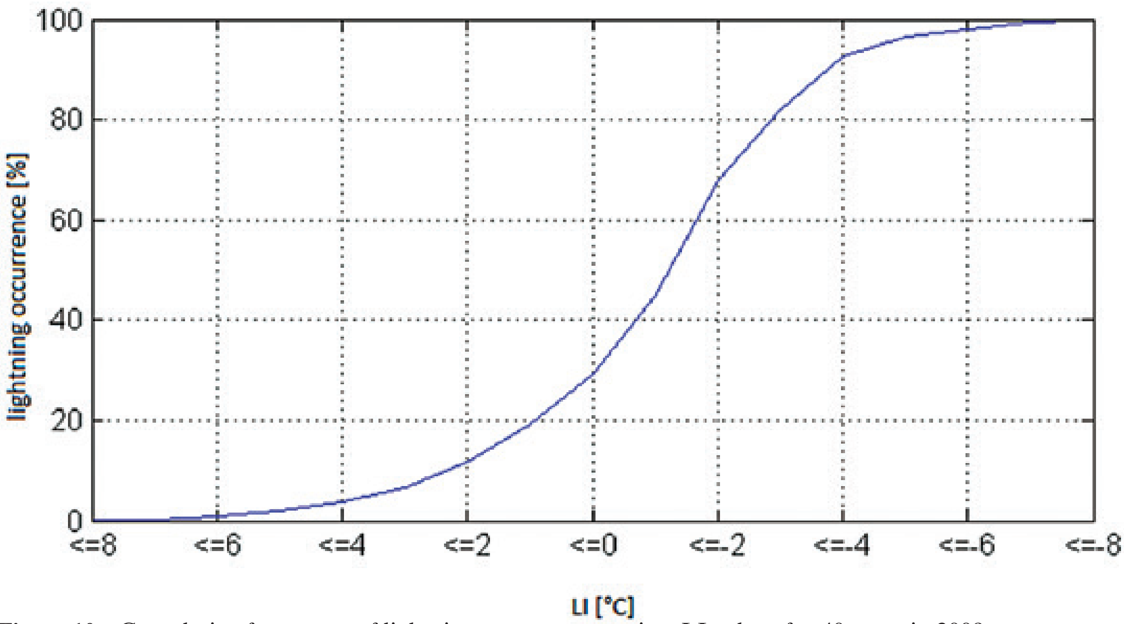

Figure 10c. Cumulative frequency of lightning occurrence against LI values for 40 cases in 2009

Slika 10c. Kumulativna frekvencija pojave munja u ovisnosti o vrijednostima LI indeksa za 40 događaja u 2009. godini

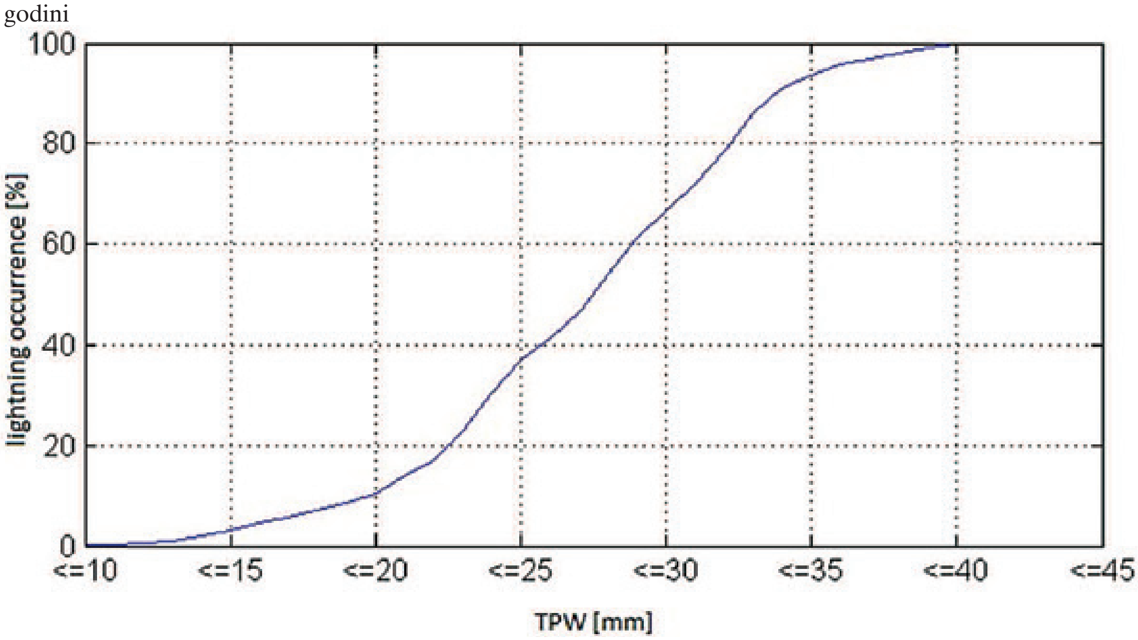

Figure 10d. Cumulative frequency of lightning occurrence against TPW values for 40 cases in 2009

