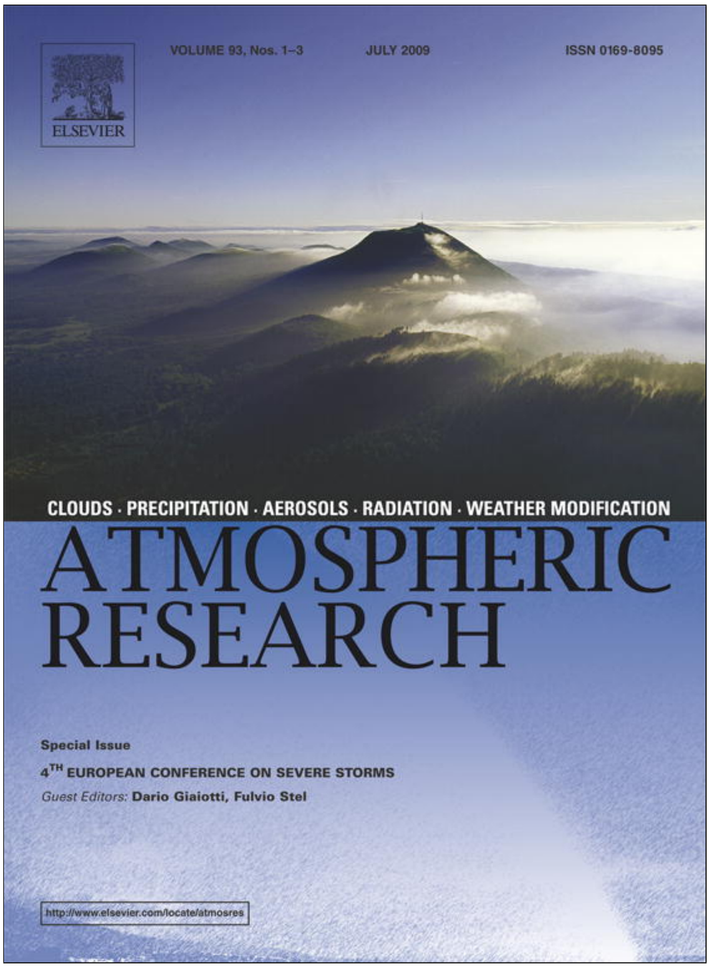
VOLUME 93, Nos. 1–3
JULY 2009
ISSN 0169-8095
ELSEVIER
CLOUDS · PRECIPITATION · AEROSOLS · RADIATION · WEATHER MODIFICATION
ATMOSPHERIC RESEARCH
Special Issue
4TH EUROPEAN CONFERENCE ON SEVERE STORMS
Guest Editors: Dario Giaiotti, Fulvio Stel
http://www.elsevier.com/locate/atmosres

Atmospheric Research 93 (2009) 270–276

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Application of Meteosat SEVIRI channel difference 0.6 μm–1.6 μm in convective cells detection

Nataša Strelec Mahović [a,*], Barbara Zeiner [b]

[a] Meteorological and Hydrological Service, Grič 3, 10 000 Zagreb, Croatia
[b] Central Institute for Meteorology and Geodynamics, Hohe Warte 38, 1190 Wien, Austria

ARTICLE INFO

Article history:
Received 29 November 2007
Received in revised form 4 September 2008
Accepted 9 October 2008

Keywords:
Convective clouds detection
0.6 μm–1.6 μm channel difference
Operational application

ABSTRACT

Convective cells detecting algorithms, used in operational weather services, are frequently based on single infrared channel data. Due to many disadvantages of these methods, an attempt is made to introduce the difference of Meteosat SEVIRI channels 0.6 μm and 1.6 μm as a tool for automatic recognition of convective clouds. The differences of reflectance values of the two channels were calculated for numerous cases and the results were visually compared to radar reflectivity data. The comparison shows that all potentially dangerous cells are detected which means promising and operationally applicable result. Due to the fact that satellite radiometer sees particles of a much smaller size than the radar does, the difference method suggested here enables the recognition of small developing cells several time-steps (up to 1 h) before they are seen in the radar imagery, provided that a proper threshold is set for the difference values. This enables the detection of convective cells in the areas not covered by radar measurements. It is also shown that the detection provided by the channel difference method is much more precise and detailed than the detection based on the IR channel data. The main disadvantage of the method is the fact that it can be used only during day-time so the night-time convection needs to be treated separately.

