USING METEOSAT SECOND GENERATION HIGH RESOLUTION VISIBLE DATA FOR THE IMPROVEMENT OF THE RAPID DEVELOPPING THUNDERSTORM PRODUCT

Oleksiy Kryvobok *
Ukrainian Hydrometeorological Institute
Kyiv, Ukraine

Stephane Senesi
Meteo-France, DPREVI/PI
Toulouse, France

Christophe Morel
Meteo-France, DPREVI/PI
Toulouse, France

1. INTRODUCTION

The paper presents the results of the use of High Resolution Visible (HRVIS) channel data of MSG for the improvement of the discrimination of convective systems from all the tracked clouds systems in the Rapid Developing Thunderstorm (RDT) product.

The principle is to estimate of young convective cloud parameters due to the increased spatial resolution of the HRVIS channel (1 km at sub-satellite point against 3 km for the other channels). This should allow the HRVIS channel to describe smaller clouds than the IR10.8 channel and improve the earliness of the first detection of convective systems during their growing phase in order to be able to warn and provide information to a forecaster when severe weather may occur.

2. CLOUD FRACTION ESTIMATION USING VISIBLE DATA

2.1 Basic definitions of cloud fraction estimation using visible data

The radiance, measured by a satellite radiometer above a partly cloudy covered pixel at visible wavelengths \( I_{\text{VIS}} \), is given by

\[
I_{\text{VIS}} = N \times I_c + (1-N) \times I_{\text{clear}}
\]  

(1)

where \( N \) – the part of pixel covered by cloud, \( I_c \) - the radiance sensed from the cloudy part of pixel, \( I_{\text{clear}} \) - the radiance sensed from the clear sky part of pixel.

After calibration of satellite data we rewrite Eq. (1) in terms of reflectance \( R \) as

\[
R_{\text{VIS}} = N \times R_c + (1-N) \times R_{\text{clear}}
\]

(2)

where \( R_{\text{VIS}} \) - the measured reflectance, \( R_c \) - the top of atmosphere (TOA) reflectance of cloud, \( R_{\text{clear}} \) - the TOA reflectance of clear sky surface.

The cloud fraction \( N \) is evaluated from Eq. (2) as

\[
N = \frac{R_{\text{clear}} - R_c}{R_c - R_{\text{clear}}}
\]

(3)

From Eq. (3) the cloud fraction is determined by \( R_c, R_{\text{clear}} \). In our further reasoning \( R_c \) is TOA reflectance of fully cloudy pixel and \( R_{\text{clear}} \) is TOA reflectance of clear sky pixel.

2.2 Clear sky pixel TOA reflectance

We used the “clear sky nearby pixel method” for the estimation of clear sky TOA reflectance. The idea of the method is to find the clear sky pixel on
the image, which has the same or almost the same TOA reflectance as the cloudy contaminated pixel, in the case if the latter would be cloud free. It is well-known that TOA reflectance in visible channels is determined by surface reflectance and atmospheric contribution. We use the visible reflectance map (Gutman et al., 1995), the land cover map and monthly atmospheric integrated water vapour content climatology data (Oort, 1981) to find the most representative cloud free nearby pixel. The visible reflectance map and the land cover map are used to find the cloud free pixel which has the closest surface reflectance as a cloudy pixel on HRVIS image, because the reflectance map for this channel is not available. We proceed from the supposition that cloudy and the cloud free pixels have the same surface reflectance, if they belong to the same category on land cover map and have the minimal difference in visible reflectances. TOA reflectances of two pixels will be the same, if the integrated water vapour content difference will be minimum in over these pixels.

This approach is applicable for low (VIS0.6, VIS08) and for high resolution (HRVIS) data over a small domain around the pixel of interest where satellite and sun angles are almost constant. For VIS06 data we use only the visible reflectance map, because the map and data are obtained in the same spectral region. For VIS08 data we use only integrated water vapour content information, because spectral reflectance in the channel is very low over sea (where this data are used).