Slika 10d. Kumulativna frekvencija pojave munja ovisnosti o vrijednostima TPW indeksa za 40 događaja u 2009. godini

4. DISCUSSION AND OUTLOOK

Contrary to the expected results for HK discriminant, found for other regions (e.g. de Coning et al., 2010, for the South Africa) the values of the HK discriminant for the Central European region are rather low, ranging from 0.35 for K Index to 0.2 for the other two indices. These values could not be used to derive the probability of lightning occurrence. Besides already mentioned factors that have influence on these results (e.g. lacking of lifting mechanism factor), the problem seems to be also a rather small domain with a small number of days (only 40) used in the analysis. It is expected that the results would be better if the statistical parameters were calculated for much larger number of cases, even considering the cases for days with less convective activity. This can be seen when comparing Fig. 11 and Fig. 12 - there is slight increase of HK maximum value if 13 more cases are considered. Therefore the study will be continued in that direction, in order to get HK discriminant significant enough to be used as the weighting factor in deriving combined stability index (de Coning et al., 2010).

A comparison of FAR values in Fig. 11 and Fig. 12 shows that for higher index values FAR is dropping down to smaller values with increased number of cases. Reason for that is the fact that the number of pixels with TPW value >35 mm grows, when the number of cases is increased, i.e. that range becomes statistically more relevant.

5. CONCLUSIONS

Global Instability Indices derived from Meteosat satellite data for a wider Croatian area are validated in this paper. The advantage of the satellite-based instability indices, if compared with those derived from radiosounding data, is their temporal (up to 5 minutes) and spatial (up to 3x3 km) resolution. Besides single-point validation of GII indices against radiosonde data, lightning occurrence, as an indicator of convective activity, was also used for the verification of GII indices and for deriving the statistical correlation between index values and occurrence of the convection.

When visually comparing values of the indices over the studied domain and occurrence of convective clouds later on (seen in IR10.8 channel images), it was seen that overlapping of high instability index values and convective clouds is significant. Overlapping of index values and cloud mask reveals one negative aspect of GII

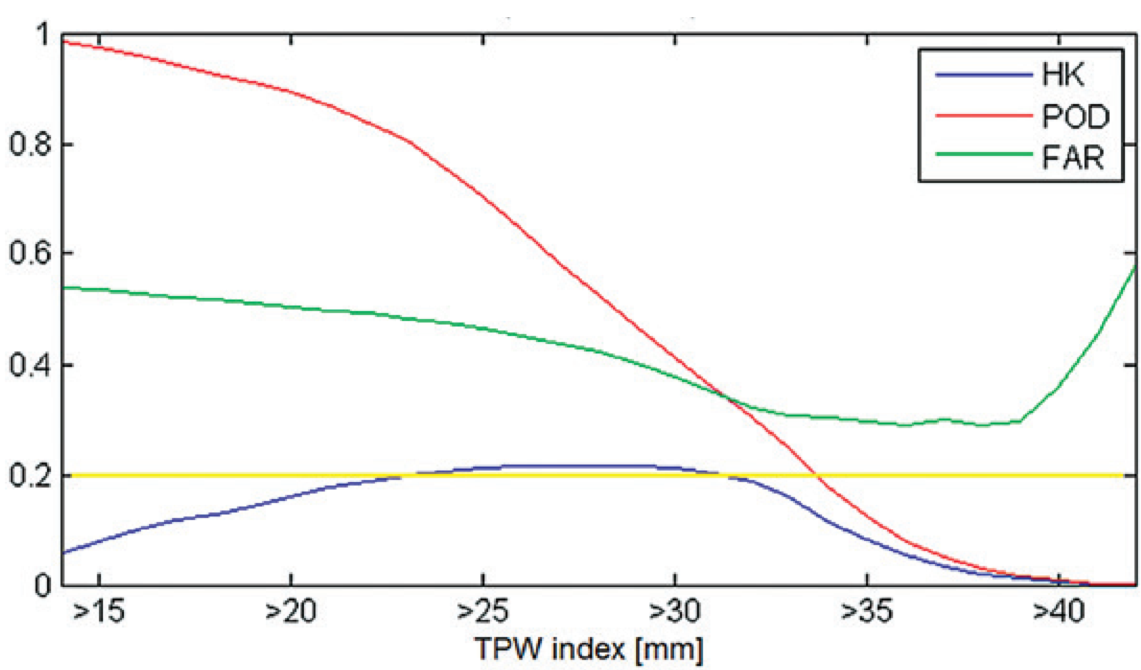

Figure 11. Statistical parameters for TPW index for 27 cases in 2009 (yellow line as a reference)

