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ATMOSPHERIC PROFILES AND STABILITY INDICES RETRIEVED USING REMOTE SENSING

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АТМОСФЕРНИ ПРОФИЛИ И ИНДЕКСИ ЗА УСТОЙЧИВОСТ, ПОЛУЧЕНИ ЧРЕЗ ДИСТАНЦИОННИ МЕТОДИ И СРЕДСТВА

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Abstract: *A new source of information for monitoring the atmospheric stability is now available thanks to remote sensing. MODIS data provide information for temperature profile, dew point profile, K-index, Lifted index and Total totals. In Bulgaria these data are available up to eight times for 24 hours in 5x5 km grid in real time in Aerospace Monitoring Center. This allows a better understanding of the processes in the atmosphere in non-frontal cases. The three stability indices help for analyses and now-casting for quickly developing cloud systems, especially Cumulonimbus and probability of thunderstorm activity as well. This kind of information is of a great use in airports, moreover that, so far, all the airports in Bulgaria used data from the only atmospheric sounding in Sofia in 12 UTC or model atmospheric profiles.*

Introduction

Nowadays detailed study of the atmosphere requires different sources of information. Satellites tend to become more and more important in providing data, moreover that for many cases and regions of interest these are the only available data. When we use satellite data we always should consider the temporal and spatial resolution. The algorithm MOD07 – “Atmospheric Profiles”, established by NASA MODIS Science Team provides data for the profiles of the temperature and the dew point, as well as for three stability indices: Lifted Index, K-index and Total Totals in real time.

A first attempt for using this data into operational work is presented in this report. An effort is made for detailed analysis of all three indices together. Special attention is paid to night images, which are more important for now-casting and forecasts, especially when it is about non-frontal processes with developing of Cumulonimbus and probability of thunderstorm activity summer-time. The limitation of MOD07 is that it works in “clear sky”, which means that at least five of twenty-five 1km pixels must be considered cloudless by another algorithm of MODIS Atmosphere – MOD35 – “Cloud Mask”. All the analysis can be made for the region that is in the geographical coverage of the receiving station, but with respect of the territory of Bulgaria.

Theoretical background

Stability indices

Using stability indices in everyday work is very appropriate in study of the moment statement of the stratification Instability is a critical factor in severe weather development. Severe weather stability indices can be a useful tool when applied correctly to a given convective weather situation. However, great care should be used when applying these empirical indices because they simply cannot be applied to every weather situation and must always be applied in conjunction with other parameters. A number of indices are tied to specific pressure levels which may (or may not) be representative of a particular convective weather situation. Soundings must be looked at as a whole. Stations at high elevations make some indices irrelevant. Local adaptations must be made at such. It also should be considered that sometimes the upper air sounding itself may not even be representative of the overall synoptic situation. Severe weather indices only indicate the *potential* for convection. There must still be sufficient forcing for upward motion to release the instability before thunderstorms can develop (http://www.crh.noaa.gov/crh/?n=tsp10-sevwea-stab).

Meteorologists use stability indices to quickly assess the susceptibility of the atmosphere to severe weather. Stability indices are a measure of the atmospheric static stability (Ackerman and Knox). Below are presented some of the indices that now can be studied better thanks to the information received from satellites.

Lifted Index (LI)

Lifted Index is one of the most often used indices and has proved useful role in detecting the likelihood of severe thunderstorms. By definition it is a difference between the external temperature (T_{500}) and the internal temperature (Tp_{500}) at level 500 hPa:

(1) $$LI = T_{500} - Tp_{500}.$$

The main interpretation of the values is according to whether they are positive or negative. In general positive LI indicates stability and negative – instability. There are some specifics presented in table 1. Another classification is presented in table 2.

Table 1. Classification of LI and associated weather, (http://www.engineering.uiowa.edu/~hmet/Handouts/Indices-1.pdf)

Lifted Index [ºC]	Associated weather
> 2	No convective activity
0 to 2	Shower probable, isolated thunderstorms possible
-2 to 0	Thunderstorms probable.
-4 to -2	Severe thunderstorms possible
< -4	Severe thunderstorms probable, tornadoes possible

Table 2. Classification of LI and atmospheric instability (Galway 1956, http://www.crh.noaa.gov/crh/?n=tsp10-sevwea-stab)

Lifted Index [ºC]	Stability
0 to 3	Stable. Weak convection possible with strong lifting or forcing mechanism
0 to -3	Marginally unstable
-3 to -6	Moderately unstable
-6 to -9	Very unstable
< -9	Extremely unstable

Interpretation of values that are close to zero, but positive is the most difficult. Those are exactly the values that could be essential for development of non-frontal Cb clouds and severe thunderstorms.

