FIRE DANGER ASSESSMENT BASED ON THE IMPROVED FIRE WEATHER INDEX

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ABSTRACT

This paper analyzes the problem of fire danger assessment and identifies the necessary sources and characteristics of satellite, ground and statistical data for the new approach of fire danger assessment. Modern information systems for fire danger assessment and fire monitoring using satellite and weather data are considered. The fire danger assessment method has been adapted for all types of land cover in Ukraine, which previously was successfully used in the Canadian methodology for determining the Fire Weather Index (FWI).

Index Terms— fire monitoring, FWI, satellite data, information technology, weather data

1. INTRODUCTION

Today at the global and regional level there are modern information systems for fire danger assessment and fire monitoring, in particular, with the use of satellite data [1]. In most countries, such systems are based on fire danger assessment using weather conditions. In particular, Canada, New Zealand, Fiji, Mexico, Alaska, Florida, Michigan, Croatia, and Southeast Asian countries use the Canadian Forest Fire Danger Rating System (CFFDRS), Australia - McArthur Forest Fire Danger Index [2]. The United States uses the National Fire Danger Rating System [3]. NASA's Fire Information for Resource Management System (FIRMS) provides near-real-time active fire data for 3 hours after satellite observations using the Moderate Resolution Imaging Spectroradiometer (MODIS) on board NASA Terra and Aqua satellites and the Visible Infrared Imaging Radiometer Suite (VIIRS) aboard NASA/NOAA Suomi NPP and NOAA-20 National Polar Orbit Partnerships [4], [5]. Since April 2014, the Copernicus Global Land Service is providing a burned area product with a spatial resolution of 300 m, generated every 10 days based on PROBA-V satellite data. The Global Fire Emissions Database contains satellite information (500 m MODIS) on fire activity and vegetation productivity to estimate monthly burned area and grid-related fire emissions, as well as data that can be used to calculate emissions with a higher time. The Canadian Forest Fire Hazard Assessment System has been under development since 1968. Currently, there are two subsystems, on the base of Canadian Forest Fire Weather Index (FWI) and the Canadian Forest Fire Behavior Prediction, which are widely used in Canada other countries. The European Forest Fire Information System (EFFIS) is a web-based geographic information system that provides information on forest fires and fire regimes in Europe, the Middle East and North Africa in near-real-time and historical terms. Currently, the EFFIS fire danger forecasting module provides access to fire danger indices using numerical weather forecast based on two deterministic models. In particular, the FWI index is calculated according to the model of the European Center for Medium-Range Weather Forecasts (8 km element grid), which provides forecasts for 1-9 days, and the French model MeteoFrance (10 km element grid), which provides forecasts for up to 3 days.

The analysis of fire information and fire danger forecasting systems showed that these systems pay more attention to weather data, which makes their applicability more difficult. The most successful systems are those implemented in Europe and North America (EFFIS, FIRMS, CFFDRS), which use satellite data in their methodologies. However, these systems have been developed in general, taking into account the specific natural conditions and flammability of a particular area and cannot be automatically transferred to any area. Therefore, Ukraine cannot fully borrow their experience without proper modernization. In this paper modification of the FWI index for Ukraine is proposed, taking into account necessity of use of satellite data, weather data and land cover information.

2. MATERIALS

As data sources for fire danger assessment and fire monitoring, satellite, statistical and ground data were used. One of the satellites with high spatial resolution, the data of which allow monitoring fires, are Sentinel-2 and Landsat-8, with medium spatial resolution — MODIS and Sentinel-3 data (Table 1).

The main informative variables for the FWI index retrieval are relative humidity (%, RH), temperature (°C, T), wind speed (km/h, V) and daily rainfall (mm, P), taking into account the threshold value of 2 mm. As a rule, these data are taken from NASA POWER service, which provides meteorological datasets with a spatial resolution of 0.5°×0.5° [10].

Table 1. Satellite data for FWI index

Mission (satellite)	Spatial resolution	Temporal resolution
MODIS Aqua and Terra	250 m (RGBN) 1 km (thermal band)	2 images / 1 day
Landsat-8	30 m (RGBN) 15 m (panchromatic band) 100 m (thermal band) – interpolated up to 30 m	1 image / 16 days
Sentinel-2A, B	10 m (RGBN)	1 image / 5 days
Sentinel-3A, B	300 m (RGBN) 1 km (thermal band)	2 images / 1 day

In this paper, to calculate the FWI fire hazard index, it is proposed to use Copernicus Atmosphere Monitoring Service (CAMS) data with a spatial resolution of 1 km [6]. Besides that, it is advisable to use data from MODIS and Sentinel-3 temperature bands (with 1 km spatial resolution). In addition to satellite data, the State Emergency Service (SES) of Ukraine data were used to assess fire danger (in particular, for verification), as well as data on active fires FIRMS based on satellite data [4].

3. METHODOLOGY

As basic method for fire danger assessment using satellite and weather data, land cover maps characteristics, FWI index calculation was used. The classical scheme for the FWI index retrieval is presented in Fig. 1.

