Proceedings for the 2018 EUMETSAT Meteorological Satellite Conference,
17-21 September 2018, Estonia, Tallinn

FULLY AUTOMATED QUANTITATIVE ESTIMATION OF CLOUD TOP HEIGHT USING STEREOSCOPIC METEOSAT SATELLITE OBSERVATIONS

Ján Kaňák

Slovak Hydrometeorological Institute, Jeséniova 17, Bratislava, Slovakia

Abstract

EUMETSAT provides perfect stereoscopic data from Meteosat 10 (Basic service) and Meteosat 8 (IODC service) over large areas of Central and East Europe, Middle East Asia, central and South African regions from 2016. Meteosat 11 will continue in filling this dataset together with Meteosat 8 from March 2018. The presentation will describe proposed experimental product, which is using AMV algorithm (Atmospheric Motion Vectors) to detect mutual parallax shifts of clouds in coupled imagery. This product is based on previous investigations of manual measurements of parallax shifts, which were presented at EUMETSAT 2017 conference in Rome. Parallax shifts are currently calculated for 32x32 pixel boxes over 16x16 pixels grid, but are planned to be tested for smaller/optimized boxes and grid spacing. Fully automated calculations over the big regions covered by dual satellites observations can serve as important supplement data to other methods and products like NWCSAF Cloud Top Height and Cloud Type, or shadows length based estimations of cloud top heights. Algorithm is working not only with HRV but also with other (IR and VIS channels) data. Considering 12 SEVIRI channels we obtain very wide experimental set of dual satellite parallax shifts for different cloud types and heights. New, third generation of geostationary satellites with finer image resolution and global coverage bring us to new possibilities how to combine and use more efficiently overlapping satellite fields of view.

DUAL SATELLITE VIEW AND STEREOSCOPIC SATELLITE IMAGE

During summer 2016 Meteosat 8 was moved to its new geostationary position at 41.5E for continuation of IODC services. From October 4, 2016 new satellite constellation of Meteosat 10 at 0° and Meteosat 8 at 41.5° is available for stereoscopic observations over large areas defined by 0 and 41.5E meridians and works within wide latitudes interval, from Northern Europe down to South Indian Ocean, including equatorial regions of Africa. Correct stereoscopic images can be created after re-projecting image data from both satellites into common map projection. In our work Albers equal-area projection was used.

RELATION OF DUAL SATELLITE PARALLAX TO THE CLOUD TOP HEIGHT

Using one satellite we can estimate parallax shift of cloud but we need additional parameter to know – the cloud top height. Using two satellites, which are observing the same cloud from different positions in space, we have enough geometrical information to estimate real horizontal cloud position and also real cloud height. In our work we realized this estimation by numerical iteration process – calculations of the horizontal distance between two lines connecting the satellites and the cloud in different elevations – with the aim to find the height of minimum distance between both lines. It is intercept point in optimal case, but the precise position of lines in our model depends on satellite image resolution and its geo-referencing, therefor we are looking just for minimum distance of these lines instead of their cross-point. Examples of such estimations are shown in *Figure 1*.

It should be noted the relation: Higher cloud →bigger parallax →higher cloud top height.

Visual method is inconvenient and subjective. Instead automatic calculations can be used in next steps:

- To detect parallax shifts
- Calculate cloud top height

Required are:

- Precise image geo-referencing
- Appropriate algorithms to detect clouds shifts
- High computing resources

