DROUGHT AND VEGETATION FIRES DETECTION USING
MSG GEOSTATIONARY SATELLITES

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Abstract

The potential of MSG products for application in monitoring and analyses of land surface conditions at extreme weather and climate environment of drought and vegetation fires is exploited at NIMH of Bulgaria. On this basis, a diagnostic system has been developed to support the activities of National Civil Protection Authorities. Designed to provide early warnings for thermal anomalies on the land surface (drought and vegetation fires), it is working in operational mode since February 2010, combining modelling in the Soil-Vegetation-Atmosphere continuum and multispectral satellite information. The development of a Drought Index (DI) that can reflect regional climate/soil/vegetation types is performed. Daily colour-coded DI maps are used operationally to characterize the pre-fire conditions in addition to the remote sensing of thermal anomalies at forest/field vegetation by MSG SEVIRI FIR product and the MODIS Aqua/Terra TAB product. In this relation, the validity of the 3rd MPEF FIR edition is further evaluated by using truth ground detections.

The usefulness of LSA SAF LST product for assessing vegetation water status and pre-fire conditions as additional or complementary to the SVAT-model derived land surface information is initially evaluated. The utility of LST as a diagnostic tool for forest fire risk assessment is tested for real forest fire situations. The results may serve as a background for further studies for both:
- LST operational use as a short-term early warning index of water stress as well as
- LST use for climatic applications regarding drought conditions and relation to vegetation (fuel) types, forest fire risk and actual fire occurrence.

INTRODUCTION

Fire events are a function of three main factors: probability of fire, fuel load, and fuel moisture. Fuel moisture influences the fire regime and couples fire to climate being a critical parameter that influences the probability of fire occurrence and the severity of fire behaviour.

Recently the Eastern Mediterranean region, including Bulgaria, has suffered from major forest and other wild-land fire problems. Humans-caused fires, starting accidentally or deliberately mainly related to agricultural land–use are becoming more prominent and their widespread in dry weather and climate environment is the main reason for forest fires ignition in the country.

The objective of this paper is to present first results of a complex research on the fire events in the drought prone area with Mediterranean influence in Bulgaria. The next section is focused on the components of an Operational System, which has been introduced at the National Institute of Meteorology and Hydrology of Bulgaria (NIMH) to work in support to the National Authorities. For estimation forest/field moisture at different fuel types, a Soil-Vegetation-Atmosphere-Transfer (SVAT) scheme based on numerical modelling of land surface processes with ground meteorological observations as input data is used. A Drought Index, derived as a threshold scheme of SVAT-model soil moisture outputs is introduced. Remote sensing of thermal anomalies at forest/field vegetation from MSG SEVIRI and MODIS Aqua/Terra is operationally performed. The 3rd edition of MPEF FIR product for thermal anomalies detection by MSG data has been operationally used since 2009 and evaluated in parallel, based on the experience at NIMH of Bulgaria (Stoyanova, et al., 2008; Stoyanova and Georgiev, 2009).
Land Surface Temperature (LST) product derived operationally with high frequency from MSG has the potential to be used in support to early warning and forest fire risk mitigations. The usefulness of MSG LST product of the LSA SAF as an index of vegetation water status and pre-fire conditions is studied and results are presented in the third section of this paper.

Most research concerning the use of remote sensing techniques for forest fire applications have focused on detecting active fires, mainly using middle-infrared images (e.g. Ahern et al., 2001). In the scope of fire problem, vegetation water content is important for evaluating drought and wildfire risk in natural plant communities, regarding the pre-fire phase which is critical to better manage fire suppression resources, to reduce accidental fire ignitions and mitigate fire propagation rates (Chuvieco et al., 2004).

Remote sensing data have been frequently used to estimate the water status of plants, both in agricultural and ecological research. However, the first step towards establishing an operational technique to retrieve vegetation water content using remote sensing is to clearly identify where the potential lies. Plant canopy temperature is affected by live fuel moisture changes because water availability is a critical parameter in plant evapotranspiration. Based on this principle, several authors have tested the use of thermal images to estimate plant water content (e.g. Moran et al., 1994).

