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Improved Fire Weather Index assessment based on the satellite weather data and soil moisture deficit

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SUMMARY

The method of fire danger assessment using an improved Fire Weather Index is proposed. A modification of FWI method involves utilization of the soil moisture deficit, in addition to the six components (subindices) of the FWI system, which are predictors of daily potential fire. In order to calculate the subindices values weather data are downloaded from the Copernicus Atmosphere Monitoring Service. Soil moisture deficit is calculated using Sentinel-1 radar satellite data on water saturation degree of soil surface layer and geospatial parameters from 3D Soil Hydraulic Database of Europe.

Introduction

Satellite data is the important source of information for active fire monitoring as globally (*Chuvieco et al, 2020*), as well as at regional level (*Shumilo et al, 2020*) as well as fire danger assessment. It also provides a lot of models for fire risk assessment (*Hernandez-Leal et al., 2006; Kussul et al., 2010*). Today the Fire Weather Index (FWI) is one of the most common of fire danger assessment at the global and regional levels in the world. FWI developed in Canada (*Wagner, 1987*) and used in the Canadian Forest Fire Danger Rating System (CFFDRS). CFFDRS regularly provides fire intensities and temperature anomalies maps and also supports relevant online resources of South-East Asia and Mexico. FWI is used as criteria for the harmonized fire danger assessment of in the European Forest Fire Information System (EFFIS) that provides near real-time and historical information on the forest fires levels in the Europe, Middle East and North Africa regions. Despite its wide dissemination worldwide and relative universality, *FWI* has limitations due to its components. They are determined only from meteorological data and without taking into account the fuel type or, at least, the ecosystem type or land cover, because they were developed for forest fires. The latter reduces the relevance - the degree to which *FWI* assessments conformity the actual fire danger for natural ecosystems other than forests. Therefore, the accuracy of assessment is reduced. A significant limitation is the low spatial resolution of meteorological data. Therefore, the fire danger assessment and forecast can be carried out with low accuracy. Thus, the direction of improving the fire weather index *FWI* is an enhancement of spatial resolution, relevance and accuracy of estimates. In particular, the enhancement of the spatial resolution of *FWI* assessment maps can be achieved–through the use multispectral satellite data with certain meteorological parameters from various space systems and the use of modern methods of spatial-temporal fusion of the multisensory satellite data. As a result, high spatial resolution fire danger assessment maps can be obtained. Another way to improve relevance, spatial resolution and fire danger accuracy assessments could be to estimate an improved index based on a combination of the *FWI* and soil moisture deficit.

The aim of the study is to estimate an improved fire weather index based on the satellite weather data and soil moisture deficit.

Methodology

The improved fire weather index FWI_{impr} is proposed to be calculated as a linear convolution of two partial criteria normalized to a single score scale [0, 100] - weather index *FWI* and soil moisture deficit (SMD) estimated using satellite data. The improved fire weather index calculation scheme according to the specified idea is shown in fig. 1. The weather index is calculated using satellite data and well-known algorithms implemented in the CFFDRS. Six components of this system are (Fig. 1): three fuel moisture codes (*FFMC*, *DMC*, *DC*) and three fire behavior indices (*ISI*, *BUI* and general index *FWI*). They are calculated from weather data and provide numeric assessment of the relative probability for wildland fire. The source data for the sub-components calculation are noon temperature, relative humidity, rainfall (accumulated in 24 hours) and / or wind speed.

To estimate the moisture deficit in the soil using data from soil hydraulic database and radar satellite data, a methodology was developed and tested in (*Pidgorodetska et al.,2021*), according to which the moisture deficit in the soil surface layer with a depth of 0.05 m is ultimately determined as follows:

$$m = 10h\rho_w(\theta_{FC} - SSM \cdot n),$$

where h (m) is the soil layer depth; note that given limited capabilities of satellite radar imagery $h = 0.05$ m; ρ_w (t/m^3) is the density of water, 1 t/m^3; θ_{FC} (%) is weighted average value of the volume field capacity on a given depth range; here $\theta_{FC} = \theta_{FC\_0-5}$ for the first standard depth range 0–5 cm (*Tóth et al., 2017*); SSM (%) is the soil saturation degree from satellite radar data; n (in unit fractions) is the porosity, i.e. the ratio of the pore volume to the entire soil volume.