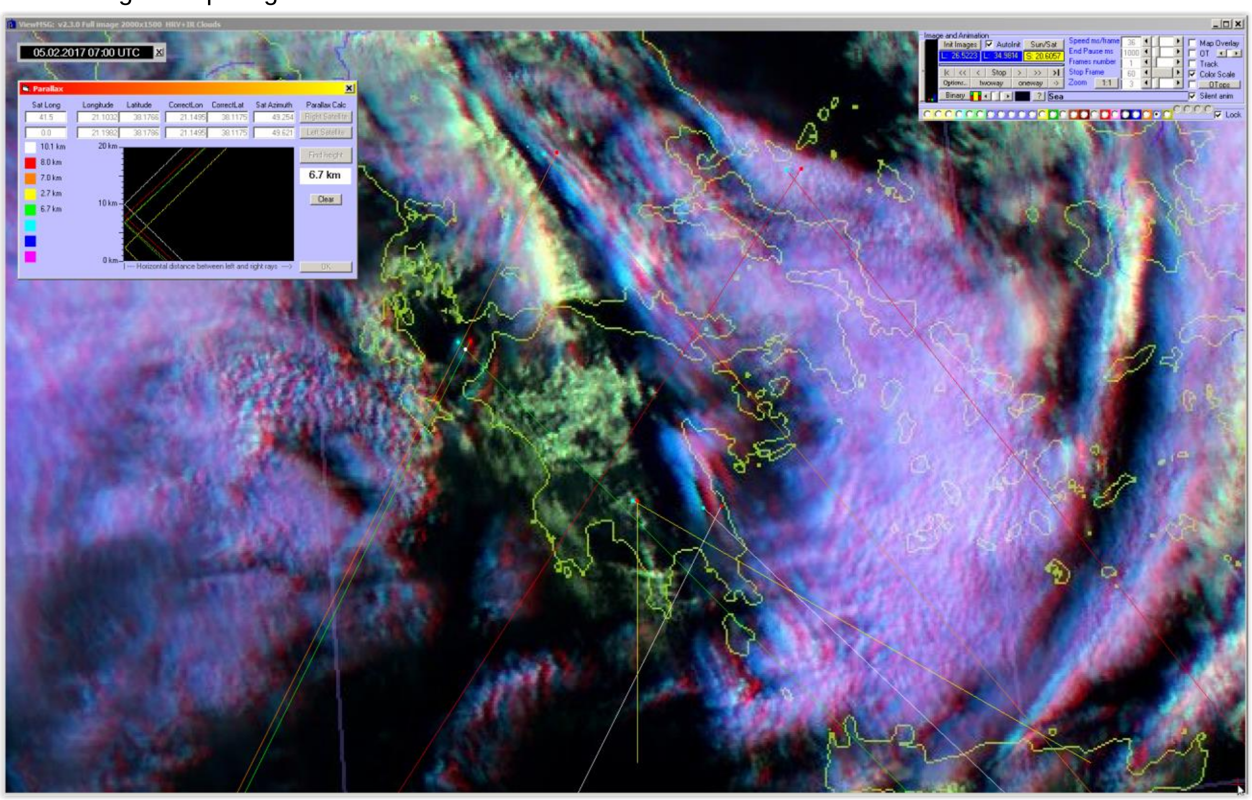

***Figure 1*: Clouds over Greece 5.2.2017 07:00 UTC. Measured were values: 10.1, 8.0, 7.0, 2.7, 6.7 km.**

MATHEMATICAL BACKGROUND FOR CALCULATIONS AND USED ALGORITHMS

The parallax correction functionality needs the following inputs:

Satellite height above the Earth's center (in km): h_{sat}

Latitude of sub satellite point: φ_{sat}

Longitude of sub satellite point: λ_{sat}
Height of the observed cloud (in km): h_{cloud}
Assigned latitude of the cloud in satellite geo-referenced image: φ_{cloud}
Assigned longitude of the cloud in satellite geo-referenced image: λ_{cloud}

The parallax correction functionality produces as output:
Parallax corrected latitude of the cloud in geo-referenced image: $\varphi_{cloud,corr}$
Parallax corrected longitude of the cloud in geo-referenced image: $\lambda_{cloud,corr}$

The following geo-projection parameters are required:
Earth radius, equator (in km): R_{equ}
Earth radius, pole (in km): R_{pole}
Mean Earth radius (in km): $R_{mean}=0.5\ (R_{equ} + R_{pole})$
Radius ratio: $R_{ratio} = R_{equ} / R_{pole}$

Full description including equations is available if EUMETSAT CWG web side in document written by M. Koenig: https://www.essl.org/cwg/res/parallax/DescriptionOfTheParallaxCorrectionFunctionality.pdf
Here we provide only list of partial calculation steps:
Step 1: Express satellite position in Cartesian coordinates
Step 2: Express the measured cloud position in Cartesian coordinates
Step 3: Compute local ratio of Earth radii, corrected for cloud top height (squared)
Step 4: Compute the difference vector between the satellite and the cloud position
Step 5: Compute the correction for the line of sight at the cloud top height h_{cloud}
Step 6: Apply correction to Cartesian coordinates of cloud position
Step 7: Convert corrected Cartesian coordinates back to latitude and longitude

Also FORTRAN source code was provided by EUMETSAT but in this work calculations we encoded using C language.

