Hrvatski meteorološki časopis – Croatian Meteorological Journal, 42, 2007., 3–13.

Izvorni znanstveni rad

INTEGRATED SEMI-QUANTITATIVE PRECIPITATION ANALYSIS

Integrirana polukvantitativna analiza oborine

DUNJA MAZZOCCO DRVAR[1], ALEŠ POREDOŠ[2] and LOVRO KALIN[1]

[1]Meteorological and Hydrological Service, Zagreb, Croatia
[2]Environmental Agency of the Republic of Slovenia, Ljubljana, Slovenia
drvar@cirus.dhz.hr

Prihvaćeno 22.12.2007. u konačnom obliku 3.3.2008.

ABSTRACT: In their everyday operational work, forecasting offices issue weather warnings at a high update frequency and with very precise geographical specifications. In order to meet these requirements, the analysis system cannot be restricted to stations but needs to be spatially quasi-continuous. In regional nowcasting, an integrated semi-quantitative precipitation field is constructed as a combination of conventional surface observations and radar data, while in areas with no rain gauge data and low radar reliability satellite data are exploited. For this purpose, satellite/NWCSAF precipitation products are validated. An applicable algorithm which would provide semi-quantitative information about rainfall is proposed. The work is being done within the framework of the Central European Nowcasting Project CONEX II.

Key words: nowcasting, precipitation analysis, verification, NWCSAF, INCA

SAŽETAK: U svakodnevnom operativnom radu prognostičari izdaju upozorenja na opasne vremenske pojave i to razmjerno često te uz sve veću geografsku točnost. Da bi to bilo moguće, analitički sustav ne može biti ograničen položajem meteoroloških postaja, već treba biti kvazikontinuiran. U regionalnoj prognozi neposrednog razvoja vremena izrađuje se integrirano polukvantitativno polje oborine kao kombinacija uobičajenih prizemnih motrenja i radarskih podataka, pri čemu se, u područjima gdje nema kišomjera, a radarski podatak ima razmjerno malu vjerodostojnost, koriste satelitski podaci. U tu svrhu provodi se validacija satelitskih NWCSAF oborinskih produkata. U radu se, nadalje, predlaže algoritam koji bi sadržavao polukvantitativnu informaciju o oborini. Rad je proveden u okviru srednjoeuropskog projekta o prognozi neposrednog razvoja vremena CONEX II.

Ključne riječi: prognoza neposrednog razvoja vremena, analiza oborine, verifikacija, NWCSAF, INCA

1. INTRODUCTION

The aim of this study is to validate the precipitation products of the NWCSAF (NoWCasting Satellite Application Facilities) against available data and to construct an algorithm which would provide satellite-based semi-quantitative information about rainfall.

The NWCSAF (http://nwcsaf.inm.es/) is a project team involving experts from Meteo France and the Swedish (SHMU) and Austrian (ZAMG) meteorological services under the leadership of the Spanish Meteorological Institute (INM). This group has developed a software package which contains nowcasting products derived from the MSG (Meteosat Second Generation) and PPS (Polar Platform Satellite) satellite systems. The package includes Cloud, Precipitation, Air mass, Wind, Thunderstorm and Conceptual Model products providing information about cloud-top temperature, height and type, presence of snow/ice, dust or volcanic ash, the probability of precipitation and its estimated rate, total precipitable water, layer precipitable water, instability in cloud-free areas and the classification of air masses.

Since NWCSAF products were not at the disposal of DHMZ when this work was done, data were taken over from ZAMG. Therefore, the analysis was performed for the Austrian area with INCA (Integrated Nowcasting through Comprehensive Analysis) data taken as reference.

INCA (Haiden, 2007) is a high-resolution observation-based analysis and forecasting system. It is conceived to improve the forecasts of surface parameters such as temperature, wind, radiation (cloudiness) and precipitation at short lead times of up to 6 hours. The prerequisite for such a comprehensive nowcasting system is a high-quality analysis, which cannot be restricted to stations but needs to be spatially quasi-continuous.

The verification of precipitation products was performed on the NWCSAF version 1.2 results, for almost 2-month spring data (1 April - 27 May 2006). Qualitative validation was carried out by comparing the products subjectively through several case studies, while quantitative verification was performed by comparing the satellite products with the INCA precipitation field for the corresponding point in time. For that purpose, coarser satellite data were interpolated into the finer INCA grid, resulting in point-to-point verification of a total number of about 760 million events.

2. SHORT DESCRIPTION OF THE PRODUCTS

There are two precipitation products in the NWCSAF/MSG programme package (http://nwcsaf.inm.es, Meteorological Products, PGE04: PC and PGE05: CRR): Precipitating Clouds (PC), showing the probability of precipitation and Convective Rain Rate (CRR), quantifying rainfall from convective clouds. Both products have different night-time and day-time algorithms.

2.1 Precipitating Clouds (PC)

The Precipitating Clouds product is used to determine the likelihood of precipitation using visible and infrared SEVIRI signatures (Spinning Enhanced Visible and Infra Red Imager). The algorithm is divided into two classes, with 0 meaning NO PRECIPITATION (0-0.1 mm/h) and 1 standing for PRECIPITATION (>0.1 mm/h). The PC algorithm is constructed on the basis of pre-existing AVHRR algorithms as a linear combination of spectral features which have the highest correlation with precipitation, with special attention to those in the visible spectrum containing information on cloud microphysical properties at the top (effective radius and cloud phase) and scaled to values 0-10 (0-100%) to show the probability of precipitation. The algorithm is cloud-type dependent and it has different day and night versions, where the night algorithm is identical to AVHRR. On the other hand, the day AVHRR uses 3.7 μm so that there is a shift to SEVIRI's 3.9 μm, resulting in discrepancies. This is one of the intrinsic restrictions of the algorithm. Additional tuning is needed.