Comparison with methods based on Radiative Transfer Model (RTM) calculation shows (Kryvobok, 2005) that the nearby clear sky pixel reflectance, which is observed by satellite itself, is more plausible that simulated by RTM, because this value corresponds to the real atmospheric state instead of simulated one, which is based mostly on climatological data.

2.3 Estimation of fully cloudy pixel reflectance

The estimation of fully cloudy pixel reflectance is based on simulation of cloudy reflectance on TOA by RTM. Theoretical modeling and real observations (Cahalan et al., 1994; Kobayashi, 1993; Riihimaki, 2001) show that for optically thick cloud (>100) TOA reflectance to a great extent, does not increase with further increase of optical and geometrical thicknesses of cloud. Convective clouds are really optically thick, even if their geometrical size is not so large (O’Hirok et al., 1998). After the review of last studies (Rosenfeld et al., 1998; Hess et al., 1998) we have found the observed typical values of convective clouds properties, which we used for the RTM calculation of fully cloudy reflectance. We consider in our computation the convective cloud, which is equivalent to the growing cumulonimbus about 700m height.

2.4 Cloudy pixels diagnostic on visible channels

We use threshold technique for cloudy pixel diagnostic. Threshold technique is based on a pixel by pixel analysis of radiance and comparison of this value with a threshold. The pixel is classified as cloud contaminated if a value of measured radiance is more than a threshold. One of the main advantage of the threshold method is that it is relatively easy to adapt thresholds to varying meteorological conditions, viewing geometry using external data (NWP data, RTM calculation, climatological atlas). According to the Wielicki and Parker (1992) the reflectance threshold in visible channels is the most sensitive for low clouds identification. As they noted a reflectance threshold can be used efficiently for cloud altitudes below 3 km. The tests are applied to the visible or near-infrared TOA reflectances aim to detect clouds having a reflectance higher than the underlying surfaces. The visible reflectance threshold is better to use over land, where cloud free reflectance is not so high and less dependent on vegetation, near infrared reflectance threshold is better to use over the sea, because the solar reflection over sea is very low. These thresholds are calculated using RTM depending on different atmospheric states, viewing geometry and different kind of surfaces. In order to get more realistic threshold values, which can be pre-computed we need to add TOA reflectance a pre-defined margin (to account for noise and variation of surface reflectance).

3. METHODS OF CLOUD FRACTION ESTIMATION FROM SEVIRI DATA

3.1 Estimation of pixel cloud fraction as mean value of N high-resolution pixels

The cloud fraction estimation of a low resolution pixel is based on the estimation of the cloud fraction of each high resolution pixel in the corresponding low resolution pixel. For each high
resolution pixel we estimate the cloud fraction $N_{HR}$ as

$$N_{HR} = \frac{(R_{0.75} - R_{\text{threshold}0.75})}{(R_{0.75} - R_{\text{threshold}0.75})}$$

(4)

where $R_{0.75}$ - the reflectance of HRVIS pixel, $R_{\text{threshold}0.75}$ - the threshold reflectance, $R_{0.75}$ - the reflectance of the fully cloud covered HRVIS pixel.

We used the abbreviation High resolution Cloud Fraction Field (HCFF) for the cloud fraction field estimated from HRVIS data.

The cloud fraction ($N$) of low resolution pixel is

$$N = \frac{\sum_{i=1}^{9} N_{HR,i}}{9}$$

(5)

where 9 - is the number of HRVIS pixels inside one low resolution.

It is the most suitable method for the cloud fraction estimation of small convective clouds. The accuracy of the method depends on the threshold reflectance and $R_{0.75}$. We used the abbreviation Converted Cloud Fraction Field (CCFF) for cloud fraction field estimated using this method.