Finally repeat steps 1 to 7 for both left and right satellite positions and then apply iteration process described in previous section - relation of dual satellite parallax to the cloud top height.

The most important part of automatic processing is algorithm for detection of mutual cloud parallax shift in left and right image. For this purpose we used AMV algorithm originally intended for detection of cloud movement in time sequence of images. AMV algorithm was developed in the frame of CEI Nowcasting project; see J. Kaňák (4) and M. Benko at all (5). Example of AMV algorithm applied to dual satellite Meteosat HRV images is shown in *Figure 2*. Blue vectors correspond to mutual parallax shifts of cloud fields and their length is related to cloud top height measured in this case again in manual way. Main difference is that while manual estimations are available for cloud edges only, AMV outputs are possible for inner surfaces of clouds.

16X16 VERSUS 8X8 PIXELS AMV STEPS AND PRODUCT EXAMPLES

AMV algorithm in this case is necessary to parametrize for proper work with HRV Meteosat imagery and we tested two options – spacing with 16 and 8 pixels image steps. This means that motion (parallax shift) vectors are calculated for each 16^{th} or each 8^{th} pixel in vertical and horizontal direction in the image.
List of parameters is shown in *Table 1* and examples of results for both options are shown in *Figure 3*.

Parameter:	Option 1: Step 16x16	Option 2: Step 8x8
Correlation window size	33	33
Span of possible displacements	36	36
x-coordinate of first column	32	32
y-coordinate of first row	32	32
x-difference between vectors	16	8
y-difference between vectors	16	8
number of vectors in x-direction	122	244
number of vectors in y-direction	91	182

