LST as a biophysical driving parameter of drought and fire activity in Mediterranean climate environment

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ABSTRACT

The study is focused on the current challenges in assessing drought, its effective monitoring by remote sensing, and its impacts on fire activity in the region of South-eastern Europe. Using long-term (2007–2018) LST datasets retrieved by the LSASAF LST product from geostationary MSG observations, spatial–temporal variability of drought over Bulgaria is characterized. The anomalies of LST and temperature difference LST-T2 (as a first proxy of sensible heat exchange with atmosphere) are considered. To characterize spatial–temporal patterns of fire activity (July–September), long-term satellite data records from SEVIRI observations (2004–2019) in terms of the number of biomass burning detections according to the LSASAF FRP-Pixel product are used.

The relationships between the spatial–temporal variability of LST, fire activity and Soil Moisture Availability (SMA) for main land cover types are quantified. All significant fire events occur in days associated with positive LST anomalies and negative SMA anomalies. Exponential regression models fit the link between LST monthly means, LST positive anomalies, (LST-T2) and the number of FRP detections at high correlations. Quantitative relations between the biophysical index LST and the changes in the dynamics of vegetation fire occurrence are inferred. Dependences are found for forest, shrubs, and cultivated LCs that indicates the satellite IR retrievals of radiative temperature is a reliable source of information for vegetation dryness and fire activity.

Long-term trend analyses of fire activity into different land cover types are performed. Maps with the location of hot spots of fire activity are constructed; no positive trend of fire activity in regions with forest land cover types and an increasing trend is mostly scattered in the shrub lands are indicated.

The aim: Drought & fire activity in Mediterranean climate environment

We use long-term spatially and temporally consistent satellite observations from SEVIRI sensor of geostationary MSG satellite to assess the biophysical forcing effect for vegetation fires on a climatic basis at a regional scale. The study is focused on two key aspects of wild fire problem that are not systematically studied in the literature:

(i) evaluation the importance of LST (monthly mean values, anomalies, and difference with air temperature, T2m) as precursor/s of vegetated land surface dryness and related pre-fire signals of vegetation stress and fire occurrence;
(ii) To explore the variability of these biophysical drivers of vulnerability to biomass burning across the climatic gradient, delineated into main land cover types, and to quantify the relations with fire activity, using long-term records of satellite information from Meteosat, ground observations and SVAT model data of Soil Moisture Availability (SMA) to the land cover as a reference data over the Eastern Mediterranean region (Bulgaria).

Specific objectives to be solved are:

- To characterize spatial-temporal patterns of fire activity (July-September) using long term satellite data records from SEVIRI observations (2004-2019) in terms of number of biomass burning detections according to LSASAF FRP-Pixel product;
- Using LSASAF LST product data to investigate and evaluate statistically the relationship of biophysical parameters LST, LST anomaly, and the difference between skin and air temperatures (LST-T2m) to the occurrence of wild fires on a short-term climatic basis (2007-2018);
- To characterize the wild fire vulnerability of the main vegetation types (forest, shrublands, cultivated) in reaction to the LST and SMA warm and dry anomalies.

1. Background

Fire is a global phenomenon closely linked to climate variability and human practices with critical regional implications *(e.g. Bradstock, 2010; Krawchuk and Moritz, 2011)*. It is an important process in modulating the Earth system, through the links among weather, climate, and vegetation as well the potential to feed back to the global climate system through changing the ability of the surface to absorb and emit energy (*Vlassova et al., 2014, 6, 6136-6162; Liu et al. 2019)*.

The motivation of this research is our hypothesis that different fire regime components (occurrence, size/severity) would exhibit characteristic spatial and spatial-temporal patterns that reflected differences in the relative importance of various drivers of physical and environmental processes. Knowledge about fire-climate relations on a regional scale is important to define more risky regions and periods as well as for projection the effects of global environmental change.