2.2 Convective Rain Rate (CRR)

The Convective Rain Rate product is constructed on an empirical thesis: the higher and thicker the clouds, the higher is the probability of precipitation occurrence and intensity. The algorithm is based on a bi-spectral method of rainfall estimate as a function of IR, WV and VIS signal. To exclude homogenous light rain, a filtering process is performed and, taking into account the temporal and spatial variability of cloud tops, the amount of moisture available to produce rain and the influence of orography, several corrections have to be applied. The rainfall rate is divided into classes from 0 to 10, where, for example, values 0-1 imply light precipitation (with a rain rate of 0.0-1.0 mm/h), 2-4 mean imply medium precipitation (2.0-5.0 mm/h) and 5-10 stand for strong precipitation(>5.0 mm/h).

3. OVERVIEW OF PREVIOUS EXPERIENCES

Up to now, most of the product validation work has been done by the developers. The results are given in the Product Assessment Review Papers, available on the NWCSAF web site. Also, extensive verification was performed at the Hungarian Meteorological Service as an Associate Scientist Activity within the NWCSAF. The findings were presented in the referenced papers (Putsay M. and M. Dioszeghy, 2004 and Putsay M. and M. Dioszeghy, 2005). The investigation was widened through correspondence.

The overall conclusion of those diverse investigations is that the product is generally useful when radar is not available, keeping in mind numerous restrictions. Taking into consideration the complexity of the algorithms and their different performance in different synoptic environments, the animation and visual assessment of images is crucial to understand the varying performance of the method and to

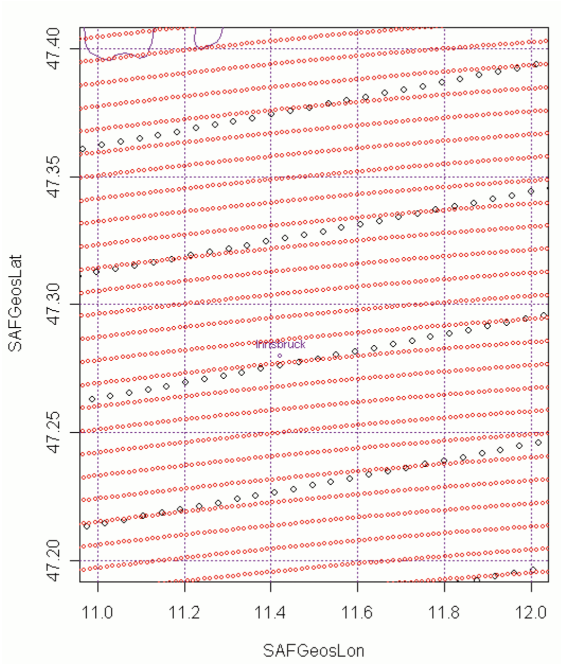

Figure 1. Distribution of the MSG pixel centres (black) and INCA (red) points in their original projections.

Slika 1. Raspodjela centara piksela MSG (crno) i točaka INCA (crveno) u izvornim projekcijama modela.

look into the discontinuity between the day- and night-time algorithms of the PC product.

4. DATA

Data taken as the true precipitation field, INCA, are given in Lambert conical projection at 46°N and 49°N reference latitudes and the central reference point at 47°30' N, 13°20' E. It is a 600 km x 350 km grid, at a resolution of 1 km, giving a total number of 601x351 points. The referent precipitation field INCA is a combination of 5-min radar data from four radars in Austria, in polar-stereographic projection, and 1-min TAWES (ZAMG, 1992) precipitation amounts, retrieved from a network of more than a hundred automatic surface stations all over Austria. Both data are aggregated to 15-min amounts and bi-linearly interpolated onto a regular 1km x 1km grid. The integrated precipitation field is constructed in such a way that it gives as far as possible the observed values at the station locations and reproduces the spatial structure of the radar information in between.

The satellite NWCSAF data are in the GEO satellite projection with the central reference point at 0° N, 0° E. The field is divided into 544 columns and 480 lines giving a total of 261 120 small areas. To be able to make a point-to-point verification, a data set has been produced in which the mean value of each satellite area is presented by pixel centres.

The spatial distribution of the MSG pixel centres and INCA points is shown in Figure 1. The difference in the projections is clearly seen. The extraction of the MSG pixels that fall into the INCA grid gives only 12 002 hits out of 210 951 points in total, which is less than 6%. Since the purpose of the study is the operational use of precipitation fields, smoothing satellite data seemed to be a better solution. A few experiments with different smoothing factors were performed and the test is shown in Figure 2. When the smoothing factor was too small a lot of INCA points were missed, whereas when it was too big some of the fine structures in the data, such as the no-precipitation area in the centre, were lost. Finally, the

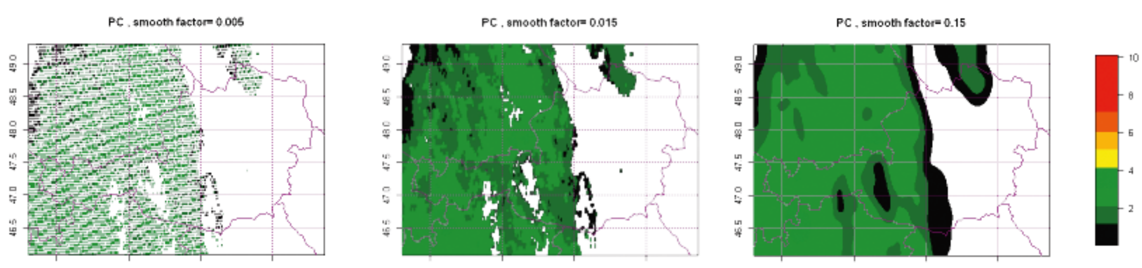

Figure 2. PC data over the Austrian area smoothed by three different factors: 0.005 (left), 0.015 (centre) and 0.15 (right).