3.2 Estimation of cloud fraction using low resolution VIS data

Data of VIS0.6 channel is preferable for cloud fraction estimation over land, because cloud free reflectance is not so high and less dependent on vegetation

$$N = \frac{(R_{0.6} - R_{\text{threshold}0.6})}{(R_{0.6} - R_{\text{threshold}0.6})}$$

(6)

Data of VIS0.8 channel is used over sea, because the solar reflection over ocean is very low

$$N = \frac{(R_{0.8} - R_{\text{threshold}0.8})}{(R_{0.8} - R_{\text{threshold}0.8})}$$

(7)

where $R_{\text{threshold}0.6}$, $R_{\text{threshold}0.8}$, $R_{0.6}$, $R_{0.8}$ the reflectance thresholds and fully cloudy pixels reflectances for corresponding channels (VIS0.6, VIS0.8).

The method gives a reasonable result for clouds with a size comparable of a pixel size, but it depends on a threshold reflectance and $R_{0.6}$. We used the abbreviation Low resolution Cloud Fraction Field (LCFF) for the cloud fraction field obtained from low resolution data.

4. DESCRIPTION OF CLOUD CONVECTIVE SYSTEMS

We have studied two developing convective systems on 4 July 2004. These systems were observed over North part of Africa (Figure). The first system (indicated as I on Figure) is an example of the very rapid developing thunderstorm characterized by continuous growth of one cloud from 11:15 to 12:00 UTC. Only few very small clouds are observed at 11:00 UTC and in the next 15 ÷ 45 min they merged and became as one very large mature convective cloud. The dynamic of the development of this system is shown on Figure. On the RDT product the system was detected first at 11:30 UTC with corresponding characteristics: phase of development – growing, min temperature – 46°C. At the next 15 min it was detected also as growing with a min temperature – 52°C and at 12:00 UTC the system was detected as decreasing with a min temperature – 50°C. The second convective system (indicated as II on Figure) was located close first one. This system is characterized by isolated small convective clouds, which began to merge in a mature phase of their development. They began to grow, the most rapidly, at 12:00 UTC. At 12:15 UTC the cloud system is consisted from some smaller convective clouds, which begin to merge. This convective system is much smaller than the first one. First detection on the RDT product was at 12:15. Characteristics of the second system on the RDT product were the following: phase of development – growing, min temperature – 37°C.
5. ANALYSIS OF CLOUD FRACTION FIELD

a) Convective system I.
The cloud fraction field of convective system I shows that at 11:15 UTC there are some cloudy objects on the images. They are characterized by small convective clouds of few pixels size. We obtained inhomogeneous cloud fraction fields over the region. The values of HCFF are almost 100%. It means that some of convective clouds were as large as few pixels and well developed. On low resolution images the values of cloud fraction fields are max 79% (CCFF) and 56% (LCFF). On the next images the cloud fraction fields are characterized by increased values 100% and by increased number of pixels, which cloud fraction value are 100%. Clouds merged and cloud fraction field became more homogeneous with decreased values on the edge of the clouds, where partly cloudy pixels are located. This was observed on HCFF and CCFF from 11:30 to 12:00 UTC. The values of LCFF are not higher than 90-95% for this period of time.

We have also analyzed the evolution of HCFF over the small domain (6x6 HRVIS pixels). The analysis shows that at 11:15 UTC when very intensive cloud formation (appearance of small clouds) was the HCFF was inhomogeneous. The values of cloud fraction are varying from 2 to 92%. There were an intensive development and a merging of small clouds on the next images. The cloud fraction became homogeneous with values about 100%.

a) Convective system II.
The convection development of the convective cloud system II was not so obvious. The cloud fraction fields on low resolution images are inhomogeneous with values from 14 to 29% at 11:30 UTC and even 78% at 12:00 UTC. On the contrary on HCFF at 11:30 UTC these values are
65% (32 ÷ 42 for CCFF). On the next images we see continuous increase of cloud fraction values, which are 100% (100% for CCFF) at 12:00 UTC. The dynamic of the cloud fraction field of small cloud over the domain (9×9 HRVIS pixels) shows that between 11:15 and 11:30 UTC we can not see any constant center of development of convective cloud. The values of HCFF are varying from 6 to 64%. Very likely those clouds dissipated or moved outside the domain after formation. An intensive formation of the clouds began at 11:45 UTC, half of pixels became cloudy with cloud fraction values from 2 to 93%. Then, when clouds developed and merged (12:00 UTC), HCFF became homogeneous, mostly, with high values (80÷100%).