The proposed approach relies on the potential of Meteosat Second Generation (MSG) geostationary meteorological satellite to provide a range of data for monitoring and analyses of land surface conditions during extreme weather and climate environment of drought and vegetation fires.

**OPERATIONAL ASSESSMENT OF LAND SURFACE DROUGHT AND VEGETATION FIRES**

An integrated Information System for assessment of vegetated land surface status on the bases of meteorological modelling and satellite data has been developed at NIMH of Bulgaria. It is designed to provide early warnings for thermal anomalies on the land surface (drought and vegetation fires) and is working in operational mode since February 2010. The system combines model indexes and multispectral satellite information that include:

- Thermal anomalies detection and monitoring by MPEF FIR product from the Full and Rapid Scan Service (RSS) MSG missions received via EUMETCast in real time.
- Thermal anomalies detection and monitoring by MODIS Thermal Anomalies Product (TAP) product (as a reference source) received via EUMETCast with 1-2 hours delay.
- Assessment of vegetation drought stress and fuel moistening based on a Drought Index (DI) designed from the output datasets of a Bulgarian SVAT model /'SVAT_bg'/.
- MPEF Multispectral Precipitation Estimates (MPE) product from MSG data.
- Interactive satellite data processing with SYN ERGIE Forecasting System (configuration for Bulgaria, 2008) in support to Land Surface Applications that may serve as a decision making tool for Forecasting and Early Warnings, including fire development.

**Soil-Vegetation-Atmosphere-Transfer Model (‘SVAT_bg’) model of NIMH**

A 1D (vertical) meteorological SVAT model has been developed at NIMH of Bulgaria to serve as a source of data for land surface analyses. This model, referred to as ‘SVAT_bg’, simulates the biogeophysical cycle, accounting for site-specific soil and vegetation physical properties (Stoyanova and Georgiev, 2007; 2008). The following main output parameters are operationally daily derived:

- Moisture of the soil-vegetation system at 4 soil depths (5 cm, 20 cm, 50 cm, 100 cm) for land covers of field cereals/stubble and perennial grassland/lucerne, by using 10-daily soil moisture measurements performed in the agro meteorological network of NIMH of Bulgaria as reference data.
- Drought Index, derived through a 6-level threshold scheme, as a measure of water availability in the soil-vegetation continuum and fuel moisture conditions. The index is visualised in colour-coded maps covering the main administrative units of Bulgaria (Fig. 3a) and operatively
applied for cropped field and lucerne as a diagnostic tool for issuing warnings of weather and climate drought extremes on a daily basis.
- Radiative properties of vegetated land surface via the ‘SVAT_bg’-derived canopy leaves temperature $T_l$.

**MPEF FIR Product: 3rd edition capabilities in active fire detection**

The 3rd edition of MPEF FIR product was operationally introduced on 30 July 2009. It is based on the improved algorithm of the Active Fire Monitoring Product for the MSG satellites (Joro et al., 2008), which has turned a static into a dynamic application dealing with areal emissivity differences for both the Meteosat-9 full disk product and Meteosat-8 RSS product. The product is operationally used at NIMH of Bulgaria and evaluated in parallel, based on the previous validation experience (Stoyanova et al., 2008; Stoyanova and Georgiev, 2009). Two aspects of the validation study will be presented in this paper.

Firstly, the FIR product’s ability to identify exact fire location was verified by comparison with TAP derived by MODIS instrument (Aqua/Terra polar satellites) with a higher resolution. A simple quantitative testing procedure (Stoyanova, et al., 2008) was applied for the period from 30 July to 30 September 2009. The MODIS fire pixels were associated to SEVIRI fire scenes by conversion to MSG coordinates and mapping them into the SEVIRI pixels in order to assess the accuracy of the MPEF SEVIRI product to detect the exact location of fires.