1. Introduction

One of the most challenging tasks in the operational nowcasting service is the early detection of potentially dangerous convective clouds. Automatic convective cloud detection methods, used operationally in many weather services, are often based on single infrared channel data. The main advantage of such methods is their applicability during both day-time and night-time. However, due to the fact that the criteria in these methods are only cloud-top temperatures and the shape of the clouds, they have proven to be unsuccessful in many cases. Misdetections occur mostly due to detecting cirrus shields, large frontal areas or parts of fronts as convective clouds. These errors could be reduced in some cases by introducing the difference of two IR channels (10.8 μm–12.0 μm) in order to detect and eliminate thin high cirrus clouds, but the problem still remains. If the cloud-top temperature thresholds are set to lower values than low water clouds and sometimes even fog patches are detected as convective clouds. This can cause many problems in operational forecasting process.

Taking into account the properties of visible channels, which enable the differentiation of cloud phase and particle size and give the insight into the optical depth of clouds, an attempt has been made to reinforce the automatic convection detection method by introducing data from Meteosat SEVIRI channels 0.6 μm and 1.6 μm.

2. Properties of solar channels 0.6 and 1.6 μm

The solar channels are primarily used for defining depth of the cloud and its water or ice content, but also cloud particle size and phase. The properties of these channels are often exploited in composite images (Roesli, 2004). Visible

* Corresponding author. Tel.: +385 1 4565 772; fax: +385 1 4565 757.
E-mail address: strelec@cirus.dhz.hr (N.S. Mahović).

0169-8095/$ – see front matter
doi:10.1016/j.atmosres.2008.10.023

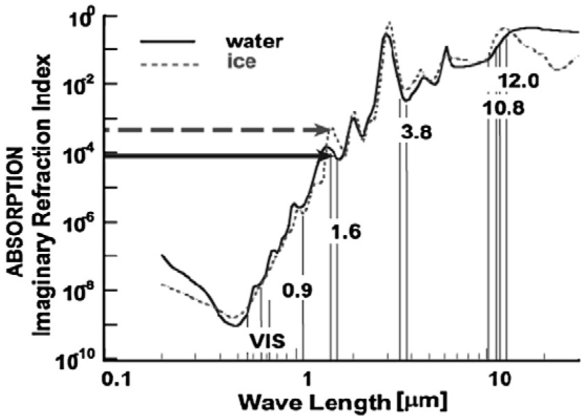

Fig. 1. Absorption of ice (dashed) and water (solid) in different spectral regions. Different absorption of ice and water clouds for 1.6 μm channel is marked by arrows. (adapted from MSG-Interpretation Guide).

reflectance at 0.6 μm is a measure of the optical depth of clouds or the albedo. The albedo of a cloud is determined by its thickness, composition and particle size distribution. The highest reflectance values in 0.6 μm channel come from optically thick water clouds and snow. Reflectance values for very thick clouds (large Cb clouds) can sometimes be above 90%. On the other hand, transparent clouds (such as cirrus clouds) produce much lower reflectance values. If the reflectance threshold is set to 40% cirrus clouds can be ruled out and only thicker clouds remain.

In the 1.6 μm channel the radiation is slightly absorbed by cloud water and the ratio between scattering and absorption makes it sensitive to the particle size (Nakajima and King, 1990) and especially to phase (ice or liquid) present (Rosenfeld et al., 2004). In other words, apart from enabling distinction between thick and thin clouds, solar reflectance component of 1.6 μm channel gives the information about cloud particle size and enables the distinction between ice and water clouds. As seen in Fig. 1. water clouds reflect much more in 1.6 μm channel than ice clouds since ice absorbs more strongly then water at 1.6 μm.

3. Difference of 0.6 μm–1.6 μm channel reflectance

Although both solar channels can display the properties valid for convective clouds, there are many other types of clouds with similar characteristics in single channels. In other words, there can be no threshold set that would clearly point out only convective cells in solar channels, as it is done with the infrared based detection method. In order to utilize properties of both solar channels at the same time, and to rule out the clouds which are of no interest, difference of reflectance in 0.6 μm and 1.6 μm channel is used. Multi-spectral analysis of satellite images using a combination of one visible and one near-infrared channel is extensively used in many methods for determining cloud microphysical properties (Nakajima and King, 1990; Jolivet and Feijt, 2003). It is also often used operationally in composite images, where it enables better identification of young, severe storms (Kerkmann, 2005). High value of the difference means that reflectance in 0.6 μm channel is very high, signalising the clouds are dense and thick, whereas the reflectance in 1.6 μm channel is very low because of the ice particles on top of the clouds. Therefore, very high values of the difference are found only at thick clouds with ice on the top, i. e. convective clouds.