In respect to that the main task of the study is to find the usefulness of HRVIS data for the RDT product to improve an earliness of first detection of convective systems during their growing phase, we analyzed more detailed the cloud fraction field earlier than was the first detection on the RDT product. As already noted, the first detection of the convective system I was at 11:30 UTC and the convective system II - at 12:15 UTC. Analysis of the cloud fraction field at 11:15 UTC for the convective system I (15 min before the first detection on the RDT product) shows that the highest cloud fraction values (HCFF) are reached 92% (five pixels, less than one low resolution). For CCFF and LCFF the maximum values are 78 and 56 correspondingly, all other values are much less. Analysis of the cloud fraction field at 11:45 and 12:00 UTC for the convective system II shows that the cloud fraction values are reached about 90%, 30 minutes before (5 pixels) and, 15 minutes before (almost for all pixels), the first detection on the RDT product. Correspondingly, CCFF values are reached 70% (one pixel), ≈80÷90% (3 pixels) and LCFF values are 41% (one pixel), 78% (one pixel).

Thus high value (≈90%) of convective cloud fraction can be observed on HCFF even before 30 minutes the first detection on the RDT product, only few pixels have this range of values. We have obtained high value of cloud fraction (≈80÷90%) on CCFF only 15 minutes before the first detection on the RDT product and, mostly, for one pixel in the convective systems.

The analysis of cloud fraction fields shows that the method based on analysis of visible satellite data gives plausible results. In the case of small broken clouds we obtained the realistic cloud fraction field, inhomogeneous with mostly low values of N. Over a large mature cloud we obtained a high value of the cloud fraction over the thickest part of cloud (center) and lower value on the edge of the cloud where really partly cloudy pixels (part of pixel covered by cloud) or pixels, which are not thick enough are located. Over a large cloud we obtained a homogeneous cloud fraction field, because real convective cloud is thick and cover a large area without any gaps inside of it. Cloud cover evolution shows a real growth of clouds - gradual increase of N and increase of cloudy pixels.

At the same time we need to note of an underestimation of cloud fraction field using low resolution (VIS0.6) data. On our point of view it is, because simulated cloudy reflectance values are higher that really should be in this channel. We expect that more detailed RTM and more detailed microphysical and geometrical information for convective clouds will decrease the uncertainty in estimation of the TOA cloudy reflectance. Another problem of the used method for cloud fraction estimation is a dependency on the atmospheric state. Integrated water vapour content and aerosol concentration strong influence on the clear sky TOA reflectance. Current version of the method uses climatological water vapour content and aerosol concentration, which gives some uncertainty in the TOA reflectance estimation and subsequently on cloud fraction. Use of NWP data instead of climatological will decrease of uncertainty in the TOA reflectance estimation and improve evaluation of the cloud fraction. The “weakness” of the method is, also, that it needs the reflectance map of surface in HRVIS channel, which is not available now. The spectral interval of HRVIS channel cover part of visible and near-infrared, where surface types have completely different reflectance characteristics (vegetation). The scheme, which we used there, based on joint analysis of land cover map and visible reflectance map in 0.6 μ (AVHRR channel 1), that does not reach a high accuracy in the clear sky TOA reflectance and subsequently in the cloud fraction.

6. CONCLUSION

The study shows that more realistic cloud fraction fields were obtained using HRVIS data than low resolution data. Computed cloud fraction fields show plausible values when compared to a visual interpretation of the HRVIS image; nevertheless, some unrealistic values raise the question of designing a reliable scheme for dynamically adapting the optical thickness of clouds used in the reflectance simulation to the actual cloud field. The next question would be to get a reference
observation data set for objective validation of fractional cloud cover for the more difficult case (regarding radiative transfer modeling) of broken, non-plane parallel, cumulus clouds. So, the possible use of derived fractional cloud cover should be only in a qualitative way at that stage.

7. REFERENCES


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