K-index (KI)

A very precise index is K-index (KI). By definition (2) it is calculated from T_{850}, T_{500} and T_{700}, that are the temperatures and Td_{850} and Td_{700}, that are the dew point for each level:

(2) $$KI = (T_{850} - T_{500}) + Td_{850} - (T_{700} - Td_{700}).$$

KI is a measure of the potential for development of thunderstorms, based on two parameters (temperature and dew point) at three isobar levels all together (850 hPa, 700 hPa and 500 hPa). This is the index used most often for assessment in non-frontal cases. It is not recommended for forecasting of very severe thunderstorms. A classification of its values is presented in table 3.

Table 3. Classification of KI and thunderstorm probability (http://www.engineering.uiowa.edu/~hmet/Handouts/Indices-1.pdf)

K-index [ºC]	Thunderstorm Probability
< 15	0%
21 to 25	< 20%
26 to 30	20-40 %
31 to 35	40-60%
36 to 40	60-80%
> 40	> 90%

Total Totals Index (TT)

Total Totals Index consists of two components: Vertical Totals (VT) and Cross Totals (CT). VT represents static stability between 850 mb and 500 mb. The CT includes the 850 mb dew point. As a result (formula 3), TT accounts for both static stability and 850 mb moisture. However, TT would be unrepresentative in situations where the low-level moisture resides below the 850 mb level. If a significant capping inversion is present, convection will be inhibited even with a high TT.

$VT = T_{850} - T_{500}$,

$CT = Td_{850} - T_{500}$,

(3) $TT = VT + CT = T_{850} + Td_{850} - 2T_{500}$.

Compared to KI, in Total Totals, dew point is calculated at one level only. A classification of TT and the associated weather is presented in table 4. One more classification is presented in table 5.

Table 4. Classification of TT and associated weather (http://www.engineering.uiowa.edu/~hmet/Handouts/Indices-1.pdf)

Total Totals Index [ºC]	Associate weather
44 to 45	Isolated to few moderate thunderstorms
46 to 47	Scattered moderate, a few heavy thunderstorms
48 to 49	Scattered moderate, a few heavy and isolated severe thunderstorms
50 to 51	Scattered heavy, a few severe thunderstorms, isolated tornadoes
52 to 55	Scattered to numerous heavy, a few scattered severe thunderstorms, a few tornadoes
> 56	Numerous heavy, scattered severe thunderstorms, scattered tornadoes

Table 5. Classification of TT and thunderstorm chances (Miller 1972, http://www.crh.noaa.gov/crh/?n=tsp10-sevwea-stab)

Total Totals [ºC]	Thunderstorm chances
45 to 50	Thunderstorms possible
50 to 55	Thunderstorms more likely (some severe)
55 to 60	Severe thunderstorms likely

The above classifications of the three indices are from American references and the values are based on climate and empirical specifications there. One classification in Europe goes that the development of thunderstorms can be described by values TT>45 ºC or KI>24 ºC for 00 GMT and for 12 GMT - TT>46 ºC or KI> 22ºC. Moreover that there are an additional condition:

(4) $LI = (LI_{500} + LI_{600} + LI_{700})/3 < 3.0$,

where LI is taken at levels 500 hPa, 600 hPa and 700 hPa so the instability of lower levels is taken into consideration (http://www.westwind.ch/w_0sok.php).

MODIS and MOD07

MODIS (Moderate Resolution Imaging Spectroradiometer) is the 36-channel spectroradiometer onboard Terra and Aqua satellites from NASA's Earth Observation System. Some of the main advantages of MODIS are the biggest number of spectral channels, the spectral interval 0.4 – 14.4 µm, as well as the three available spatial resolutions (250, 500 and 1000 m), wide field of view, 24-hours of operation (http://modis.gsfc.nasa.gov/).

Based on the full set of data from these satellites NASA MODIS Science Team established algorithms gathered in three packs Atmosphere, Land and Ocean. Each product contains a set of data and processing methods. The final product is usually a mean of visualization and analysis of a great number of parameters that characterize the atmosphere, the land cover and the water. In this report is presented the algorithm MOD07 - "Atmospheric profiles". The atmospheric profile algorithm is a statistical regression with the option for a subsequent non-linear physical retrieval. The operational retrieval algorithm requires that at least 5 of the 25 pixels in a 5x5 field-of-view area be assigned a 95% or greater confidence of clear by the cloud mask (Menzel *et al.,* 2002; Seeman *et al.,* 2006).