On the other hand, the areas which show low reflectance values in 1.6 μm channel due to small vertical depth have also low reflectance values in 0.6 μm channel and can therefore be easily discriminated in the difference image, because the resulting difference value is small. If the threshold is set

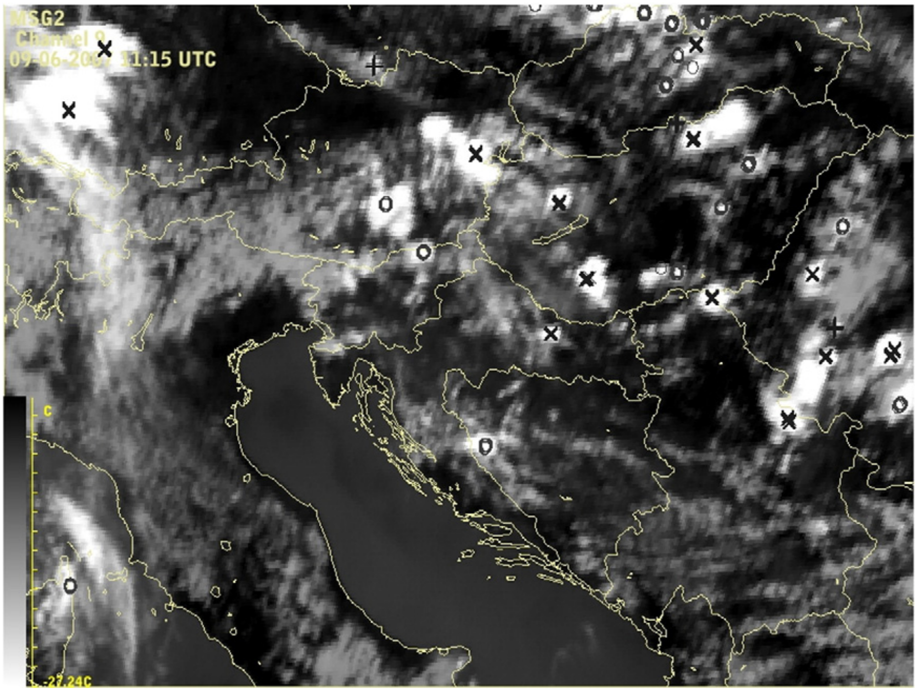

Fig. 2. Meteosat 9 10.8 μm image for 09 June 2007, 11:15 UTC, overlaid by the locations of convective cells as detected by an algorithm based on IR satellite data. Different signs show centres of the detected cells and the cloud-top temperature of the coldest tops: + (-33 °C<T_{top}<-42 °C), O (-42 °C<T_{top}<-55 °C), X (T_{top}<-55 °C).

properly the difference of reflectance values in 0.6 and 1.6 µm channels can be used in automatic convective cells detection.

4. Visualisation and comparison to radar data

For the purpose of calculating the difference of reflected components, radiance values in channel 0.6 µm and 1.6 µm were transferred to reflectance values. The relations for calculating the reflectance values can be found in Rosenfeld, 2005.

The differences of reflectance values of channel 0.6 µm and 1.6 µm have been calculated pixel by pixel for numerous cases of convective development during spring/summer season 2007 and the detected systems were visually compared to