Although relationships between drought and fire seem quite interrelated, only few studies have explored the LST as a pre-fire indicator *(Yang, 2022; Song, 2019)*. Short-term analyses based on LST daily anomalies are performed to predict fire occurrence *(Yang, 2022)*.

The vegetation cover partitions the incoming solar radiation into sensible and latent heat fluxes depending on its structure, affects the surface roughness, which can in turn alter heat and moisture transport; the type of vegetation and its seasonal dynamics affect vulnerability to fire ignition and spread. That is why spatial-temporal patterns of Land Surface Temperature (LST) can contribute to monitor the processes that structure ecosystem development and may build a relationship with fire occurrences to help fire management.

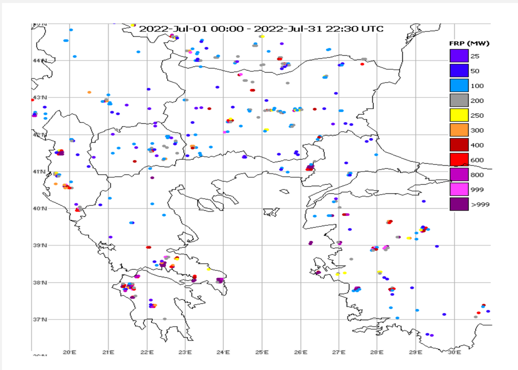
Satellite measurements are a source of information for accurate estimation of LST at the global and regional level, thus help evaluate land surface–atmosphere exchange processes and can provide a valuable metric of surface state *(Liu et al. 2019; Kustas and Anderson, 2009).*

2. Materials and Methods

2.1. The LSASAF FRP-PIXEL Product

Fire activity characterized by biomass burning detections according to:

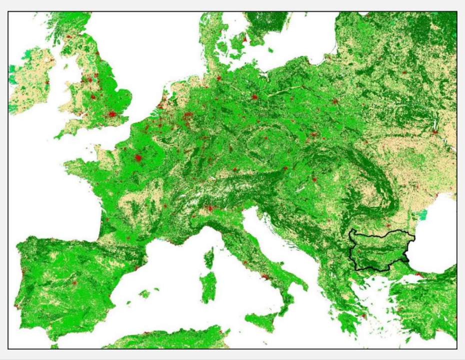
- ✓ Radiative power released by fire events, as provided by the LSA SAF Fire Radiative Power-Pixel (FRP) Product *(Wooster et al, 2015; Govaerts et al. 2015; Trigo et al. 2011).*
- ✓ The type of fire detection algorithm proposed for use with SEVIRI is based on the principles applied to generate active fire detections within the MODIS Fire Products *(Giglio et al., 2003).*



2.2. Ground observations of forest fires

Ground observations of the number of actual forest fires are considered according to the data base of Executive Forest Agency of Bulgaria (SFA), the responsible national institution are used for comparison with satellite detections.

2.3. Target region and land cover



- (LC) provided from the ESA-CCI Land Cover Map product at a spatial resolution of 300 m
https://www.esa-landcover-cci.org/?q=node/164
- For the purposes of the study the LC types are reclassifie into three main vegetation groups: - forests ; - scrubland, and - cultivated

Figure: Geographical distribution of the vegetation cover types according to the ESA-CCI Land Cover database 2018 over Europe. The target region Bulgaria, SE Europe, reclassified in three categories: forest, shrubland, grassland.

2.4. Biophysical indexes

- The LSASAF LST product *(Trigo et al, 2008)* is applied

The LST retrieval based on clear-sky measurements from the MSG system in the thermal infrared window (MSG/SEVIRI channels IR10.8 and IR12.0), every 15 min within the area covered by the MSG disk. Theoretically, can be determined 96 times per day from MSG but, in practice, fewer observations are available due to cloud cover. Long-term LST data records (June–September, 2007–2018) are used.

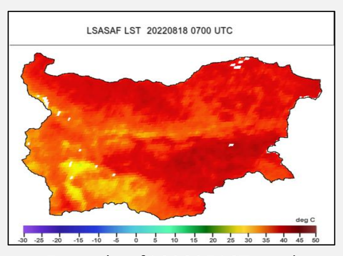


Figure: Example of LSASAF LST product at clear sky.