Slika 2. Podaci PC iznad Austrije izglađeni s tri različita koeficijenta: 0.005 (lijevo), 0.015 (sredina) i 0.15 (desno).

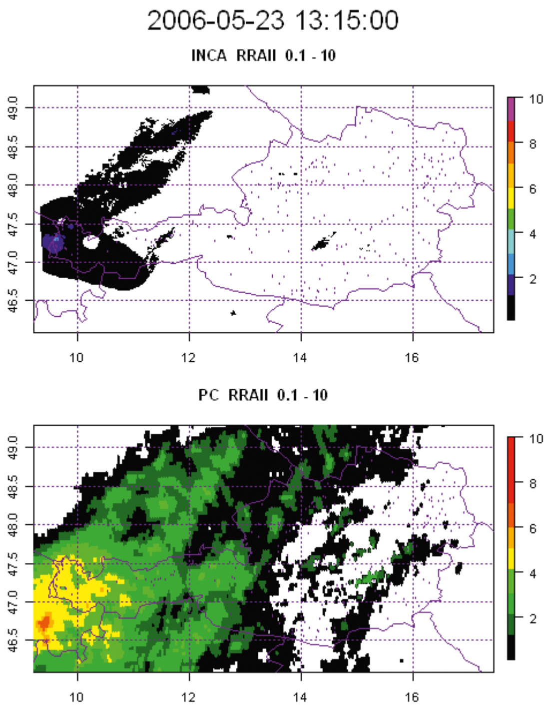

Figure 3. Precipitation area by satellite algorithm, INCA RR (rain rate) in mm/h (top) and daytime PC precipitation probability in values corresponding to %/10 (bottom) for 23 May 2006 13:15 UTC.

Slika 3. Područje s oborinom dobiveno satelitskim algoritmom, INCA RR (jačina oborine) u mmh^{-1} (gore) i dnevna vjerojatnost oborine PC u vrijednostima koje odgovaraju vjerojatnostima u desetinama postotka (dolje) za 23. svibnja 2006. u 13:15 UTC.

smoothing factor 0.015 was chosen as the one which would enable a comparative subjective verification and, at the same time, retain all the fine-scale structures.

5. CASE STUDIES

Following previous experiences and keeping in mind the operational purpose of this work, several synoptic case studies were carried out to test the suitability of the NWCSAF products.

In all the cases considered, a general overestimation of the precipitating area presented by the PC was observed, although mostly smaller than 20 to 30%. One of the numerous examples is presented in Figure 3.

This problem results from the nature of the input data. As explained in 2.1., in the PC algorithm, potentially raining clouds are detected by the NWCSAF Cloud Type product using

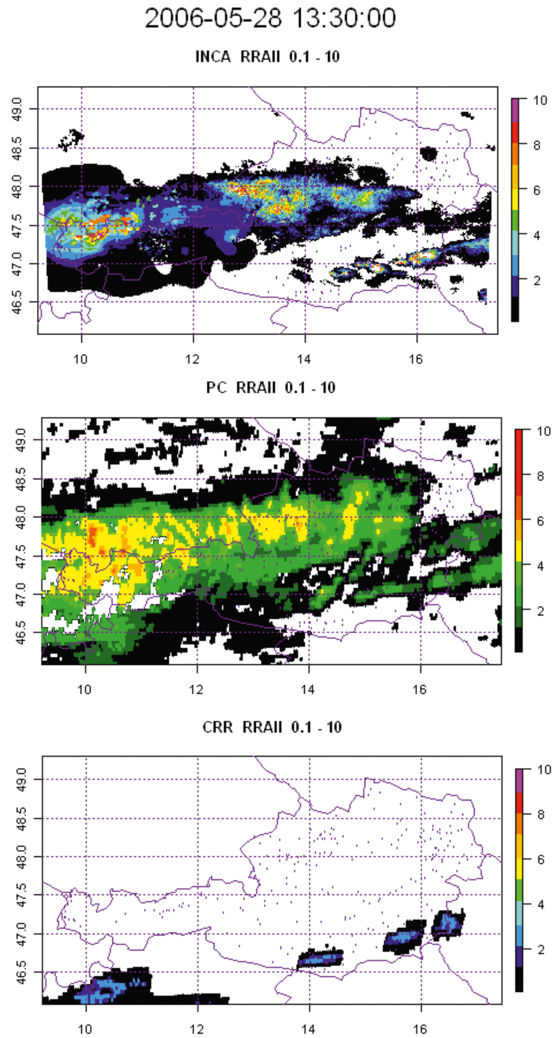

Figure 4. INCA Rainfall Rate for all classes (RRAll) in mm/h (top), PC values (probability in %/10) (middle) and CRR values in mm/h (bottom) for 28 May 2006, 13:30 UTC.

Slika 4. Jačina oborine po INCA za sve klase (RRAll) u mmh^{-1} (na vrhu), vrijednosti PC (vjerojatnosti u desetinama postotka) (u sredini) i jačina konvektivne oborine CRR u mmh^{-1} (na dnu) za 28. svibnja 2006. u 13:30 UTC.

the cloud-top brightness temperature. For the same reason, the CRR rainfall rate is generally exaggerated, but the amplitudes, e.g. the extremes, are highly underestimated. Furthermore, a transition from the night to the day algorithm is observed with clear difference in their performance.