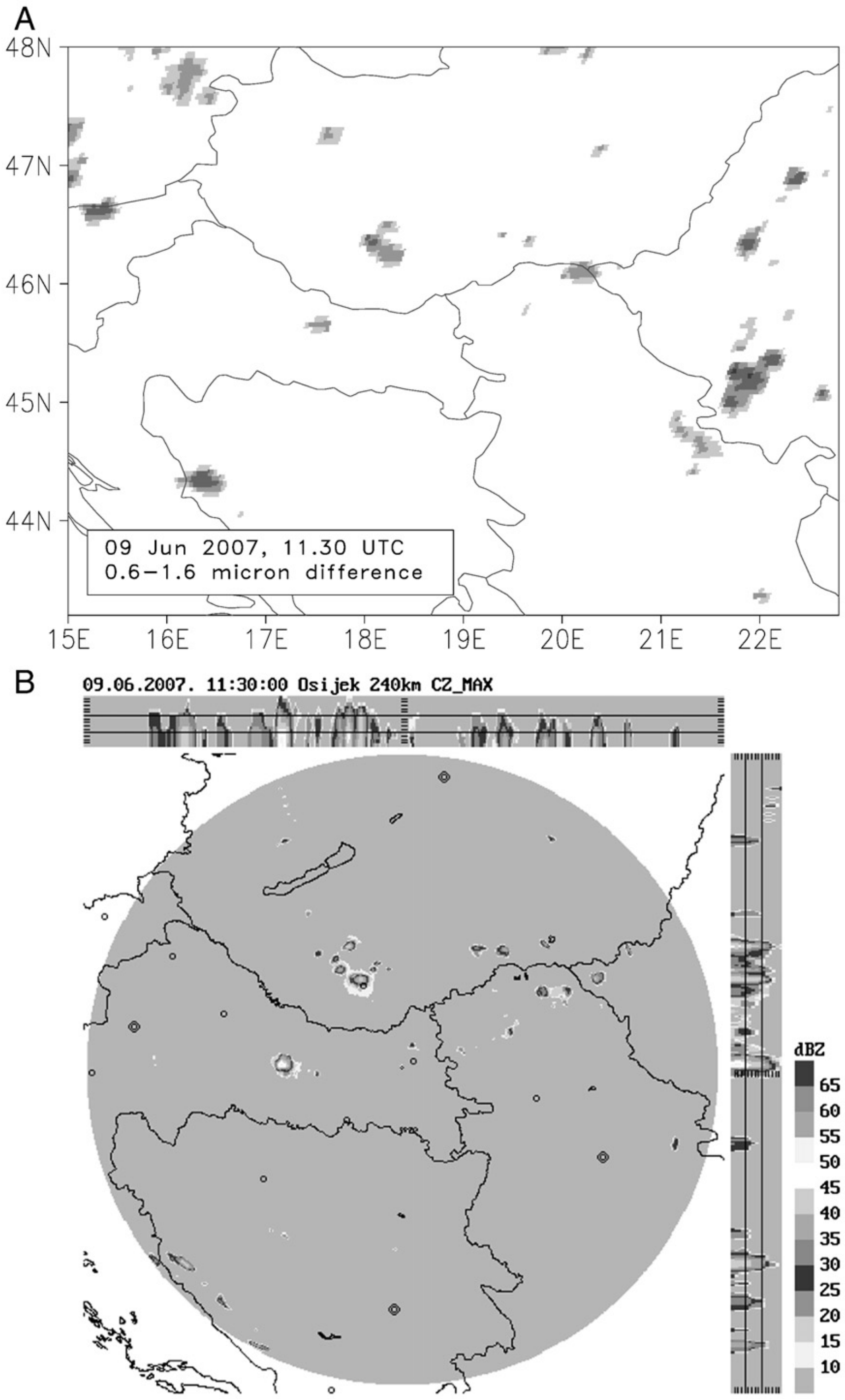

Fig. 3. (A) Difference of reflectance of 0.6 µm–1.6 µm channel for 09 June 2007, 11:30 UTC. Regions with difference >20% are shaded in 10% intervals. (B) Corresponding radar reflectivity data for 09 June 2007, 11:30 UTC. Maximum reflectivity product is displayed.

radar reflectivity data. The reason for making the comparison with radar reflectivity comes from the problem of poor radar coverage of the Croatian territory. Namely, only the northern part of the territory is covered by radar measurements, whereas the southern part, which includes a large part of the Adriatic Sea and the coast, has no coverage at all. Therefore, besides improving the infrared channel based convection detection method, it was desired to make this solar channel difference a substitute for missing radar data. Although there is a large difference in the wavelengths of the radiometers on radar and satellite, with radar measuring the particles (drops) with diameters in the order of 1 cm and satellite measuring the particles which have diameters in the order of 1 µm, visual comparison still showed results that are acceptable for the operational use. In satellite images convection is seen up to 1 h earlier than in radar, due to the fact that radar "sees" the cloud only when it already precipitates, whereas satellite sees cloud much smaller cloud particles. Radar data used for the comparison come from two radars, located in the northern, continental part of Croatia. Both radars are S-band, Doppler radars with the beam wavelength of 10 cm.

The difference threshold in the visualisation is set to be 20%. This threshold is empirically set to make the detected areas most similar to the maximum reflectivity observed by radar. If the threshold is set to a lower value, much larger areas appear as "convective", whereas if the threshold would be set higher than 20%, some small cells would not be detected. However, this threshold is still a matter of investigation.