•SVAT model and SMAI

- ✓ The Soil Moisture Availability (SMA) Concept for assessing land surface moisture state
- ✓ Based on the 'SVAT_bg' model outputs of SM, a quantitative index soil moisture availability index, SMAI has been developed and operationally calculated at a site scale for the region of each NIMH synoptic station for 4 soil layers: 0–5 cm; 0–20 cm; 0–50 cm; 0–100 cm *(Stoyanova & Georgiev, 2013)*.
- ✓ Drought Identification using SMAI, designed as a 6-level threshold scheme to account for moistening conditions. SMA is expressed by digital values ranging from 0 to 5, which are correspondingly color-coded:

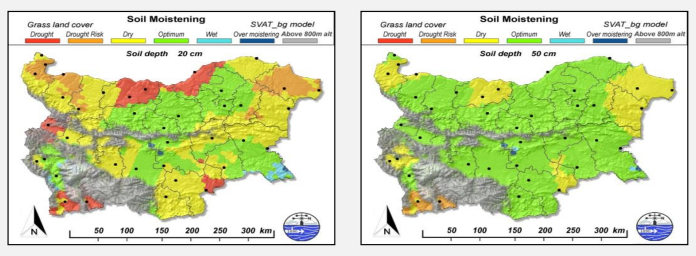


Figure: Example of color coded maps of SMAI over Bulgaria for: **(a)** 0-20 cm soil layer; **(b)** 0-50 cm soil layer. The symbol (•) indicates the location of synoptic stations used for SVAT model running.

2.5. Numerical Analyses

Table 1. Summary of data used and their characteristics.

Data	Temporal resolution	Spatial resolution
Fire Radiative Power-Pixel product	15 min	SEVIRI, about 5 km over Bulgaria
Land Surface Temperature (LST)	15 min	SEVIRI, about 5 km over Bulgaria
Temperature difference between LST and air temperature at 2m (LST-T2m)	0900 and 1200 UTC	NIMH synoptic station network
Soil Moisture Availability Index (SMAI)	Daily, 0600 UTC	NIMH synoptic station network

- Fire regime is characterized by the frequency of FRP-Pixel product detections. A dataset of FRP detections (location, timing) for the period June-September (2004-2019) is constructed. All pixels at least with one fire detection are considered.
- Each fire pixel is associated to the coordinates of nearest point of the grid, where LST, LST anomalies, and (LST-T2m) are derived. The procedure is performed for monthly accumulated energy released from fires in the corresponding grid-point.

- **Qualitative comparative analysis** to validate the adopted methodology: monthly mean LST and SMA anomalies visualized in color-coded maps are evaluated for consistency with FRP fire pixels spatial distribution over Bulgaria.

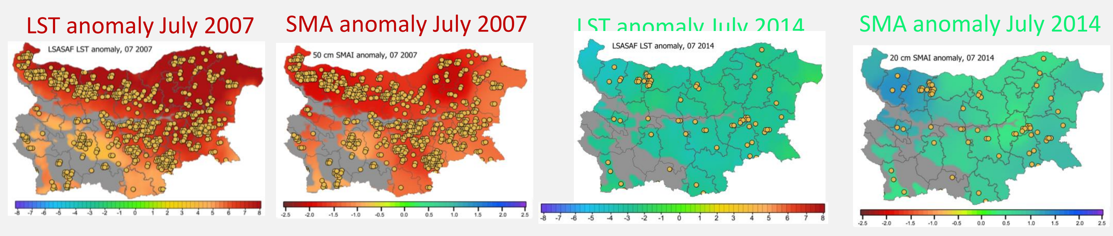


Figure: Spatial distribution of LSASAF FRP fire pixel detections superimposed over: **(a)** LSASAF LST 0900 UTC anomalies and **(b)** monthly mean SMA anomalies (50 cm soil depth). Examples for July 2007/2014, Bulgaria: The LST and SMA anomalies calculated towards 2007–2018.