An example of the afternoon term of a cold front case with a squall line, on 28 May 2006, is shown in Figure 4. Not taking into account the

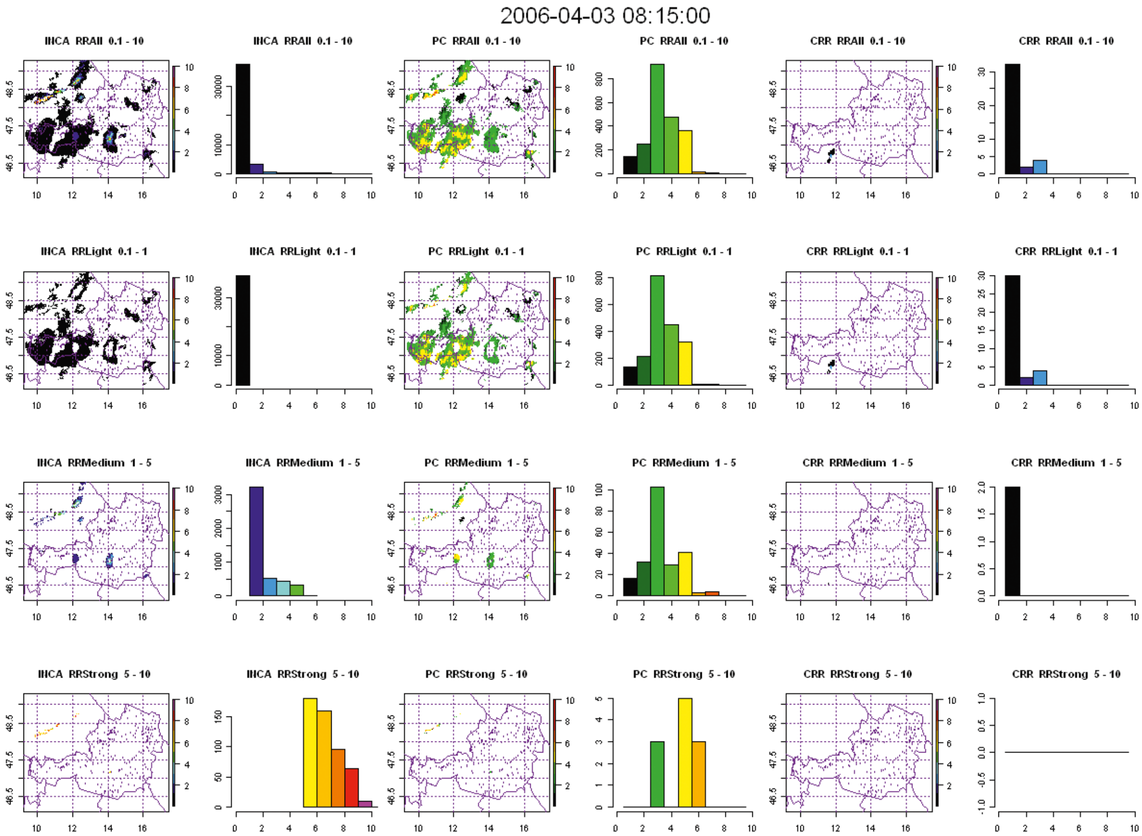

Figure 5. The INCA Rainfall Rate with a histogram in mm/h (two left columns), the PC daytime values with a histogram (two centre columns) and the CRR values with a histogram (two right columns) for the precipitating clouds with a rain rate of 0.1-10 mm/h (upper row) and three separate rain intensity classes: light (second row), medium (third row) and strong (fourth row) for 3 April 2006, 08:15 UTC.

Slika 5. Jačina oborine po INCA s histogramom u mmh^{-1} (dva lijeva stupca), dnevne vrijednosti PC s histogramom (dva središnja stupca) i vrijednosti CRR s histogramom (dva desna stupca) za oborinske oblake s jačinom oborine od 0.1 do 10 mmh^{-1} (gornji red) i tri različita intenziteta oborine, laganu (drugi red), srednju (treći red) i jaku (četvrti red) za 3. travnja 2006. u 08:15 UTC.

area with precipitation likelihood less than 15 % (black in the PC field), we can say that the satellite information was trustworthy. Also, in the CRR field, the area with pre-frontal convergence was detected nicely but the signal appeared about 2.5 hours after the beginning of convective showers. Moreover, the rain rate itself was significantly underestimated

The case of stratiform precipitation, on 29 April 2006, showed quite a good performance of the CRR algorithm. No convective precipitation was detected throughout the day and a negligible signal appeared around midnight. An analysis of the precipitating field presented by the PC confirmed the difference in behaviour of the night and day algorithms found in previous investigations. The day algorithm significantly outperforms the night one. Moreover, a pronounced daily trend in the PC was found, with the likelihood of precipitation being the highest at midday. A further investigation of the connection between precipitation probability and sun elevation angle can be found in Chapter 6.

Figure 5 shows the early stage of a convective event on 03 April 2006. It is clearly visible that, in the morning hours, the PC was higher when the rainfall rate was bigger, giving up to 70% probability in areas with stronger precipitation.

At this stage, the CRR was performing quite poorly. Later that day (Figure 6), the convection progressed and the PC got significantly higher. The CRR vastly improved, although it clearly overestimated light and underestimated medium and strong precipitation.