***Table 1*: List of parameters for AMV algorithm. Option 1 use 16-pixels step, option 2 8-pixels step.**

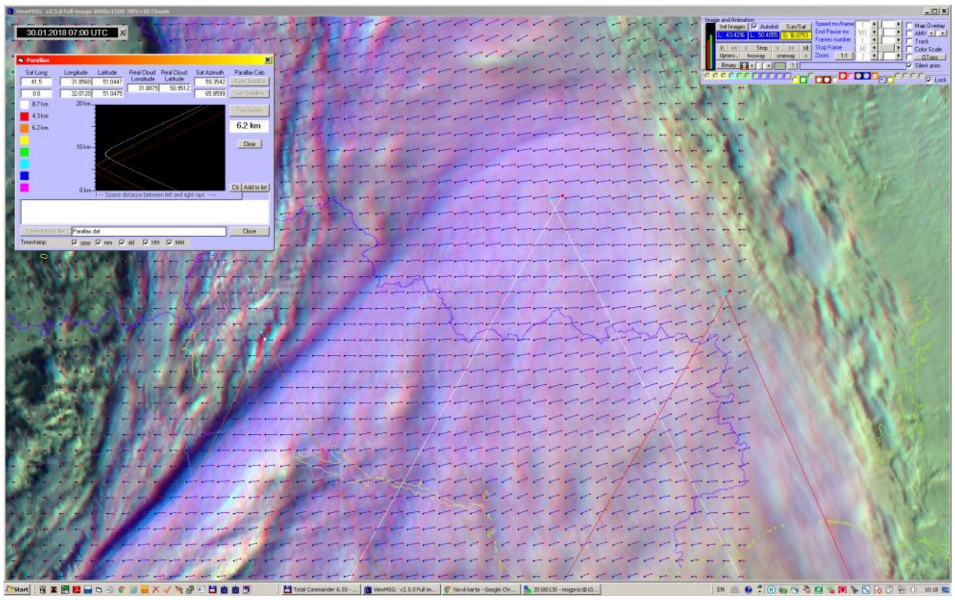

***Figure 2*: Example of AMV algorithm applied to dual satellite Meteosat HRV images.**

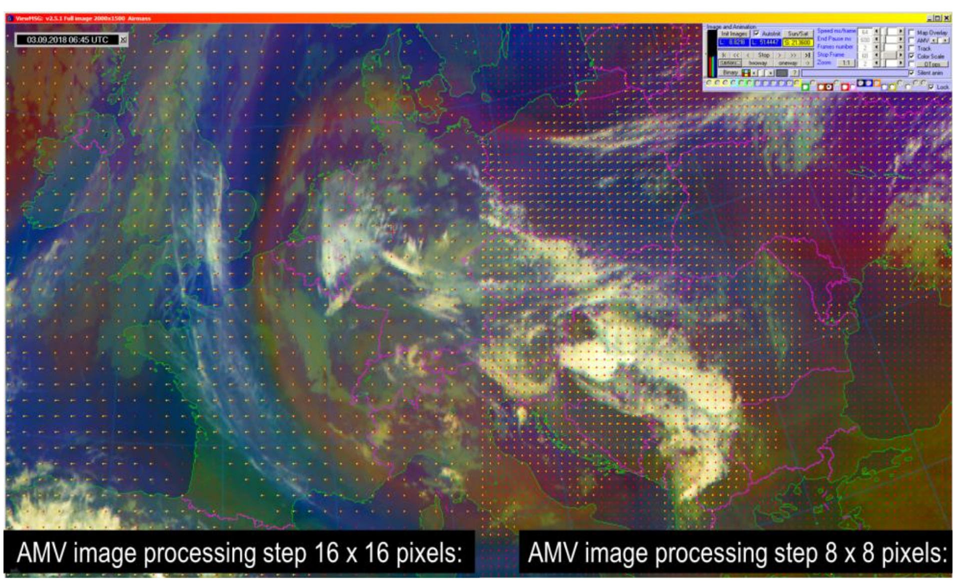

***Figure 3*: Example of AMV algorithm results for option 1 (16-pixels step) and option 2 (8-pixels step).**

IMPACT OF MSG SEVIRI IMAGERY RECTIFICATION TO PROPER DUAL PARALLAX ESTIMATIONS

HRV image resolution is 1 km and this is also theoretical limit how precisely we are able to estimate mutual parallax shifts and cloud height. Mainly east-west image shifts influence significantly our final results. Therefore we propose to perform image geo-referencing tests before calculations of parallax shifts. On *Figure 4* we demonstrate improper rectification of Meteosat 8 HRV image data with significant west to east dislocation.

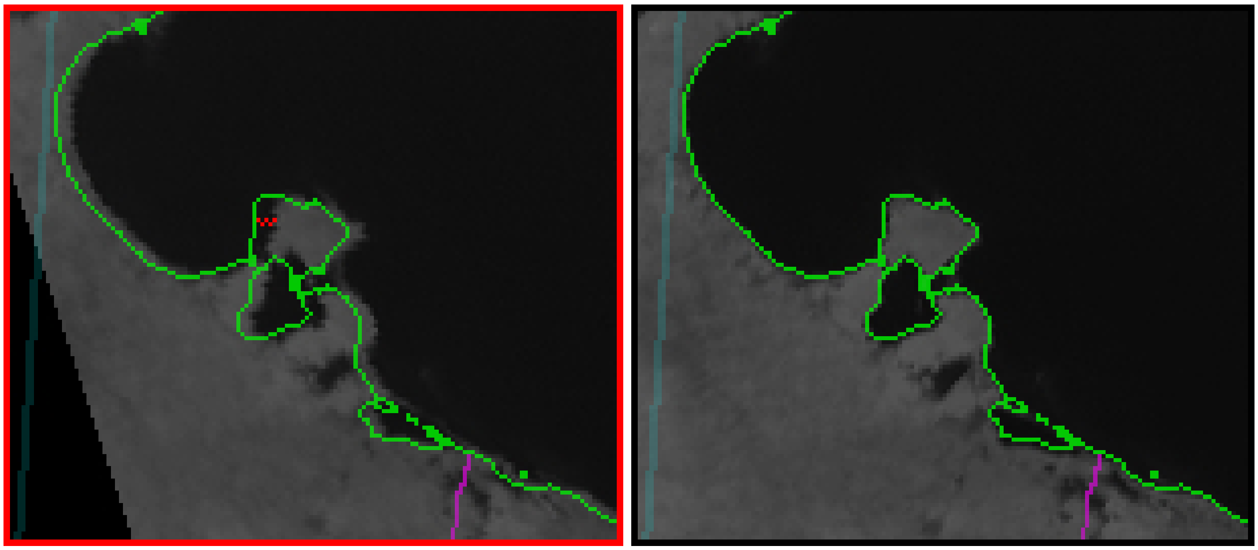

***Figure 4*: Processed Meteosat images at SHMU by MSGProc software, HRV 28.2.2018 11:00, Meteosat-8 41.5E degree and Meteosat-11 0 degree, upper HRV window. Evident dislocation is in let image, which is about 5km and strongly affects precision of detected mutual cloud parallax shifts.**