- The higher positive LST anomalies (in red color) correspond to higher number of FRP detected fire pixels.
- The stronger negative SMA anomalies (indicated by reddish colors) are related to higher number of fire detections.

The consistency of the fire activity and biophysical drivers from qualitative analyses allows quantitative studies to be further performed, covering:

- ➢ Stochastic graphical analyses for consistency between fire activity and biophysical drivers (LST, LST anomalies, (LST-T2m), SMA anomalies)
  - ✓ Spatiotemporal variability on a monthly and annual basis, as well as their anomalous distribution.
  - ✓ The summer seasonal dynamics of biophysical conditions at different LC vegetation types in relation to vulnerability of fire ignition/ spread.
- ➢ Hot spots of fire activity are identified: The spatial pattern of the accumulated biomass burning detections for the period June-September 2004-2019 based on applying Mann-Kendall test.
- ➢ To perform all these comparisons, R language for statistical computing was used.

3. Results & Discussion

3.1. Active fire monitoring from space

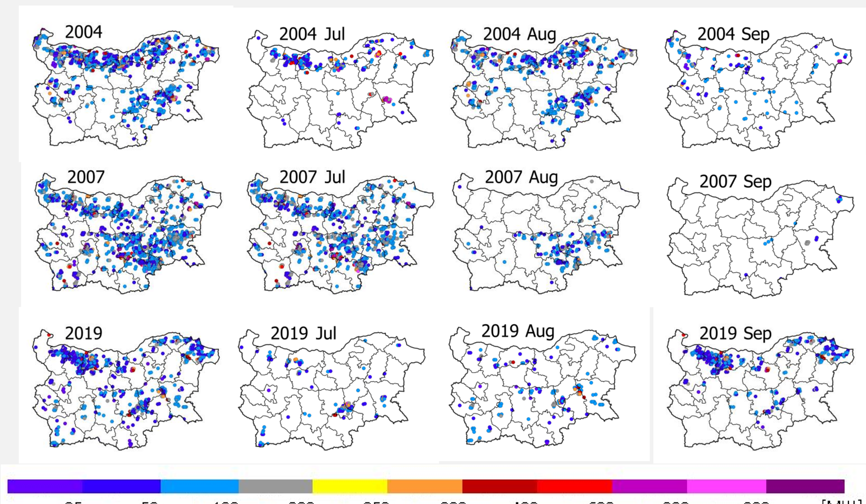


Figure: Maps of spatial-temporal (monthly/annual) distribution of fire activity over Bulgaria. Color-coded severity of biomass burning according LSASAF FRP-Pixel (MW) is indicated. Examples for July, August, September and annual for 2004, 2007, and 2019 are presented.

- The fire activity exhibits various seasonal distributions from year to year, e.g. maximum activity and severity in July 2007, in August 2004, in September 2019.
- The repetitions of spots with higher fire activity suggesti that the spatial distribution varies depending on the evolution of the horizontal patterns of the biophysical drivers.

3.2. Biophysical drivers and fire activity

Annual trends in fire activity along with LST

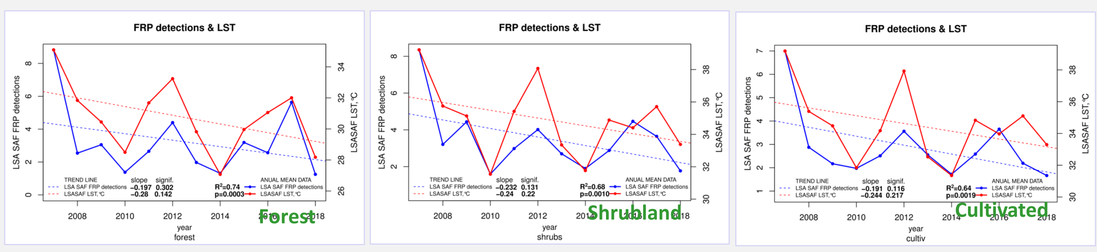


Figure: Time series of fire activity characterised by the number of detections from biomass burning per year FRP, MW (blue line) along with LST (red line) (June-Sep, 2007-2018) for (a) Forest LC; (b) Shrubs LC; (c) Cultivated LC. Each time series is fitted with a trend line using linear regression technique (least-squares method).