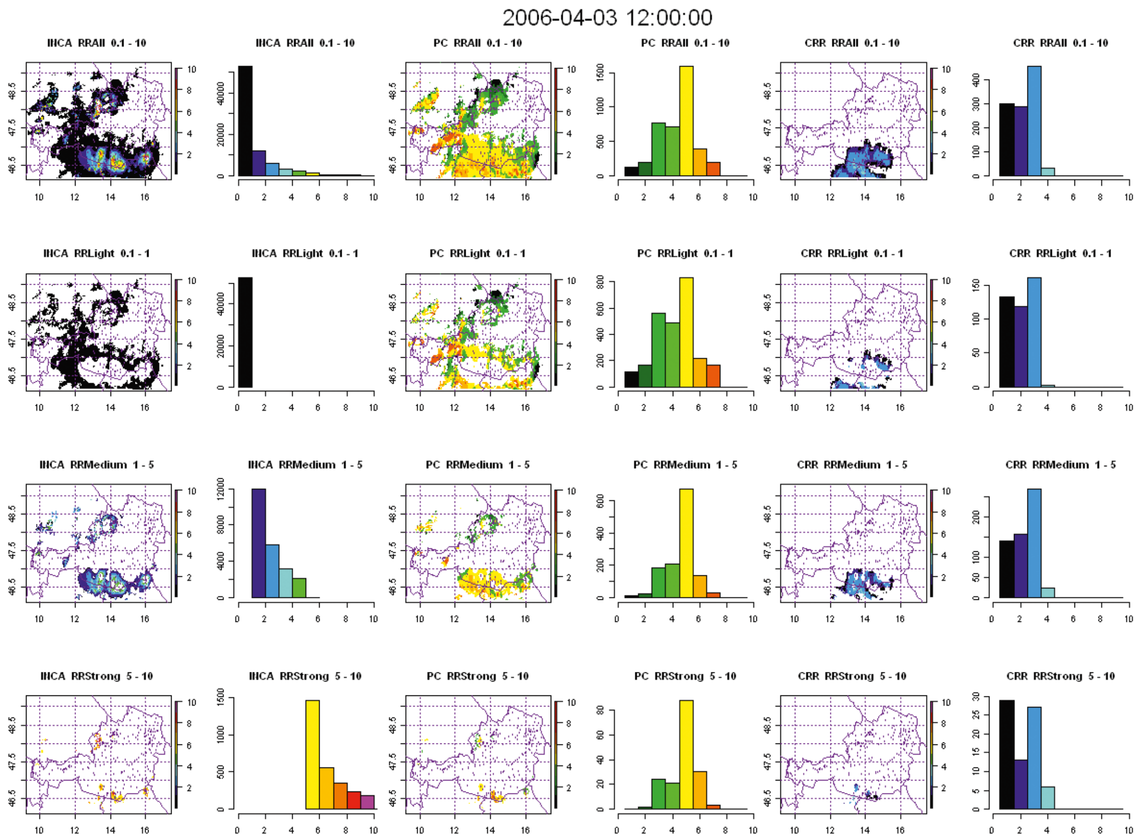

Figure 6. The INCA Rainfall Rate with a histogram in mm/h (two left columns), the PC daytime values with a histogram (two centre columns) and the CRR values with a histogram (two right columns) for the precipitating clouds with a rain rate of 0.1-10 mm/h (upper row) and three separate rain intensity classes: light (second row), medium (third row) and strong (fourth row) for 3 April 2006, 12:00 UTC.

Slika 6. Jačina oborine po INCA s histogramom u mmh^{-1} (dva lijeva stupca), dnevne vrijednosti PC s histogramom (dva središnja stupca) i vrijednosti CRR s histogramom (dva desna stupca) za oborinske oblake s jačinom oborine od 0.1 do 10 mmh^{-1} (gornji red) i tri različita intenziteta oborine, laganu (drugi red), srednju (treći red) i jaku (četvrti red) za 3. travnja 2006. u 12:00 UTC.

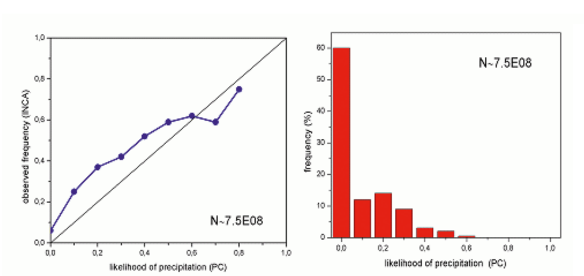

Figure 7. Reliability diagram (left) and frequency (right) of precipitation probability by the PC night and day algorithm.

Slika 7. Dijagram pouzdanosti (lijevo) i učestalost (desno) vjerojatnosti oborine PC, noćni i dnevni algoritam.

6. VERIFICATION

Objective verification was performed on an extensive data sample of over 210 000 spatial points, 4 times in an hour, 24 hours a day, for 48 spring days, covering stratiform and convective precipitation cases. For the PC the following tests were done: precipitating area, reliability diagram with histogram, smaller lowland area with stratiform precipitation and good radar coverage, as well as the daily trend. For the CRR, bias, ME, MAE and distribution, the same tests excluding the CRR=0, day and night algorithms were investigated separately.

The reliability diagram on the right-hand side of Figure 7 confirms the anticipated general

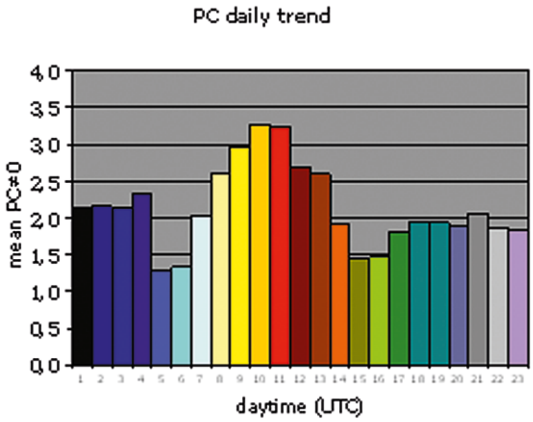

Figure 8. Daily dependence of precipitation probability PC≠0.