In Fig. 2, SEVIRI 10.8 µm channel image for 09 June 2007 at 11:15 UTC is superimposed with the locations of convective cells as detected by an operational cell detection algorithm based on IR channel data. In the product used operationally for forecasting purposes, the cells are originally marked by the crosses of three different colours, corresponding to the threshold temperatures. However, for the purpose of presentation in black and white, different temperature thresholds have been marked by three different signs. The signs show the position of the centre of the cell and the temperature of the coldest tops. What can be noticed is that most of the detected clouds (marked by a sign at the cell centre) are really convective cells, but some cells are overseen by the IR algorithm. Besides that, some of the large systems, consisting of more cells, are not detected properly and are marked by just one sign. Fig. 3A shows the difference between 0.6 µm and 1.6 µm channel reflectance compared to radar data (Fig. 3B) for the same case of 09 June 2007 at 11:30 UTC. The reason for the time difference of 15 min is the fact that in the original satellite image the time is stated according to the beginning of the scan at the south-pole. The real time of the image for the latitudes presented is about 10 min later than the nominal time of the image. Therefore, the difference product is compared to the radar data 15 min later than the nominal satellite time and the time stated in the product is 15 min later then the nominal time. In the image showing the difference of 0.6 µm and 1.6 µm reflectance (Fig. 3A) several regions of high positive difference are clearly seen. Comparison to radar reflectivity data in Fig. 3B, defines the detected systems as the systems with the highest reflectivity between 40 and 50 dBz and the highest tops reaching 12 to 15 km height. Compared to the detection in Fig. 2 the benefit of the difference method is more precise definition of the single cells within the larger systems.

It has been noticed that this method enables also the detection of small cells in the early development phase, which is a great advantage compared to the methods based on the infrared channel data. An example of this can be found in the case of 03 July 2007. Meteosat 9 IR image for 14:00 UTC is overlaid by signs indicating positions and the cloud-top temperatures of the convective cells, as detected by the IR-

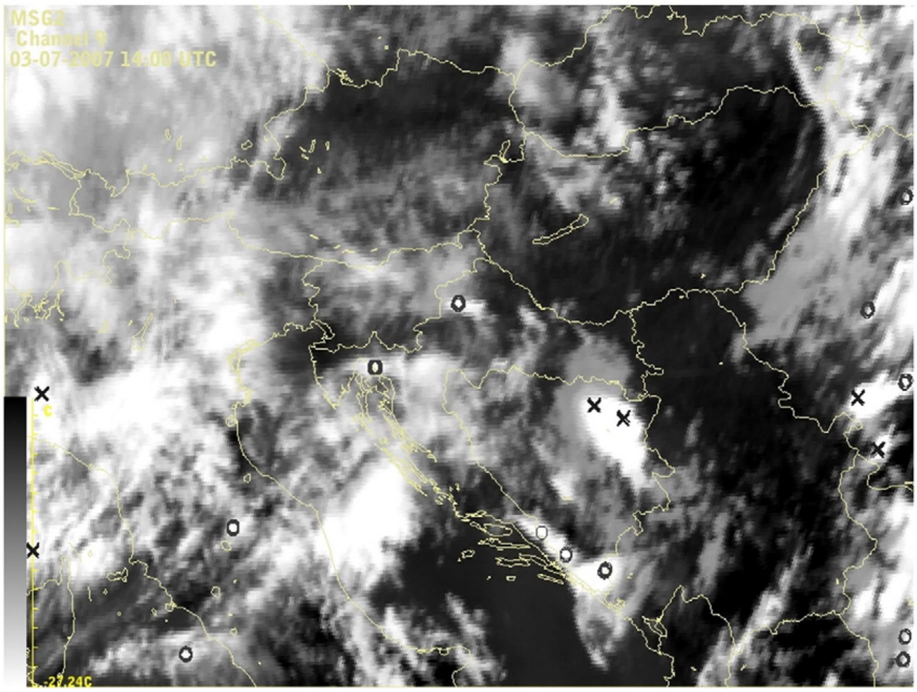

Fig. 4. Meteosat 9 10.8 µm image for 03 July 2007, 14:00 UTC overlaid by the locations of convective cells as detected by an algorithm based on IR satellite data. Different signs show centres of the detected cells and the cloud-top temperature of the coldest tops: + (-33 °C$<T_{top}<-42$ °C), O (-42 °C$<T_{top}<-55$ °C), X ($T_{top}<-55$ °C).

data based algorithm (Fig. 4). In Fig. 5A, in addition to the cells detected by the IR method, there is a small cell in the central Croatia (marked by an arrow) that was not detected by the IR algorithm. Comparison to radar reflectivity (Fig. 5B) shows that convective cell is present at that position, with maximum reflectivity above 50 dBz and top height of about 10 km. Radar image 30 min prior to that time didn't show any signal at the same position, indicating that the detection in the satellite image was almost simultaneous with the occurrence in the radar image.