Comparison of LST (at 0900 UTC) with the FRP detections:

- The course of LST over time (red lines) shows synchronized behavior with the number of detection (blue lines) for all vegetation types
- Existing linear relationship between the parameters: Trend lines of both parameters LST (red dashed line) and FRP (blue dashed line) for the considered LC types are obtained. The coefficient of determination R^2 shows how much of the observed scatter in the data is due to the hypothetical linear component as opposed to the unexplained random error.
- Despite the rather complex nature of the curves, the resulting R^2 values confirm a significant linear component (values bottom right in the panels).

3.3. Statistical analyses

A. Box plots of fire activity, FRP-Pixel detections

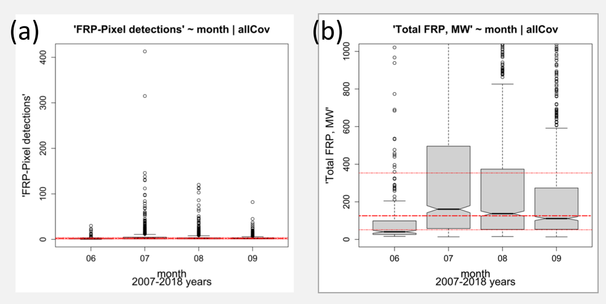
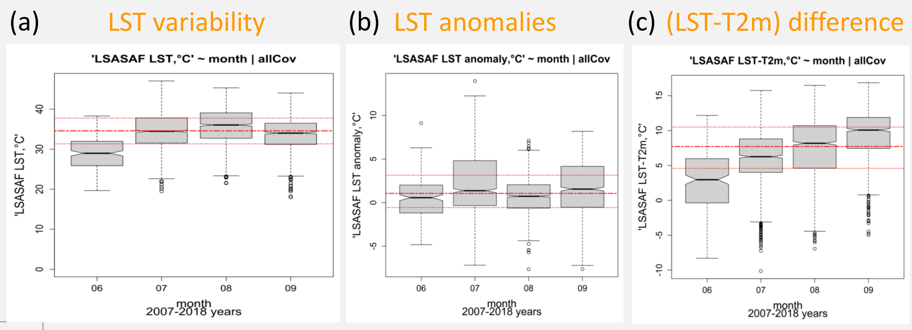


Figure: Graphical images of the concentration of the FRP detections (a) and energy released (b) during Jun-Sep:

- Extreme high values are farthest from the median in July (valid for each of the LC types).
- The variability of released energy is highest in July, from 58 MW to 496 MW (all LC types).
- Mean energy released occurs in July and accounts to about FRE = 160.95 MW, being the higher for shrubs than for forest LC.

B. Boxplots of energetic loading: LSASAF LST index



a) LST increases from June to August, with a more pronounced peak for shrubs/cultivated than for forest LC, while
b) LSTs anomalies exhibits its maximum in July (shrubs/cultivated LC) and in September (forest)
c) Related to steadily increase of (LST-T2m) temperature difference; for shrubs/cultivated it can reach about 12 °C, while for forest up to 5 °C.