Slika 8. Dnevna ovisnost vjerojatnosti oborine PC≠0.

underestimation of PC precipitation probability. The Satellite-retrieved likelihood of precipitation fits well the observed ratios: for lower likelihood (probabilities 5 to 60%), the satellite underestimates and for higher likelihood (probabilities >60%) it overestimates. However, it should be taken into consideration that a number of PC signals bigger than 6 is negligible.

The frequency histogram on the left-hand side shows that there is a huge portion of no-precipitation cases, 60%.

To test precipitation likelihood for no rain, light, medium and strong rain events, further tests were done. To be able to compare raining areas for the purpose of this and further investigations a rather hard condition is imposed on the PC. Even though small PC values represent only a small probability of precipitation, PCÆ0 values are taken as NWC SAF raining events. For no-rain events (INCA=0 mm/h) the PC was true (PC=0) in 65% of all cases. For light rain (INCA=0.1-1 mm/h) the PC was bigger than 0 in 70% of cases, for medium intensity (INCA=1-5 mm/h) as well as for strong rain (INCA>5 mm/h) in around 87% of all events. This confirms the subjectively retrieved results where, in general, the PC performs better when the rain rate is bigger. However, for all three intensity classes, the most recurrent probability is 30%, and its relative frequency also grows with the rain rate.

Considering the reliability of the data, it was necessary to check the dependence of the results on the quality of the INCA precipitation field which was taken for reference. Therefore, the same investigation was performed in the case with large-scale precipitation for the area with better radar coverage in North-western Austria. The results show an even bigger underestimation, with a likelihood of precipitation still only around 20%.

Since the dependence of precipitation probability on the time of day was observed by subjective verification, it had also to be tested objectively.

For this purpose, the PC precipitation likelihood data equal or bigger than 1 for 10% probability (excluding non-precipitation cases) were classified per hour, where 1:00 to 1:45 UTC was set as 1 UTC, 2:00 to 2:45 UTC as 2 UTC and so forth. From the histogram in Figure 8, it is clearly visible that the PC is the lowest from 5 to 6 and from 15 to 16 UTC, when is switches from the night to the day algorithm. Also, the night algorithm is quite stable with probabilities mostly around 20%, while the day algorithm has a pronounced trend, with performance increasing up to 32% with the increase of sun elevation.

Table 1. Ratio of the PC and INCA area for different PC thresholds.

Tablica 1. Odnos područja PC i INCA za različite pragove vrijednosti PC.

PC >	0.1	1	1.5	1.8	2	2.2	2.4	2.5	2.6	3	3.2	4	4.5	5
Day + Night	2.2	2.2	2.1	1.5	1.4	0.8	0.8		0.8	0.7				
Day	2.6	2.5			1.7					1.2	0.6			
Night	1.9	1.9			1.4			0.5		0.4				
Med. Prec.					8.4			4.6		4.3		1.8	0.9	0.8

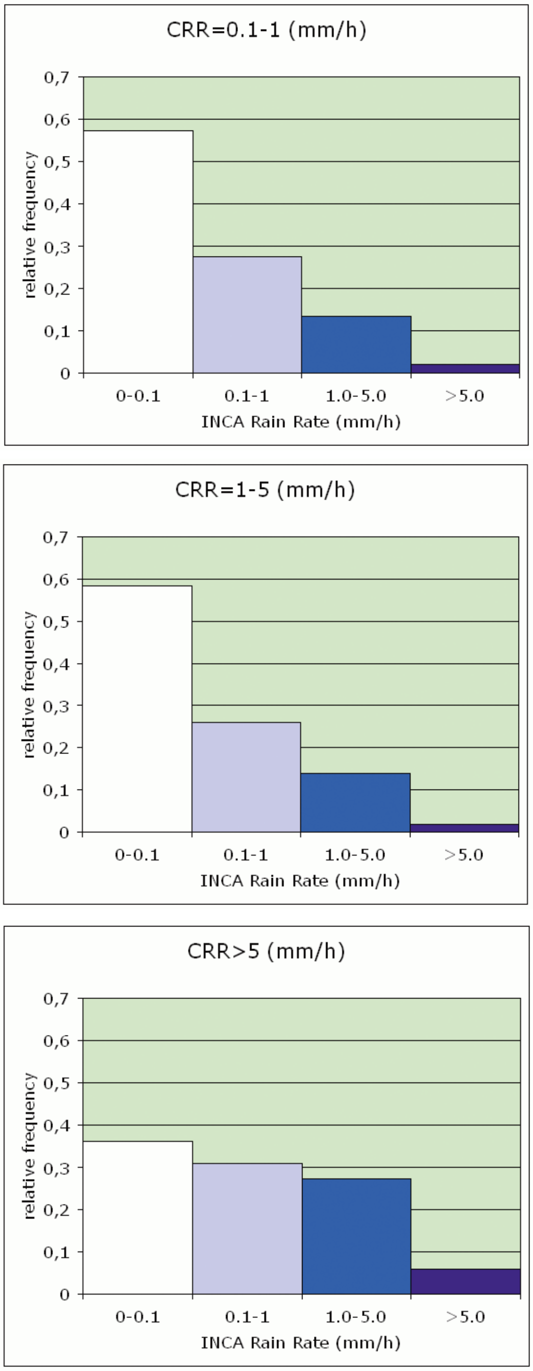

Figure 9. The histogram of the NWCSAF CRR in mm/h indicating light (top), medium (middle) and strong (bottom) precipitation compared to the corresponding real precipitation classes.