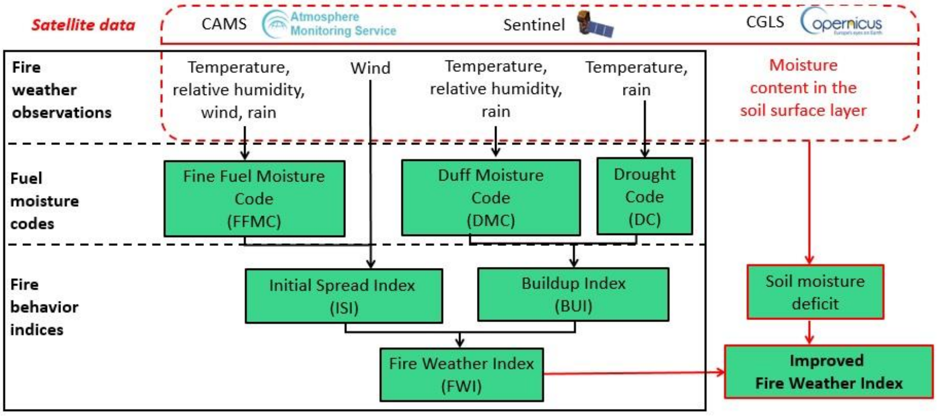

Figure 1 *Scheme for calculation of Improved Fire Weather Index based on the combination of FWI and soil moisture deficit estimated using satellite data*

Procedures for converting SMD expressed in physical units into scores, as well as procedures for determining 6 levels fire danger threshold values for the normalized moisture deficit and the resulting improved fire weather index FWI_{impr} have been developed. As a result, the FWI_{impr} rasters classification into 6 fire danger levels was carried out using the threshold segmentation and fire danger levels maps were constructed for the territory of Ukraine.

Examples

Testing and approbation of the proposed approach to improving the index FWI were carried out on the territory of Ukraine based on satellite observations for the period of August 10–15 2021.For the calculation of the standard fire weather index FWI, Copernicus Atmosphere Monitoring Service (CAMS) data from 15.08.2021 are used regarding air temperature at height of 2 m, wind speed at height of 10 m, relative humidity of air and precipitation quantity for the last 24 hours. To calculate the moisture deficit in the surface soil layer based on satellite data, the SSM CGLS product was selected for the period of August 10-15, 2021 at 1 km spatial resolution and the data from the hydrological soils properties database at 250 m (*Tóth et al., 2017*) and a set of global data (*Bosilovich et al., 2016*) were used. The result of calculating the moisture deficit in the soil surface layer up to 5 cm deep (in mm) was converted to a 100-point scale. The classification of the improved index raster into 6 levels of fire danger was carried out using threshold segmentation and is shown in Fig. 2. Class 1 corresponds to a very low level of fire danger (green), class 2 – low level (yellow), class 3 – moderate level (orange), class 4 – high level (red), class 5 – very high level (purple) and class 6 – extreme fire danger (black). The applied calculation procedure has resulted in a map from 5 fire danger levels according to index FWI_{impr} – from very low to very high (Fig.2). There is no extreme fire danger class on the territory of Ukraine at 15.08.2021.
To compare the results of calculating the fire danger levels using the proposed method, product *FWI* of the Copernicus Emergency Management System (CEMS) (*JRC, 2018*), which is freely available, was selected. This product is calculated using a standard algorithm and is based solely on weather data. The spatial resolution of the product is 0.25 geographic degrees. The map of fire danger levels, calculated according to *FWI (*CEMS) data for the territory of Ukraine at 15.08.2021, is shown in Fig. 3.