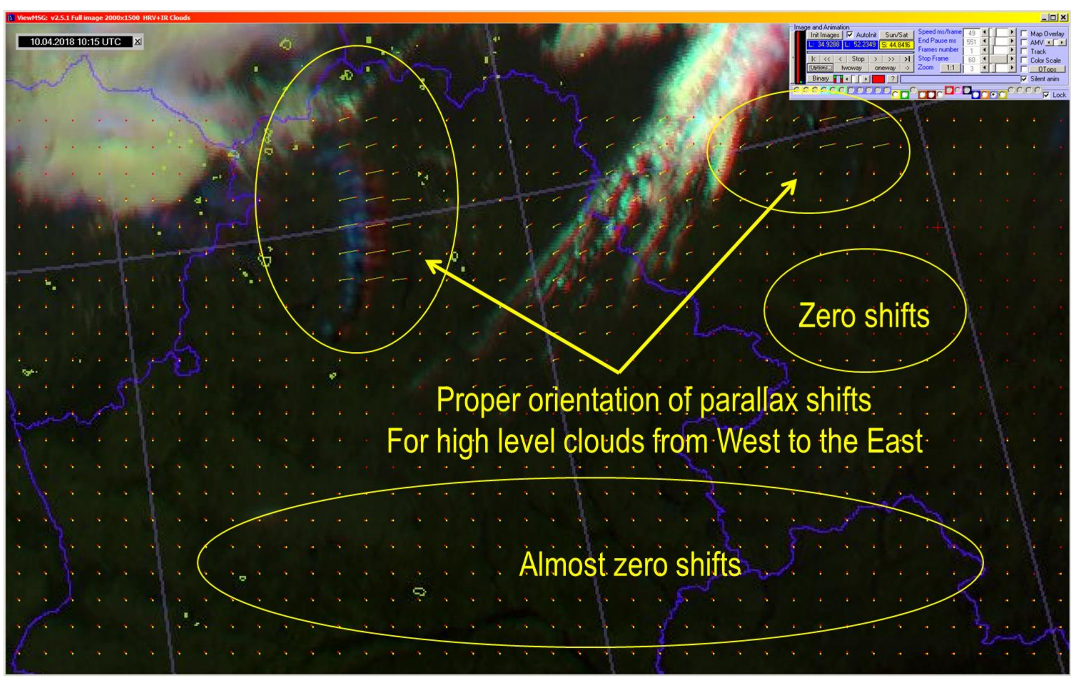

***Figure 6*: Proper orientation of vectors which indicate parallax shift is result of geolocation corrections during image post processing.**

COMPARISON TO NWCSAF CTH PRODUCT AND METEOROLOGICAL CONSEQUENCES

We prepared the database of CTH values for number of MSG timeslots from several days: 15 and 18 March 2017, 5 April, 24 May and 6 June 2017. For coupling parallax measurements with NWCSAF CTH values we used method of minimum geometrical distance. Prepared database contains 3477 single points. Using the database we calculated several statistical parameters to estimate relative precision of 3D parallax method against NWC SAF CTH method. Results of correlation and bias together with number of cases for different cloud type categories are shown in *Table 2*.

Cloud type	Cloud index	Number of cases	Bias [km]	Correlation [%]
All clouds	ALL	3477	-0.60	0.70
Very low clouds	5	32	2.00	0.31
Low clouds	6	300	0.93	0.49
Mid level clouds	7	531	0.27	0.58
High opaque clouds	8	990	-0.62	0.56
Very high opaque clouds	9	154	-0.78	0.39
High semitransparent thin clouds	11	207	-1.16	0.47
High semitransparent meanly thick clouds	12	389	-1.34	0.53
High semitransparent thick clouds	13	565	-1.38	0.48
High semitransparent above low or medium clouds	14	309	-0.94	0.50

***Table 2*: Comparison cloud height by parallax method against NWCSAF CTH for different cloud types.**

If we consider different cloud types (classified by NWCSAF Cloud Type algorithm) and evaluate cloud top height differences for each cloud type separately, using correlation and bias we can say that the best performance of cloud top estimations are for mid-level clouds and high opaque clouds. Most problematic we found very low clouds and semitransparent thick clouds. In first case geolocation of image data strongly affects estimations of mutual parallax shifts, in second case localization of semitransparent clouds is problematic due to big uncertainties of diffused cloud boundaries. Overall statistical results are showed also in plot on *Figure 6*, from which we found that 40% of cases are in the interval of bias ± 1 km.