Slika 9. Histogram učestalosti pojavljivanja NWCSAF CRR u mmh^{-1} za laganu (gore), srednju (sredina) i jaku oborinu (dolje) u ovisnosti o odgovarajućim klasama izmjerene oborine.

This might be the result of a natural trend in precipitation itself. Anyhow, a verification was performed of the April and May data. In spring, at mid-latitudes, frontal cases are much more frequent than convective ones. Even more so, the PC maximum is reached from 10 to 11 UTC, far too early for strong convective events. Hence, no connection between the maximum likelihood and actual rain occurrence is expected and this effect is considered to be the result of some deficiency in the algorithm.

To be able to provide some guidelines for the use of the product, objective verification has been carried out of the overestimation of the precipitating area found in the subjective verification and presented in Figure 3. The verification proves that the ratio between the NWCSAF raining field estimated by satellite (PC≠0) and the actual precipitating area (INCA≠0) is 2.18. To adjust the PC/INCA ratio to the value of one, further tuning was done. The results show that the areas correspond for the day algorithm, when PC≅3, for the night algorithm, as well as the day and night algorithms taken together, when PC≅2, and for the cases with medium precipitation, when PC≅4.5. This information leads to some operationally useful conclusions.

To verify the behaviour of the CRR algorithm, a data sample with CRR^{1}0 was selected. The reason for excluding CRR zero values is simple. Namely, the CRR can be equal to zero when there is either no convective cloud or the cloud is convective but the algorithm gives zero value.

This testing, presented in Figure 9, showed that a signal of light precipitation from NWCSAF CRR is proven only in 27%, of medium precipitation in 13% and of strong precipitation in 6% of the total number of cases. The results differ slightly for the day and night algorithms. Satellite information is, therefore, considered poor and of questionable operational use.

7. CONCLUSIONS AND APPLICATION ALGORITHM

Using the conclusions given in the above discussions to create some guidelines for the operational use of NWCSAF data, one must be aware of the restrictions of the validation performed. First of all, verification was done

Table2. The PC and CRR values (when reliable) considered best for representation of the rain field with light, medium and strong precipitation. Three periods of the day have been taken arbitrarily: the night period from 18 to 04, the day period from 05 to 17 and midday from 10 to 12 UTC.

Tablica 2. Vrijednosti PC i CRR (kad su podaci pouzdani) koje se smatraju najboljima za prikaz polja lagane, srednje i jake oborine. Tri razdoblja u danu odabrana su proizvoljno, pri čemu noć traje od 18 do 4, dan od 5 do 17, a sredina dana od 10 do 12 UTC.

	Light	Medium	Strong
Night	PC>1 CRR>2	PC>2 CRR not reliable	PC>4 CRR not reliable
Day	PC>3 CRR>2	PC>4 CRR not reliable	PC>4 CRR not reliable
Midday	PC>3 CRR>2	PC>4 CRR not reliable	PC>6 CRR not reliable

point-to-point, which is not the happiest solution for precipitation fields. Furthermore, the samples had different resolutions and for that reason interpolation of the coarser resolution data onto higher resolution was needed. In addition, only 50 days were taken, but the sample is huge (millions of events) and representative (stratiform and convective precipitation) so that it is not considered to be a limiting factor. One should also keep in mind that the results are very version-dependent, so that a study like this should be done with every new version of the NWC SAF programme packages.

To give information of the best possible quality, the applicable algorithm should consist of an integrated field with overlapped PC and CRR values above certain thresholds. Taking into account the subjective and objective validation performed, the values given in Table 2 are proposed.

The resulting semi-quantitative precipitation analysis field is shown in Figure 10. The available data are combined in a kind of "poor man's analysis" showing the probable area of light, medium and heavy precipitation. PC probability thresholds are used to define the raining area.

Although the CRR has been found to be unreliable, in some case studies it was evaluated as surprisingly good. Since the algorithm is supposed to work operationally, it cannot automatically differentiate convective cases from non-convective ones. Therefore, CRR information is kept when constructing the analysis field, but the user should keep in mind its nature and drawbacks.

Despite the fact that it is not conceptually and visually ideal, this product offers a general idea of the reliability of satellite data (in the areas where INCA is available, namely in Austria). Consequently, one gets a hint of the most probable precipitation situation in the areas not covered by radar and conventional measurements (in this case, neighbouring countries).