Table 1 shows a cross comparison between the three versions of the MPEF FIR product regarding their sensitivity. The MPEF FIR product is able to detect a small portion of the MODIS fire reports exactly on time: these are 6-8% for Full Disc service and 24-32% for the RSS.

**Table 1. Comparison between sensitivity of the three MPEF FIR product versions (2007, 2008 and 2009) for Bulgaria.**

<table>
<thead>
<tr>
<th></th>
<th>MSG-2 Full Disc Scan</th>
<th>MSG-1- Rapid Scan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st FIR 2007</td>
<td>2nd FIR 2008</td>
</tr>
<tr>
<td></td>
<td>31 days</td>
<td>(46 days)</td>
</tr>
<tr>
<td>MODIS fire pixels over</td>
<td>432</td>
<td>517</td>
</tr>
<tr>
<td>Bulgaria corresponding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>to MSG slots</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSG detections within</td>
<td>38</td>
<td>43</td>
</tr>
<tr>
<td>5x5 SEVIRI pixel area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>around the MODIS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>detection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coincidence of</td>
<td>7.9 %</td>
<td>7.0 %</td>
</tr>
<tr>
<td>MODIS and SEVIRI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>detections</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPEF FIR sensitivity</td>
<td>8.8 %</td>
<td>8.3 %</td>
</tr>
<tr>
<td>(SEVIRI detections,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of MODIS fire reports)</td>
<td></td>
<td></td>
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</table>

An evaluation of the FIR algorithm sensitivity to identify correctly thermal anomalies reported by Aqua/Terra satellites in a reference area of 5 x 5 MSG-pixels around the MODIS detections has been performed. The last FIR product version shows similar kind of systematic displacements of the fire locations derived by SEVIRI algorithm in respect to the MODIS hot spot detections as it was reported for the previous two versions of the product. Fig. 1 shows FIR detections displacement by 2 pixels (5 - 10 km) regarding centered MODIS fire-detection in Bulgaria for August and September 2009. The FIR product shows full agreement of the fire positions with those detected by MODIS only in 10.2 % of all cases. Displacements of the fire coordinates mainly to the northwest (NW), north (N) and west (W) directions towards the MODIS fire locations are observed.

Secondly, verification of the 3rd FIR version by comparing its performance with the actual fires in the records of the National Fire Data Bases of the Executive Forest Agency and Ministry of Interior of Bulgaria has been performed. Table 2 shows results for the first six days of the operational use, when the 3rd MPEF product version detected 163 thermal anomalies. The FIR algorithm has detected only 9 (22.5 %) of the records for actual fires registered in the National Fire Data Bases.
An attempt to evaluate the FIR product regarding its false fire-pixel classifications is also made and results are presented in Table 3. It was found that at specific locations, MPEF FIR product reports the presence of fire within the same pixel for several days. As false alarms in our results for the studied period, we consider the 12 repetitions of detected hot spots at the same location for at least three days that are not confirmed by any official reports or signals for actual fires, including thermal anomalies detected by MODIS. The rest 142 FIR-detected hot spots, which are not detected by any other source of data mentioned above, are considered as not confirmed false alarms. The MSG and geographical coordinates of the 12 systematic false classifications according to our approach are shown in Table 3. Such false fire alarms could be caused by any other permanently hot land areas or pixels in regions with inhomogeneous surfaces or because of any wrong classification of the surface types based on the climatological background information for the MSG field of view EUM (2007).