MOD07 provides data for temperature and dew point for 20 levels from 5 to 1000 hPa.

A computationally efficient method for determining temperature and moisture profiles from satellite sounding measurements uses previously determined statistical relationships between observed (or modeled) radiances and the corresponding atmospheric profiles. The input data in the algorithm is historical and the method is statistical. There is no unique solution for the detailed vertical profile of temperature or an absorbing constituent because (a) the outgoing radiances arise from relatively deep layers of the atmosphere, (b) the radiances observed within various spectral channels come from overlapping layers of the atmosphere and are not vertically independent of each other, and (c) measurements of outgoing radiance possess errors.

The main disadvantage in MOD07 is that it does not describe quite well small scale specifics in the stratification of temperature and especially in the humidity (Menzel *et al*., 2002). That can be seen in Fig. 1. In the cases with significant changes in the vertical structure of the humidity (e.g. inflow of dry air at higher levels) the profiles of MOD07 does not represent correctly the situation.

Used data

Data sources used in this report are Aerospace Monitoring Center, Agency Hail Suppression and internet based archives. Complete analyses are made for August 2008 and summer time 2009. Special cases are presented.

Analysis and results

The specifics in the profiles are presented in Fig. 1. Examples for good correlation and a bad correlation are chosen. Chosen dates are 6 and 17 August 2008 and the graphics are built on the complete sets of data (till 100 hPa). On 6 August 2008 the profiles of temperature (T) and dew point (Td) retrieved by MOD07 and the atmospheric sounding (TEMP http://weather.uwyo.edu, http://www.westwind.ch/w_0sok.php) have a very good correlation. The profiles are smooth, without big vertical changes. As an example of the opposite is 17 August 2008. There are big differences especially in the profiles of the dew point. Stability indices are interesting to be studied together. Moreover a combination of these three indices is not often made in Bulgaria. So far in our country was available an only sounding in Sofia 1200 UTC. This sounding is not representative for the whole country and, for example, the airports in Varna and Bourgas had to use soundings from Bucharest or Istanbul or model data. This now can be changed using satellite data in real time, both day and night.

A nice example for LI at the territory of the country is 18.08.2008. It was chosen after a detailed analysis of the precipitation over Bulgaria. MODIS data are presented in Fig. 2. Values of LI below zero are mapped in red and mark the areas with unstable atmosphere. At 13:40 local time MODIS registers atmospheric instability mainly over East Bulgaria. During the following night, 18 vs. 19, the east regions of the country are at the periphery of a low pressure system, whose centre is over Ukraine. The atmospheric front, that passes, in a combination with the instability earlier at the day, contributes the development of clouds and leads to precipitation and thunderstorms. Rain rates at several stations are: Varna - 18.5 mm, Silistra – 13 mm, Shabla – 3.3 mm, Sliven – 2.8 mm. According to MODIS data at 13:40 local time in Varna, LI= -2.02 °C, which is an indicator for moderate instability (table 1 and 2) and low probability of thunderstorms. Such situations actually develop later. At the same time (Fig. 2) at the region of Stara Zagora LI= -0.56 °C. This value also indicates instability, but with lower thunderstorm probability and there is no precipitation there.

The development of the cloud system over the night is shown in Fig. 3.

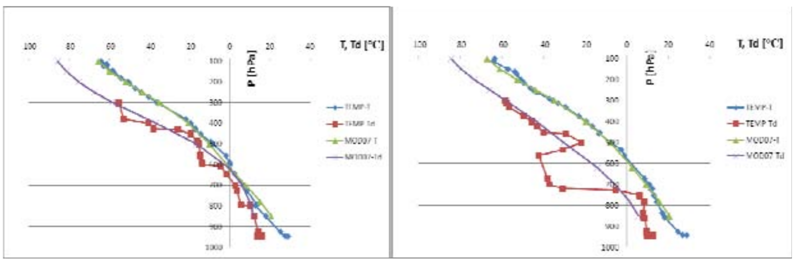

Fig. 1. Profiles of the temperature and the dew point - 6.08.2008 (left) and 17.08.2008 (right)