Following the same development further in time shows that the system developing in Central Croatia, correctly detected by the difference method, was an important system since all further development at that day was triggered at the

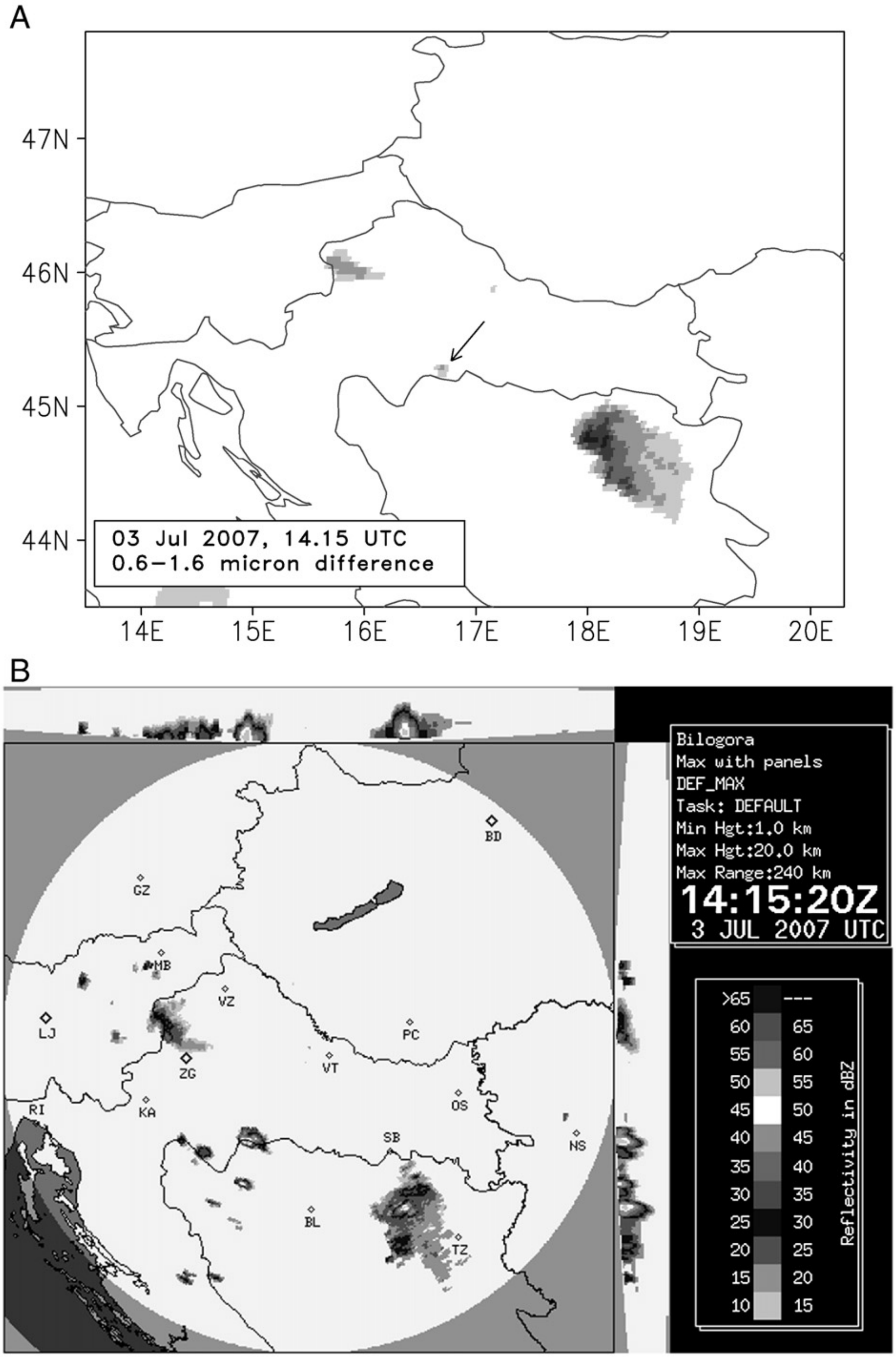

Fig. 5. (A) Difference of reflectance of 0.6 µm–1.6 µm channel for 03 July 2007, 14:15 UTC. Regions with difference >20% are shaded in 10% intervals. The arrow marks the region not detected by the IR algorithm but showing positive 0.6 µm–1.6 µm difference. (B) Corresponding radar reflectivity data for 03 July 2007, 14:15 UTC. Maximum reflectivity product is displayed.

same spot and moved north-westwards. The situation on 03 July at 16:00 UTC is shown in Fig. 6. The difference values are now slightly higher then in the previous images suggesting either that larger ice particles have formed on top of the storms, making the reflectance in 1.6 μm very low, or that reflectance in 0.6 μm is very high. Two systems with large positive differences of 0.6 μm and 1.6 μm reflectance values are detected in the region of northern Croatia (Fig. 6A). The northern of the two consists of two cells which are confirmed by the corresponding radar data (Fig. 6B). The southern system has one bigger, stronger cell and two smaller ones, also seen by the radar. The system at the eastern Croatian border is the remnant of the previously active system, now showing only relatively weak radar reflectivity.