<table>
<thead>
<tr>
<th>Geographical and MSG coordinates (Row / Column): Rss for Rapid Scan Service, Full for MSG Full Scan mission</th>
<th>Repetitions in 3 days</th>
<th>Geographical and MSG coordinates</th>
<th>Repetitions in 4 days</th>
<th>Geographical and MSG coordinates</th>
<th>Repetitions in 5 days</th>
<th>Geographical and MSG coordinates</th>
<th>Repetitions in 6 days</th>
<th>Geographical and MSG coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>43.80N / 25.81E</td>
<td>43.50N / 23.95E</td>
<td>42.52N / 26.88E</td>
<td>42.05N / 24.84E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Rss 3237 / 1447</td>
<td>Rss 3207 / 1411</td>
<td>Rss 3232 / 1490</td>
<td>Rss 3198 / 1458</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41.40N / 23.29E</td>
<td>43.98N / 25.70E</td>
<td>43.79N / 25.70E</td>
<td>43.65N / 23.27E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rss 3184 / 1493</td>
<td>Rss 3241 / 1448</td>
<td>Rss 3212 / 1426</td>
<td>Full 3225 / 1263</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42.08N / 24.53E</td>
<td>42.72N / 26.33E</td>
<td>43.73N / 25.25E</td>
<td>41.44N / 24.11E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rss 3199 / 1466</td>
<td>Rss 3226 / 1411</td>
<td>Rss 3236 / 1460</td>
<td>Full 3175 / 1259</td>
<td></td>
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</table>

LST PRODUCT FROM MSG AS A DROUGHT MONITORING TOOL

Traditional methods of fire risk assessment rely on meteorological danger index (MDI) that account for the critical variables of fire ignition (e.g. vegetation water status). Besides the uncertainties inherent in the derivation of a MDI, the application of such indexes also suffer the lack of meteorological data for specific areas, as well as spatial interpolation techniques that are not always suitable for use in areas with complex terrain (Aguado et al., 2003). Satellite data have the potential for providing alternatives to meteorological indexes for monitoring fire risk, given the synoptic coverage and repeated temporal sampling of satellite observations (Ceccato et al., 2001).

The concept of fire risk in this study is restricted to the likelihood of fire occurrence, given a particular vegetation water status. It is impractical to measure fuel moisture directly over large areas with the required frequency, and so procedures have been developed to estimate it from ground meteorological data, and/or from satellite remote sensing. As a first step towards an operational forest
fire risk assessment by using satellite data, the MSG land surface skin temperature derived by LSA SAF is considered. We compare the performance of satellite and SVAT_bg derived land surface temperature datasets with ground-collected data for forest fires activity. The study used spectral and weather data acquired between 2007 and 2009, as well as information on actual forest fires detected by ground observations over Bulgaria from the State Forest Agency.

**LST satellite image processing**

In 2010, research activities are initiated at NIMH to involve the LSA SAF LST product as additional or complementary to the SVAT-model Drought Index information for detection temperature anomalies and trends. The LST from MSG satellites is derived at low spatial resolution (~5 km over Bulgaria), but its 15 minutes frequency of availability allows monitoring the diurnal cycle of the temperature anomalies for applications in pre-fire and fire situations. In our work the LST values at specific points, where forest fires have occurred are used based on the following considerations and techniques:

1. We process LSA SAF data, which are operationally disseminated via EUMETCast on ¼ hourly basis in HDF5 file format.
2. To avoid the possible seasonal bias of the LST algorithm to the atmosphere and land surface conditions, the research is limited only for July (of 2007, 2008, 2009 and 2010 years).
3. The test sites are actual forest fires, detected by the Executive Forest Agency.
4. Usually the accuracy and validity of LST derived by satellite measurements are not suitable for using these data on a pixel basis due to different reasons (e.g. unavailability of data in cloudy pixels; LST anisotropy and view angle effects, pixel geolocation errors, etc). For that purpose, LST values are averaged in areas of 5x5 pixels (~25 km) around the fire locations.
5. Hourly averaged LST values for two types of land cover (forest and crop/grass field) are used.

**MSG LST as a measure of plant canopy temperature and water status**

Land surface temperature plays an important role in the physics of land surface as it is involved in the processes of energy and water exchange with the atmosphere that is simulated in the meteorological and climate models. We have studied the information content of LST data derived from MSG by comparing it with two parameters from the Bulgarian SVAT model output as follows.