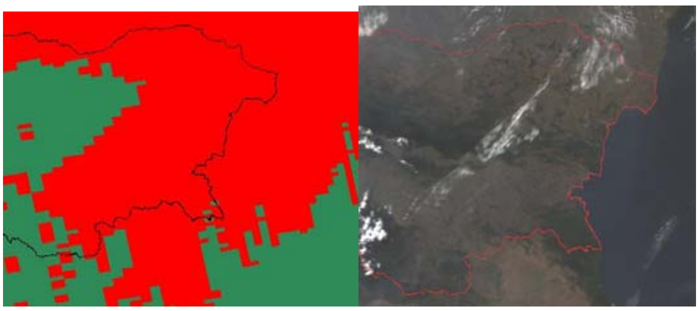

Fig. 2. 18.08.2008, 13:40 local time, Lifted index (left), LI<0 (red), LI>0 (green), satellite image (right)

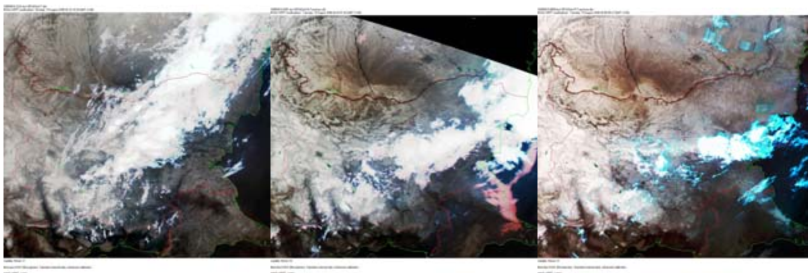

Fig. 3. Satellite images left to right: 18.08.2008- 22:16, 19.08.2008 - 03:51 and 06:59, local time

A new method should be developed for operational work with the night indices. The values from the night are not even close to those that were described in tables 1-5. This is mainly because of the temperature fall close to the land surface. For this reason it is very appropriate to monitor the trend of the indices, not the values themselves. When there are significant changes towards instability, it is usually followed by thunderstorms and precipitation. In case with not so significant changes cloud development is observed, but without rain. Monitoring of the processes for longer than 24 hours period is useful in frontal system forecasts.

For study of the non-frontal development of cloud systems is chosen 30.06.2009 for Sofia. In table 6 are presented the data from MOD07 and the atmospheric sounding.

Table 6. Stability indices from MOD07 for 30.06.2009

Date	Time [local]	LI [°C]	KI [°C]	TT [°C]
30.06.2009	03:00	7.70	20.00	41.13
30.06.2009	12:21	-0.62	33.99	53.84
30.06.2009	23:28	3.43	31.57	46.71

The values from sounding at same day at 15:00 local time are: LI = -1.53 °C, KI = 38.40 °C, TT = 51.40 °C. By comparing these data it can easily be seen the trend of the indices. The precipitation in Sofia for 30.06.2009 is 3 mm. For two of the periods in table 6 are made maps of the three indices. Instability regions can be easily defined. The colour table (table 7) is made according to the definitions of the indices (Tables 1-5). The maps are presented in Figs. 4 and 5. In the early hours on 30.06.2009 (Fig. 4) attention should be paid to West Bulgaria. The values of the indices there show more instable atmosphere, compared to the other regions of the country. On the maps in Fig. 5 the areas with higher instability are: Plovdiv-Pazardzhik, Razgrad-Turgovishte and by the rivers Strouma and Mesta. On the satellite image from 12:21 local time the beginning of developing of convective processes can be observed. In Fig. 6 afternoon satellite images from NOAA on 30.06.2009 are presented. By comparing these images can be seen the development of thunderstorms.

Table 7. Colour table for figures 4 and 5

LI		**KI**		**TT**	
Value	Colour	Value	Colour	Value	Colour
-10 to -6	red	15 to 20	blue	20 to 40	light green
-6 to -3	orange	20 to 25	light green	40 to 44	green
-3 to 0	yellow	25 to 30	green	44 to 47	yellow
0 to 3	green	30 to 35	yellow	47 to 50	orange
3 to 6	light green	35 to 40	red	50 to 60	red
6 to 9	light blue				
9 to 20	blue				
Other values - white					

The minimum of KI and TT (maximum of LI, respectively) in the region of Silistra-Dobrich in Fig. 7, presents the most stable atmosphere over Bulgaria at that moment. This stability is obvious in Fig. 9 as well – the cloud free area in North-East Bulgaria. On that date in Sofia is registered 3 mm rain accumulated for 6 hours till 21:00 GMT. There was thunderstorm activity. The data from Agency Hail Suppression, available in Aerospace Monitoring Center, register precipitation in a lot of stations, in many of them the precipitation is very intensive, e.g. in Rakovski the precipitation is 20 mm from 15:00 to 18:00 local time.