Slika 11. Statistički parametri za TPW indeks za 27 događaja u 2009. godini

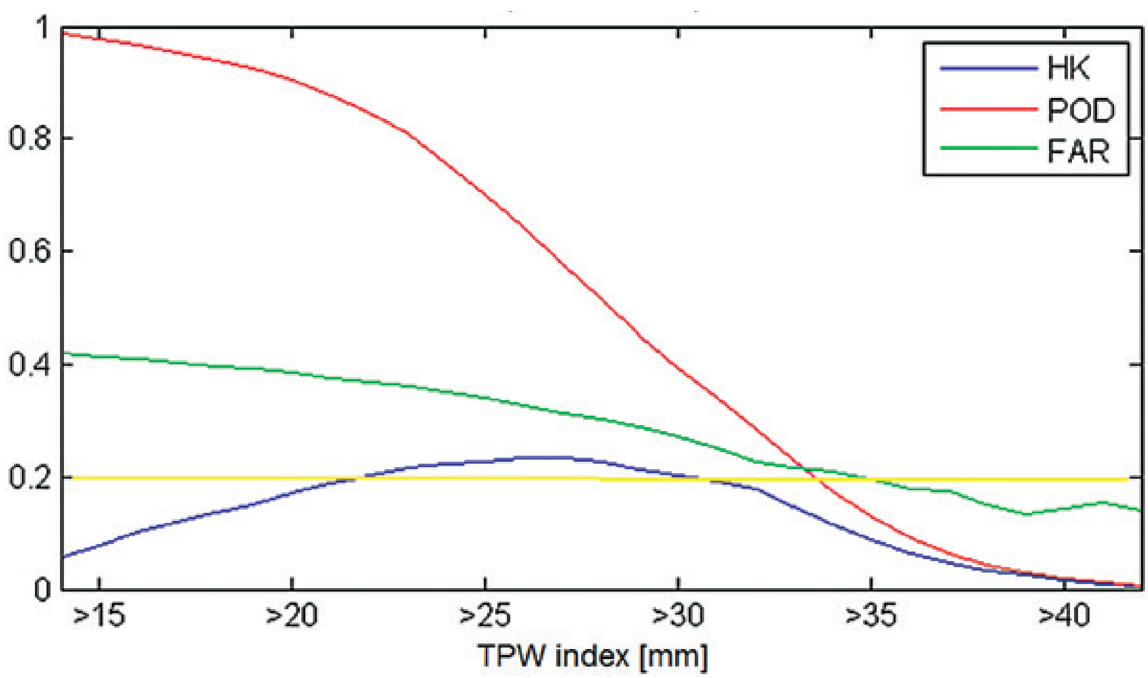

Figure 12. Statistical parameters for TPW index for 27 cases in 2009 and additional 13 in 2010 (yellow line as a reference)

Slika 12. Statistički parametri za TPW indeks za 27 događaja u 2009. godini i dodatnih 13 u 2010. godini.

satellite-based indices - it is not possible to derive the index values in the cloud-covered pixels of the domain. The effect of cloudy pixels was minimized by using time-averaged values of GII.

Radiosounding-based indices were compared to GII indices for 10 radiosounding stations within the observed domain, for 5 different cases. This was done for a purpose of verification of satellite-based indices, since the assumption was made that the indices derived from the radiosounding data are depicting the real state of atmosphere, thus serving as independent variable in gaining correlations between the two. Scatter plots and correlation coefficients showed high correlation between two sets of data. Values of coefficient for K, LI and TPW index were 0.934, 0.942 and 0.963, respectively. From these values we can conclude that GII indices are mirroring the same atmospheric instability as the indices based on radiosonde data and that the physical retrieval method used for deriving GII indices is verified. Since for TPW index correlation coefficient is highest we can say that the method is more successful in retrieving the distribution of moisture than the temperature in the atmosphere.

By verifying the GII indices against lighting data we have determined the threshold values for the onset of convection for each instability index. The threshold for K Index is 15 °C, for TPW is about 13 mm. It has to be noted that the threshold value which connects LI index with the occurrence of convection is around 5°C, which deviates from the usual threshold of 0°C. Using cumulative frequency we have determined the probability of occurrence of convection in some intervals of each index values. For example, for the value of K Index between 20°C and 25°C the probability for convection is approximately 10-20% (Fig. 11). For the values higher than 35°C convection probability is very high, above 90%. Due to the relatively small number of observed cases and the averaging of the index in time and space, these probabilities are not completely reliable, but approximated.

With the aim of better forecasting deep moist convection, we suggest that a similar analysis should be carried out for a higher number of cases, i.e. for a longer time period covering the same study area (larger Croatian area). Non-convective days and more summer seasons should be included, which is a plan of the continuation of this study.

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