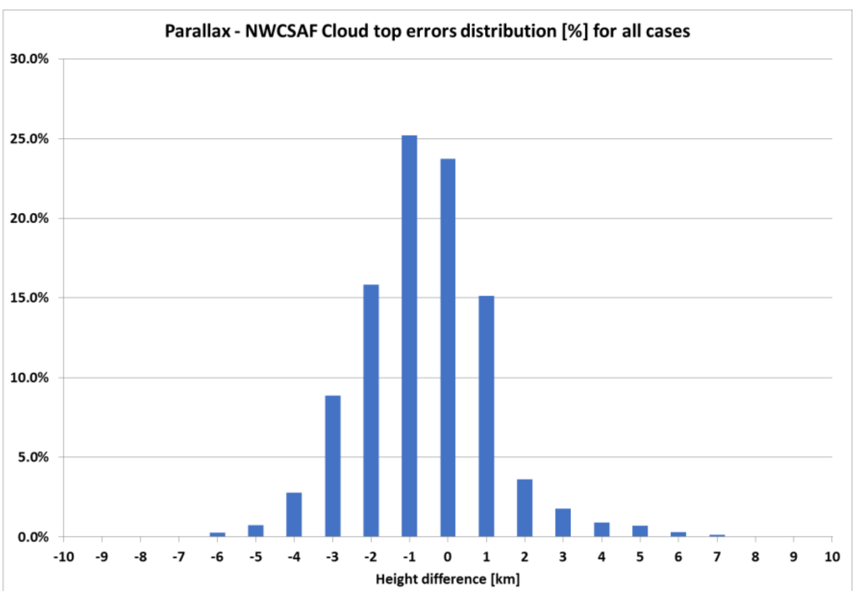

***Figure 7*: Bias distribution for Parallax based CTH and NWCSAF CTH values as final output from statistical evaluation.**

CONCLUSIONS

Satellite images play very important role in weather analyses and forecasting. Raw images from single satellite channels contain partial geometrical information only. There are various opportunities of image processing and image combinations with the aim to put more qualitative information together into one single image. Some satellite constellations provide additional possibilities how to enhance our view from space into the atmosphere to monitor cloud formations. It is up to us how to use these options effectively.

REFERENCES

1. Hasler, A.F., 1981. Stereographic observations from geosynchronous satellites — an important new tool for the atmospheric science. Bull. Am. Meteorol. Soc. 62, 194–212.
2. Fujita, T.T., 1982. Principle of stereoscopic height computations and their applications to stratospheric cirrus over severe thunderstorms. J. Meteorol. Soc. Jpn. 60, 355–368.
3. Kaňák, J., Okon, Ľ., Setvák, M., Diószeghy. M., Nietosvaara, V., 2017. Scientific and application potential of stereoscopic imagery based on METEOSAT satellites. Proceedings for the 2017 EUMETSAT Meteorological Satellite Conference, 2-6 October 2017, Rome, Italy.
4. Kaňák, J.: Tracking algorithms for Meteosat data as a CEI Nowcasting tool. The 2004 EUMETSAT Meteorological Satellite Conference, Abstract Brochure, page 75, Praha, 31 May-4 June 2004.
5. Benko, M., Jurašek, M., Kaňák, J., Simon, A., Vivoda, J., 2005: Development of nowcasting techniques at SHMÚ. WWRP Symposium on Nowcasting and Very Short-Range Forecasting, 5-9 Sept. 2005, CNRM Toulouse, France. Abstracts, 225
6. André Simon, Martin Benko, Ján Kaňák, Marián Jurašek, Jozef Vivoda:Methods of nowcasting and very short range forecasting at SHMÚ. Meteorologický časopis (Meteorological Journal), Volume 8, No.3, pp. 137-142, SHMI Bratislava 2005.
7. Kaňák, J. – Okon. Ľ. – Setvák, M. – Diószeghy, M. – Nietosvaara, V.: Potential of stereoscopic imagery based on Meteosat Second Generation satellites. 9th European Conference on Severe Storms – ECSS 2017. Pula, Chorvátsko, 18.-22. september 2017.