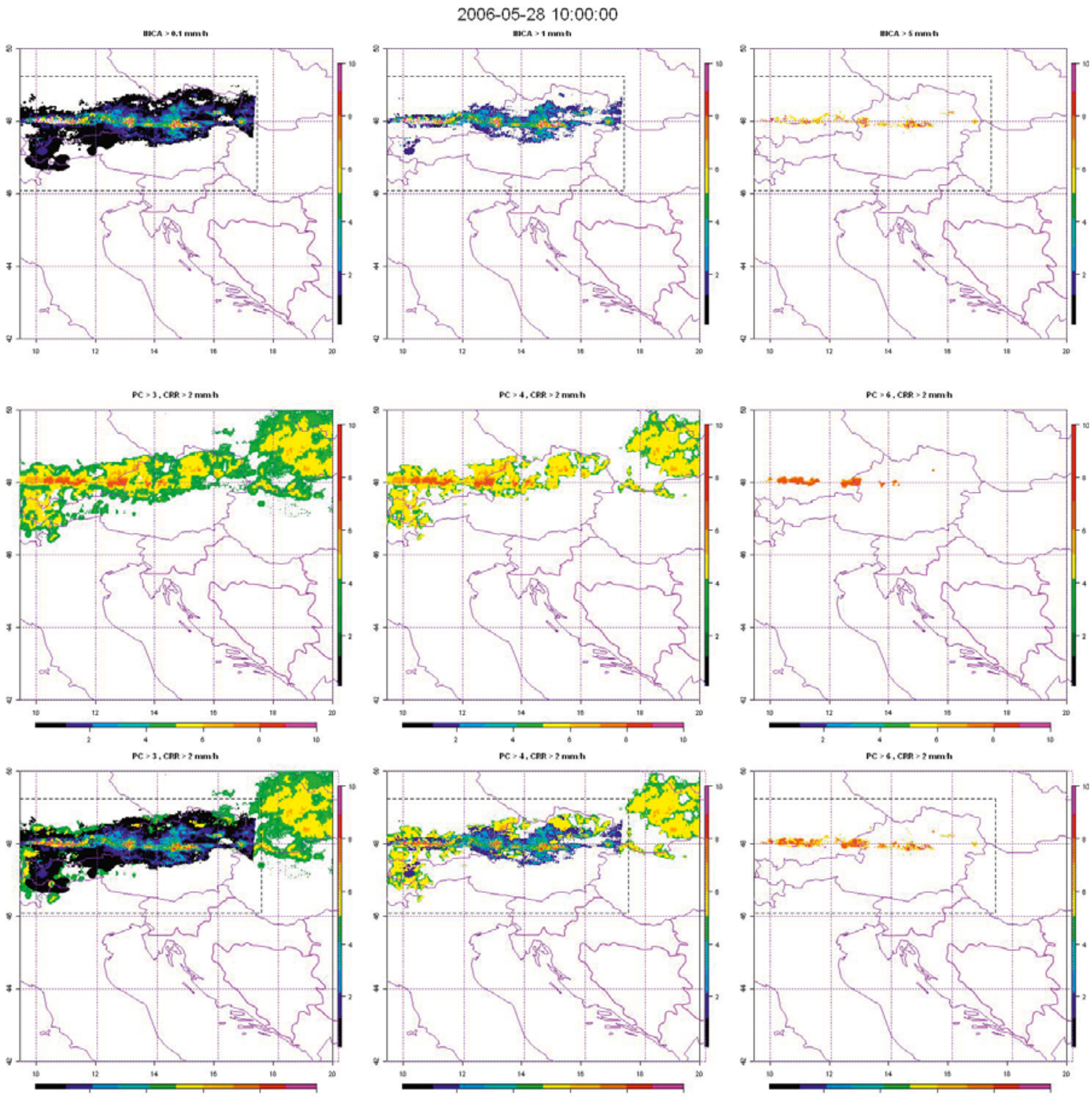

Figure 10. An example of the operational product constructed from available data for 28 May 2006, 10:00 UTC: the INCA rain rate (first row), the PC and CRR (second row) and a combination (third row) for light (left column), medium (center) and strong (right) precipitation. The PC and CRR thresholds are defined through validation. The dashed line indicates the area covered by INCA data.

Slika 10. Primjer operativnog rezultata modela konstruiranog iz raspoloživih podataka za 28. svibnja 2006. u 10:00 UTC: jačina oborine INCA (prvi red), PC i CRR (drugi red) i kombinacija (treći red), za laganu (lijevi stupac), srednju (sredina) i jaku oborinu (desno). Pragovi za PC i CRR dobiveni su validacijom. Crtkana linija prikazuje područje gdje postoje podaci INCA.

REFERENCES

Haiden, T., et al., ZAMG: Integrated Nowcasting through Comprehensive Analysis (INCA): System overview, 2007, http://www.zamg.ac.at/fix/INCA_system.doc

Putsay, M. and M. Dioszeghy, HMS: Report on the validation of the MSG Precipitating Clouds Product with Hungarian Radar data and data exchange for the tuning of the PC product, Budapest, 17 DEC 2004, http://nwcsaf.inm.es, Visiting Scientist Activities, Reports

Putsay, M. and M. Dioszeghy, HMS: Validation of NWCSAF/MSG Precipitation Products with Hungarian Radar and Tipping Bucket Rain gauge data, 30 OCT 2005, http://nwcsaf.inm.es, Visiting Scientist Activities, Reports

Scientific report on the checking and tuning of the MSG PGE04, SAF/NWC/IOP/SHMI/MSG/SCI/RP/02, Issue 1, Rev. 2, 13 May 2005, available on web, http://nwcsaf.inm.es

Scientific report on the checking of the MSG PGE04 version 1.2, SAF/NWC/IOP/SHMI/MSG/SCI/RP/03, Issue 1.1, 28 Nov 2006, available on web, http://nwcsaf.inm.es

Software User Manual for PGE04 of the NWCSAF/MSG: Scientific Part, SAF/NWC/IOP/SHMI/SCI/SUM/04, Issue 1, Rev. 2, 13 May 2005, available on web, http://nwcsaf.inm.es, Meteorological Products, PGE04: PC

Software User Manual for PGE05 of the NWCSAF/MSG: Scientific Part, SAF/NWC/IOP/SHMI/SCI/SUM/05, Issue 1, Rev. 2, 9 May 2005, available on web, http://nwcsaf.inm.es, Meteorological Products, PGE05: CRR

Zentralanstalt fuer Meteorologie und Geodynamik, 1992: TAWES Teilautoma-tisches Wettererfassungssystem der Zentralanstalt fuer Meteorologie und Geodynamik. ZAMG, Publ. Nr. 344,74 pp.