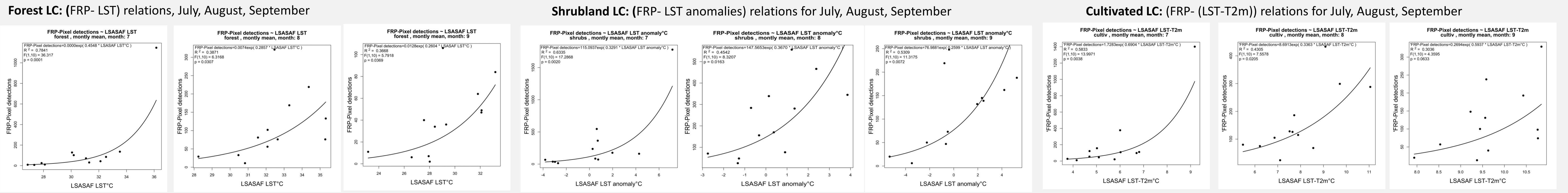
All fires in the period July-September occur in days associated with positive values of LST anomalies around the same location . All 25 % of the fire detections in days associated with negative anomalies of LST occurs in June at forest and shrubs LCs. This result suggests that in June some fires may mostly occur in dead fuel while the canopy temperature is below the historical average for today's day-of-year.

C. Correlation analyses: All results suggest that the biophysical index LST and related parameters LST anomalies and (LST-T2m) are sensitive to the dynamics of vegetation fires occurrence and severity for all studied LC types.

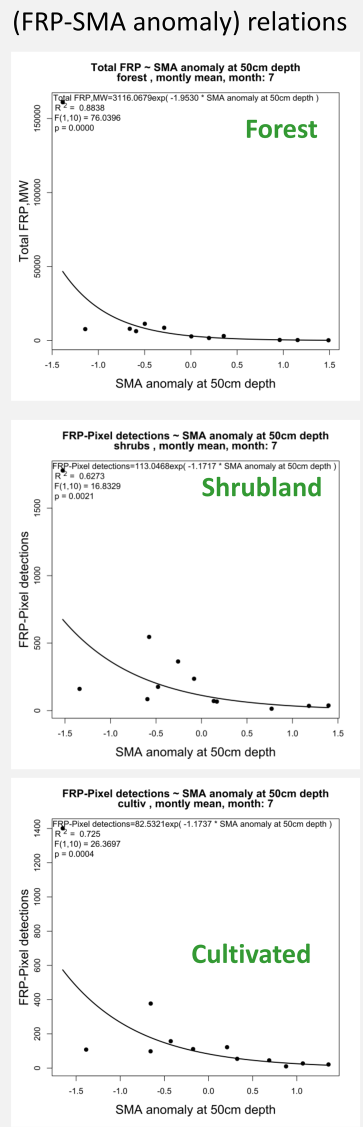
Forest LC: (FRP- LST) relations, July, August, September