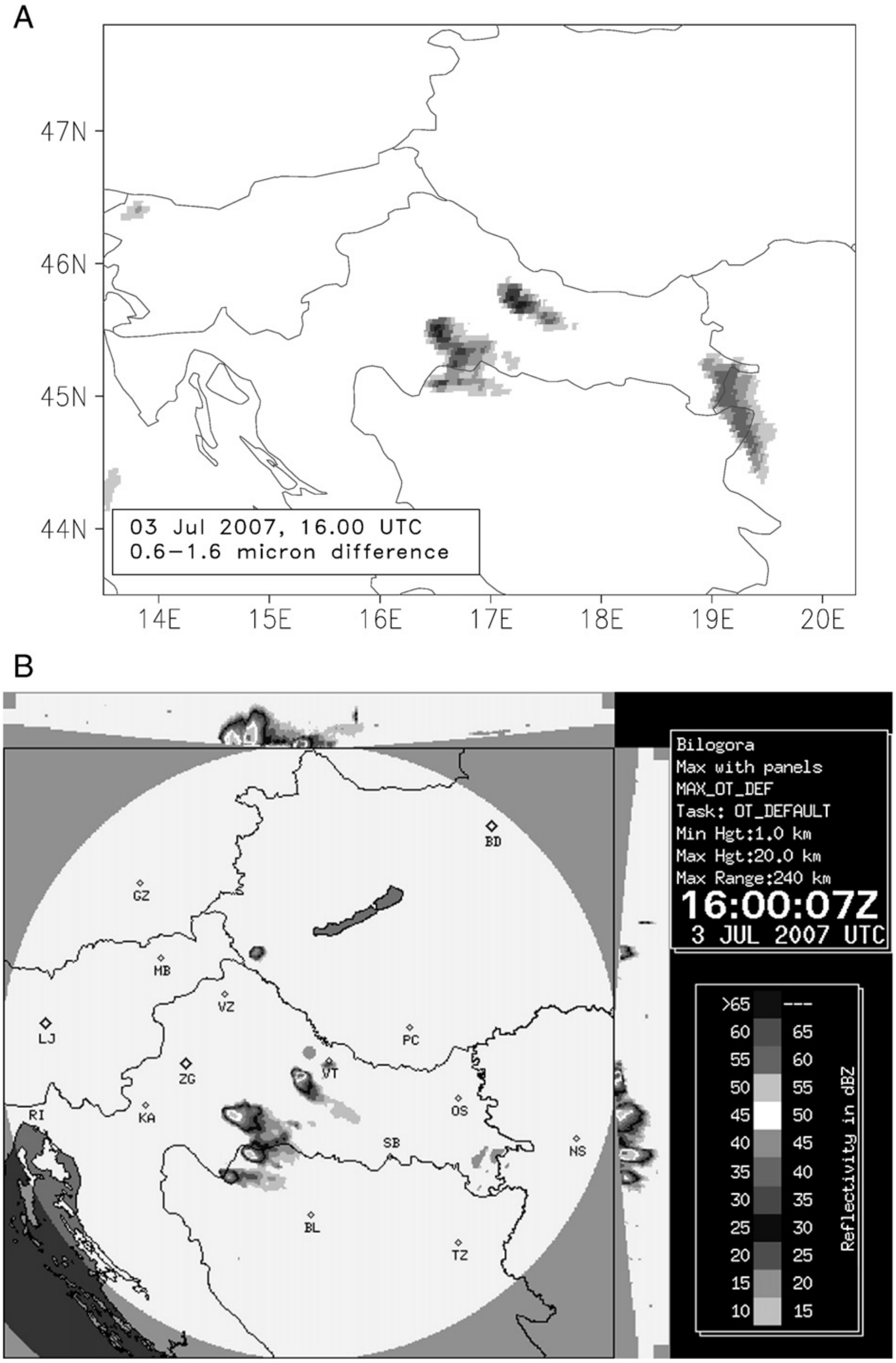

Fig. 6. (A) Difference of reflectance of 0.6 μm–1.6 μm channel for 03 July 2007, 16:00 UTC. Regions with difference >20% are shaded in 10% intervals. (B) Corresponding radar reflectivity data for 03 July 2007, 16:00 UTC. Maximum reflectivity product is displayed.