- Versus the SVAT_bg-derived canopy leaf temperature.
- Versus the Drought Index, derived through a 'SVAT_bg' based threshold scheme for evaluation of moistening conditions. In addition, the trend of LST values three days and some hours before and during fire situations are evaluated.

**LST from SVAT_bg and LST from MSG.** The SVAT_bg model-derived plant canopy leaf temperature ($T_l$) provides a site-scale information for the specific environment (climate, soil, land cover type). It is calculated for field of winter wheat for July of 2007-2010, the most active fire period for Bulgaria. LSTs (5x5 pixels averaged) values are centred at the locations of synoptic/agro meteorological stations from operational meteorological network of NIMH, Bulgaria, where the daily model outputs of canopy temperature are available. MSG LST averaged values are compared with corresponding model derived site-scale data and used to indicate the coupling between energy and water status of vegetated land surface at different weather conditions (Fig 2). Good agreement and high values of coefficient of determination, of 0.707 is obtained. Based on this result we might suppose that MSG LST gives a

![Figure 2. Scatter plot of MSG LST vs. SVAT_bg model-derived plant canopy temperature (°C) at (42.23 N 24.33 E) for July 2007-2010, Lucerne land cover.](image-url)
reasonable approximation of canopy leaves temperature, resulted from the coupling of vegetated energy and water cycles.

**Pre-fire conditions and vegetation moistening assessment by ‘SVAT_bg’ derived DI.** There are a number of introduced methods of monitoring the seasonal development of drought. For example, the Keetch-Byram Drought Index is a cumulative measure of moisture deficiency in the deep duff and soil layers. The index has proved to be a useful early warning tool and is now incorporated into the US National Fire Danger Rating System and the Australian Forest Fire Danger Rating System.

In our work, the performance of ‘SVAT_bg’ derived vegetation moistening in pre-fire situations is evaluated according to a Bulgarian DI. Fig. 3 illustrates the case of an actual forest fire on 24 August 2010 (reported by the SFA data base, Table 4) that was not detected as a thermal anomaly by MSG and was registered my MODIS sensor at 1035 UTC (see Fig. 3c). Our calculations reveal that LST (5x5 pixels averaged and centred at the forest fire locations) at the site of fire burst (Table 4, Case study 1) is ascending 3-4 days before the ignition, for both LST six hours averaged values before ignition (Fig. 4a) and LST values at 1100 UTC (Fir 4b).

![Figure 3. Drought and thermal anomalies detection on 24 August 2010: An actual forest fire in NW Bulgaria (44.033 °, 22.750°, Case study 1, Table 4) description by: (a) Bulgarian climatic DI and satellites, (b) MSG LST at 1200 UTC and (c) MODIS FTAB at 1035 UTC.](image)

Pre-fire conditions of the fuel moistening for the day of fire event are characterised by the DI, as calculations are performed for a site located in the close vicinity of the studied forest fire (up to 3 MSG pixels distance) at stubble land cover and 4 soil depths. DI maps as these in Fig. 3a show “Drought” (red colour) conditions for the surface and upper soil levels that progressively become dry before the fire event and continue the tendency of stubble field drying after that due to lack of precipitation. DI behaviour reveals a cumulative drought, which favours the forest fire development on 24 August 2010. Although drought indices can be built into a broader fire danger rating system they are most effective as an early warning system when they are maintained separately and charted to illustrate the progressive moisture deficit for a specific location. This overcomes the problems caused by variation of both forest and soil type which can mask the recognition of severe drought when a drought index is applied across broad areas.
Figure 4. MSG LST mean values curves starting 3-4 days prior forest fires (according to Table 4): (a) 6-hours before the burst time averaged LST and (b) for 1100 UTC.

**MSG LST and forest fire risk evaluation**

Efforts to provide useful drought indicator and to develop an early warning system using drought-related characteristics of surface water stress, which are derived from satellite data are further exploited. The LSA SAF LST product is used to retrieve land surface temperature three days prior the fire event for some actual fire situations (Table 4). Artificial forest fire events due to human agricultural practice are selected. For these cases, all cloud-free LST data sets over 5x5 SEVIRI pixels centred at both, the location of forest fire as well as at the nearest cropped field station (using NIMH agro meteorological network) are used. Six hours averaged prior the fire ignition LST values and LST maximum around 1100 UTC are used. Detecting thermal anomalies by SEVIRI/MODIS sensors as well as the trends in moistening conditions three days before forest fires are evaluated.