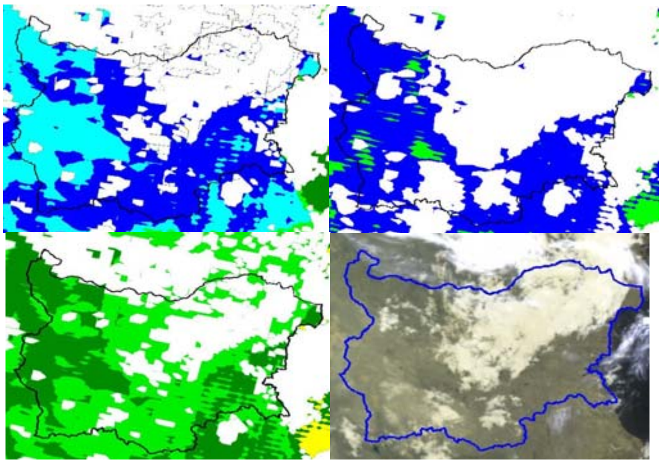

Fig. 4. Maps of indices 30.06.2009, 03:00, up: LI (left) and KI (right), down: TT (left) and satellite image (right)

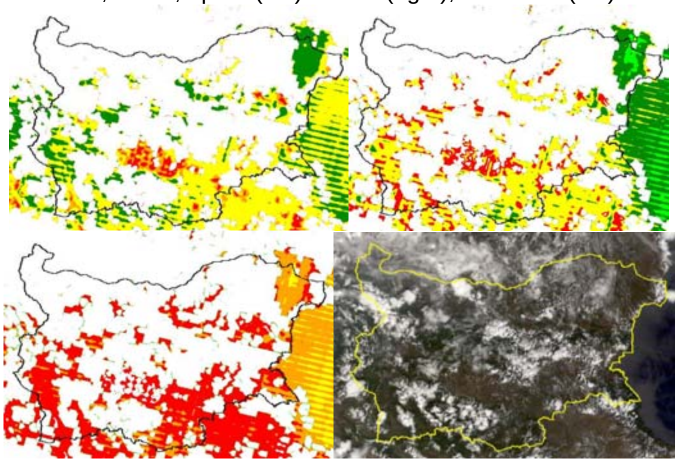

Fig. 5. Maps of indices 30.06.2009, 12:21,up: LI (left) and KI (right), down: TT (left) and satellite image (right)

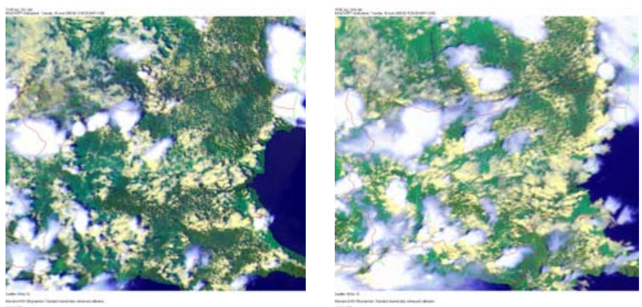

Fig. 6. Satellite images from NOAA - 30.06.2009, 13:49 (left) and 15:06 (right), local time

Perspectives and conclusions

Nowadays remote sensing is a powerful instrument for monitoring and research of our planet. Satellite data contributes the development of Meteorology in both science and operational work.

The main perspectives in the usage of MOD07 can be summarized as follows:

1. implementing all the data from MOD07 into operational Meteorology in Bulgaria;
2. improving now-casting and short term forecasts;
3. applications in Climatology, Ecology, Hydrology, etc.

The present report was made with three main goals:

1. to present the new source of information in Bulgaria – MODIS system
2. to present the achievements of MOD07 – “Atmospheric profiles” and the available data
3. to suggest analysis of combined use of stability indices LI, KI and TT.

The research that has been made includes data from the MODIS station in Sofia and from internet archives and has shown a good correlation between the stability indices and the development of cloud systems and thunderstorm activity. The analysis and results are satisfying and are just a first attempt in the usage of MOD07. The author hopes that the future work over these data will be of a great help of a variety of user of information from Aerospace Monitoring Center.

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