5. Benefits and applicability

In particular case of the operational forecast in Croatia, a direct benefit of the method is the ability to detect convective cells coming from the sea to the Croatian Adriatic coast. The main problem in that area is the lack of radar observations along the entire coast, except for a very small part of the Northern Adriatic, covered by the radars from the neighbouring Slovenia and Italy. The method of convective cloud detection based on satellite data is therefore very usable in that area. Besides coastal areas, this method seems also promising for mountainous areas where the radar cannot observe clouds developing in deep, narrow valleys.

6. Restrictions and problems

The main restriction of the method is the fact that solar channels can be used only during day-time, therefore another method should be developed for the night-time convection. There are many attempts to resolve night-time convective initiation by using combinations of infrared channels (Mecikalski and Bedka, 2006), but this has still to be applied in the operational use. Another thing that has to be pointed out is the problem with parallax correction which has to be applied in order to make the correct location of the detected systems. The problem, which could be noted in the last example in chapter 4, is also that dissipating systems still cause quite a strong signal in the difference image. The reason for that is the fact that mature convective systems have large anvils made of ice particles with very low reflectance in 1.6 µm channel whereas they still have large reflectance in 0.6 µm channel, indicating that the thresholds should be corrected or the difference results should be combined with some other indicators of convective cells. This matter will be further investigated.

7. Conclusion, discussion and future work

The aim of this work was to present the possibility of using reflectance information from the satellite data in detecting the first signs of convection and thereby to improve the operational automatic convection detection scheme. Investigation of numerous convective cases and comparison to radar reflectivity data showed that the difference of reflectivity in 0.6 µm and 1.6 µm channels gives a good indication of convective cells and can be used in automatic convective clouds detection schemes, provided that thresholds are set properly. Besides 1.6 µm channel, very similar results are obtained when solar component of the 3.9 µm channel is used in the difference. According to many previous investigations (Rosenfeld et al, 2004) solar component of the 3.9 µm channel shows even better performance in identifying the cloud properties. For some cases the difference of reflectance values from 0.6 µm and 3.9 µm channels has been calculated and compared to the difference between 0.6 µm and 1.6 µm channels. The results show that the difference values are much higher when 3.9 µm channel is taken, due to much larger absorption at 3.9 µm than at 1.6 µm. However, there was not much difference in detecting even very small cells in the early development phase. It seems though that the difference of reflectances from 0.6 µm and 3.9 µm channel could be used for identifying the phase in the life-cycle of the convective storm. This has to be further investigated. The efforts in the future will also include testing the method for winter convection cases, since the results in the present work were based on summer convection. Thresholds will be further examined. The results of the difference method will be combined with the IR detection method into one operational product.

Acknowledgements

The authors would like to thank the Austrian Federal Ministry for Education, Science and Culture for financing the project "CONEX II – Extension of an international nowcasting system in the Central Eastern European region"(No.: 45.544/1-VI/6a/2004) in frame of which a part of the research was conducted. We also wish to thank Croatian Ministry of Science, Education and Sports for funding part of the research through Croatian national project "Storms and Natural Disasters in Croatia" (No.: 004-1193086-3036).

References

Jolivet, D., Feijt, A.J., 2003. Cloud thermodynamic phase and particle size estimation using the 0.67 and 1.6 µm channels from meteorological satellites. Atmos. Chem. Phys. Discuss. 3, 4461–4488.

Kerkmann, J., 2005. RGB Composites with Channels 1–11 and their Interpretation. MSG Interpretation Guide, http://oiswww.eumetsat.org/WEBOPS/msg_interpretation/index.html.

Mecikalski, J.R., Bedka, K.M., 2006. Forecasting convective initiation by monitoring the evolution of moving convection in daytime GOES imagery. Mon. Wea. Rev. 134, 49–78.

Nakajima, T., King, M.D., 1990. Determination of the optical thickness and effective particle radius of clouds from reflected solar radiation measurements, part 1: Theory. J. Atmos. Sci. 47, 1878–1893.

Roesli, H., 2004. Introduction to Differences and RGB Composites. MSG Interpretation Guide, http://oiswww.eumetsat.org/WEBOPS/msg_interpretation/index.html.

Rosenfeld, D., Cattani, E., Melani, S., Levizzani, V., 2004. Considerations on daylight operation of 1.6 µm vs 3.7 µm channel on NOAA and METOP Satellites. Bull. Amer. Meteor. Soc. 85, 873–881.

Rosenfeld, D., 2005. Conversion from Counts to Radiances. MSG Interpretation Guide, http://oiswww.eumetsat.org/WEBOPS/msg_interpretation/index.html.