The results show that LST increases as the day gets closer to the fire day (in conformity to Guangmeng and Mei, 2004) and becomes its maximum at the day of fire or a day before (Fig. 4a, b). The calculated “SVAT_bg” DI values, which are referred to the nearest stubble field, observe progressive drought conditions for these fire days (here not presented because of the lack of space). This gives the reason to conclude that LST values prior fire event might be considered as an index for forest fire risk assessment. In all studies cases, the maximum LST value (around 1100 UTC) exceeds the air temperature by 12-15 deg and more. At this stage the LST is used as a qualitative index of risk of forest fires. We consider these results as promising for future operational use of LST data that requires much more work to be involved.

**Table 4. Description of actual forest fires used as testing cases in evaluation of LST effects.**

<table>
<thead>
<tr>
<th>Case study</th>
<th>Ignition date</th>
<th>Fire location (lat/lon)</th>
<th>Location MSG row/line</th>
<th>MSG detection</th>
<th>MODIS detection (MSG row/line)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24/08/2010</td>
<td>44.03/22.75</td>
<td>1523/3245</td>
<td>No detected</td>
<td>1524/3245</td>
</tr>
<tr>
<td>2</td>
<td>03/08/2009</td>
<td>43.77/22.47</td>
<td>1528/3239</td>
<td>1529/3239</td>
<td>No overpass</td>
</tr>
<tr>
<td>3</td>
<td>21/08/2009</td>
<td>41.97/26.15</td>
<td>1425/3195</td>
<td>No detected</td>
<td>Not detected</td>
</tr>
<tr>
<td>4</td>
<td>24/08/2009</td>
<td>42.03/25.83</td>
<td>1433/3197</td>
<td>1434/3198</td>
<td>1434/3196</td>
</tr>
<tr>
<td>5</td>
<td>23/07/2007</td>
<td>43.20/24.17</td>
<td>1257/3215</td>
<td>1256/3216</td>
<td>1255/3215</td>
</tr>
<tr>
<td>6</td>
<td>22/07/2007</td>
<td>42.00/26.08</td>
<td>1200/3184</td>
<td>11997/3183</td>
<td>No overpass</td>
</tr>
</tbody>
</table>

**CONCLUSION**

The MSG products for detection, monitoring and analyses of land surface conditions during extreme weather and climate environment of drought and vegetation fires over Bulgaria has been exploited since 2007. Considering that drought is a complex process and should be reflected by integral criteria, the diagnosis of land surface moistening and its use in early detection of drought and pre-fire conditions is evaluated. It is shown that an evaluation of satellite data derived LST as a fire risk index...
is essential before it’s using for operational purposes, to obtain more accurate maps of fire risk for the temporal and spatial allocation of fire prevention or fire management.

For a better description of the interactions between weather-climate-vegetation-forest/wild fires across inhomogeneous drought prone regions, a complex approach for early detection and monitoring of land surface thermal and moistening anomalies is proposed. This includes:

- Combined use of MSG LST as complementary to SVAT-modelling techniques and a Drought Index (accounting for the regional climate, soil and land cover type) is considered as useful.
- Initial validation results indicate that the MSG LST is a promising product as a qualitative index of vegetation drought.
- Further evaluation of satellite data derived LST for fire risk assessment is essential before it’s using for operational purposes.
- MSG LST in combination with MPEF FIR product detections would help in providing early warnings of drought and fire effects mitigations. For that purpose, quantitative evaluation of fire risk based on LST is needed but limitations in cloudy conditions makes some difficulties for operational use of this product.

ACKNOWLEDGEMENTS

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REFERENCES