Shrubland LC: (FRP- LST anomalies) relations for July, August, September

Cultivated LC: (FRP- (LST-T2m)) relations for July, August, September



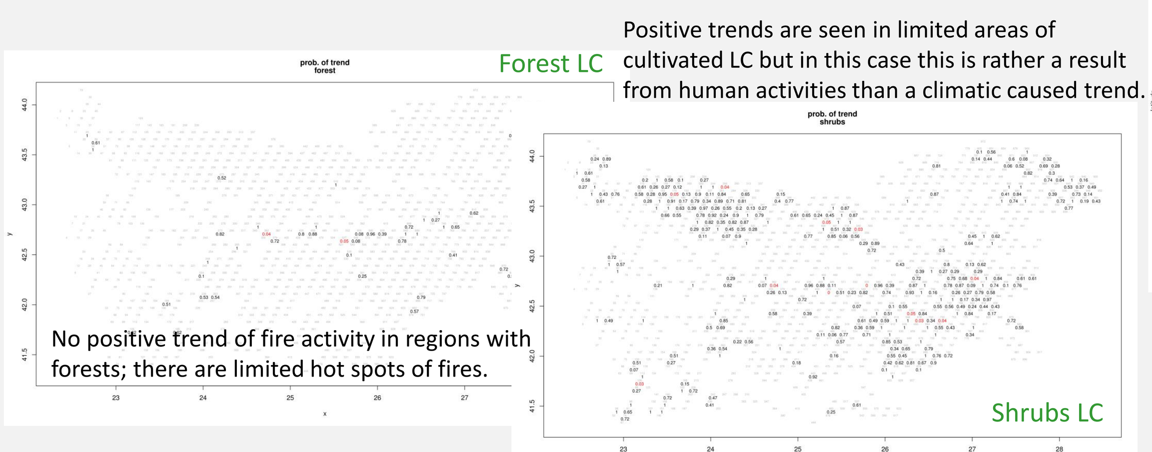
(FRP-SMA anomaly) relations



3.4. Trends in Fire activity towards trends in LST/SMA anomalies

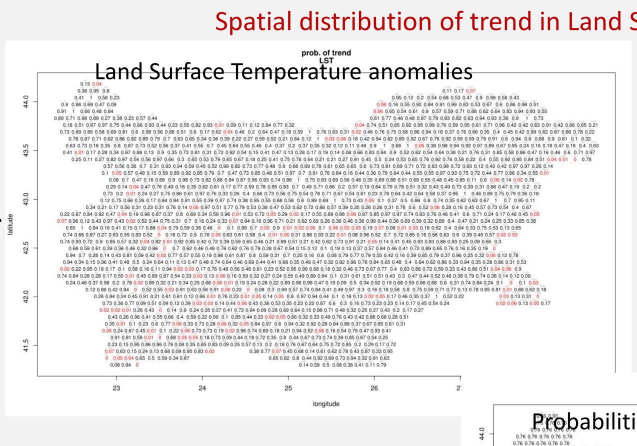
Locations with positive trend in fire activity

Positive trends are seen in limited areas of cultivated LC but in this case this is rather a result from human activities than a climatic caused trend.



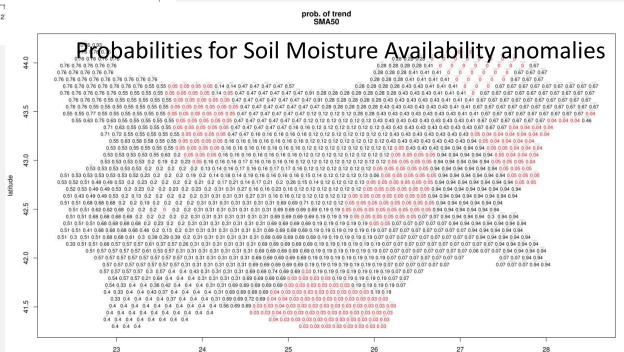
Maps of spatial distribution of fire activity characterized by the LSASAF FRP-Pixel product & Locations with statistically significant positive trend in fire activity, localized by Mann-Kendall test, in red.

Spatial distribution of trend in Land Surface state over Bulgaria



- In very few spots there is a statistically approved positive trend of fire activity in forest, shrub land.
- The small number of these spots does not allow to make clear conclusion for their relations with areas of high probabilities for trends of positive LST and/or negative SMA anomalies.
- Although in some cases it is seen.

Locations with positive trend (Mann-Kendall test) in LSASAF LST anomalies indicated in red.



Locations with positive trend (Mann-Kendall test) in SMA anomalies indicated in red.

4. Concluding remarks

- The study confirms that fire regime / occurrence exhibits characteristic spatial and temporal patterns that reflects differences in the relative importance of various environmental drivers:
  - The driving role of LST and related biophysical parameters in the spatial-temporal evolution of fire activity in Eastern Mediterranean is demonstrated.
  - The dependences are valid for forest, shrubs and cultivated LCs at high significant level.
- These indicate that satellite IR retrievals of radiative temperature is a reliable source of information for vegetation dryness and fire occurrence.
- In this regard, identification of the region's most vulnerable to biomass burning is of importance regarding some prevention activities.
- To advance the added value by using LST as a biophysical index of drought for fire management, further evidences in support of this approach are seen:
  - First, to use the related FRP products from MODIS sensor to validate the usefulness of this approach for short-term applications;
  - Second, to evaluate and adapt the LST applications in operational mode.

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