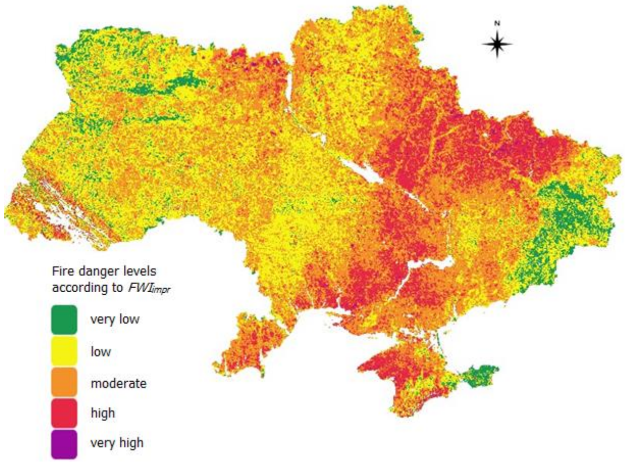

Figure 2 *Map of fire danger levels according to the improved fire weather index* FWI_{impr} *at 15.08.2021*

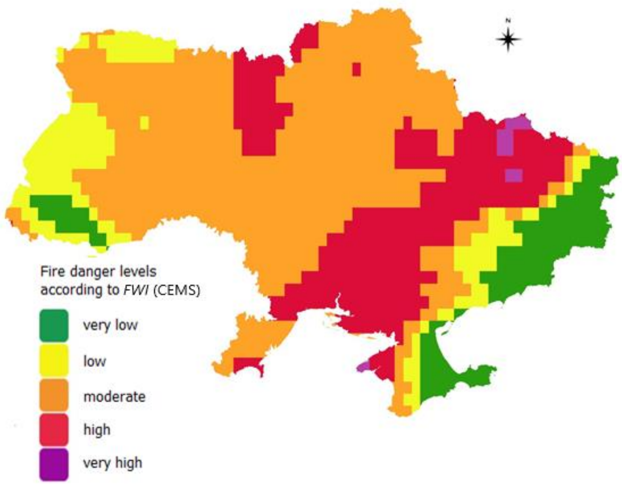

Figure 3 *Map of fire danger levels for Ukraine according to FWI (CEMS) at 15.08.2021*

The conformity assessment of the FWI_{impr} fire danger level map (Fig. 2) to the *FWI* (CEMS) fire danger level map (Fig. 3) was carried out on the basis of the confusion matrix. Conformity (overall accuracy) of the fire danger level map according to the FWI_{impr} with the *FWI* (CEMS) fire danger level map was 42.23 %. This percentage of compliance is explained both by a significant difference in the spatial resolution of the compared maps (0.25 geographical degrees and 250 m, respectively), and by the difference in the data sources on the basis of which they are built – exclusively weather data for the standard index *FWI* (CEMS) and a combination of weather, satellite data and geospatial information on the hydrological properties of the surface soil layer for an improved index FWI_{impr}.

Conclusions

1. The method of fire danger assessment using an improved Fire Weather Index FWI is proposed. A modification of *FWI* method involves utilization of the indicator of soil moisture deficit, in addition to the established six components (subindices) of the *FWI* system, which are predictors of daily potential fire. Soil moisture deficit (SMD) is obtained from Sentinel-1 radar satellite data of the

degree of water saturation of the soil surface layer, which significantly affects the possibility of occurrence and course of fire in the natural ecosystem.
2. To calculate the moisture deficit of the upper layer, in addition to satellite data, geospatial data are also used, in particular, regarding the physical and hydrological characteristics of soils. Calculations of the steady-state sub-indices of the *FWI* system included weather data from the CAMS service. The application of the proposed methodology using the specified satellite, weather and geospatial data makes it possible to assess the fire danger on a continental scale with a spatial resolution of 250 m and 1 km and a daily temporal resolution.
3 Approbation of the proposed method for modifying the *FWI* system demonstrates a fundamental improvement in the accuracy and relevance of fire danger prediction. Further refinement of the method will concern the introduction of machine learning to improve the quality of the generalized index as a linear convolution of partial criteria of fire danger. It is planned to use the developed method in the information technology being created for assessing fire danger and monitoring fires using satellite data on the territory of Ukraine.

Acknowledgement

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