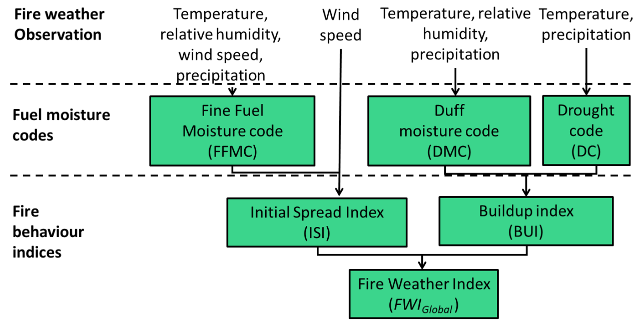

Fig. 1. The classic scheme for the FWI index calculation

The method of FWI calculation is quite cumbersome and the details of general approach are described in [7]-[8]. Despite its relative versatility and widespread worldwide, Canada's FWI fire index has significant limitations due to the fact that its components are determined only by meteorological data and without taking into account the land cover type [9] - [12]. Another important fact is that meteorological data have a sparse spatial resolution, so the forecast of fire danger is carried out for relatively large areas. Therefore, the urgent problem of improving the effectiveness of fire danger assessment is to increase the spatial diversity and accuracy. The idea behind the improvement of the methodology for determining the FWI index is to involve in the formation of a generalized index of fire danger, a factor of soil moisture deficiency. Specifically, it is the Soil Moisture Deficit (SMD) parameter [13], which depends on the soil type, and can be determined using remote sensing data in the microwave range. The usage of SMD in the extended set of parameters for FWI retrieval is shown in Fig. 2.

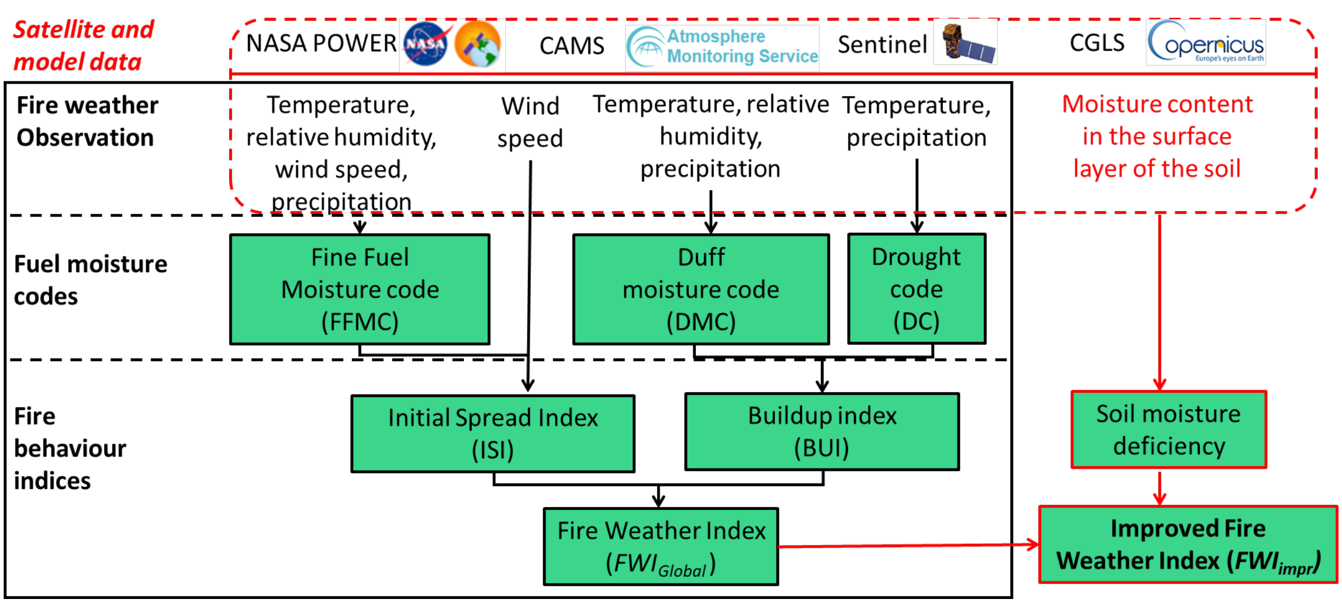

Fig. 2. Modification of the FWI weather fire index using satellite data

For calculation of the FWI index the data from CAMS weather services were also used, in particular, air temperature at a height of 2 m, wind speed at a height of 10 m, relative humidity and precipitation for the last 24 hours. Air temperature data have improved spatial resolution due to the use of ancient Sentinel-3 and MODIS satellites. The resulting scheme of the improved index is shown in Fig. 2. Given that the SMD spatial resolution is 250 m, the improved FWI_{impr} index has the same spatial resolution. The obtained improved fire danger index FWI_{impr} is a score of fire intensity from 0 to 100. Low values of FWI_{impr} indicate weather conditions with low fire danger, and higher values indicate weather conditions with high fire danger.

4. RESULTS

To create fire danger maps based on a modified index, it is necessary to collect large amounts of satellite data, their correct processing using methods and models in cloud infrastructure, to create a set of ground data for the results verification. The developed method of fire danger assessment based on the FWI_{impr} index was implemented on the vase of GEE cloud platform.

Testing of the improved fire danger index was performed using data from the SES of Ukraine on fires in the regions during the summer period for June to August 2021 (Fig. 3), and a comparison was created based on a map of active fires based on satellite data for summer time. The location of active fires is determined using the FIRMS product, which is a probability mask of fires with a scale from 0% to 100%, which shows the probability of fire (Fig. 4). Due to the fact that FIRMS data is the probability of fire, they were updated using other satellite data that identify active fires [14]. For this purpose, the products of the land surface temperature (for the detection and monitoring of active fire), created on the basis of Landsat-8 data, were used. Also, to refine FIRMS data on active fires, products based on Sentinel-2 high spatial resolution satellite data were used [15].

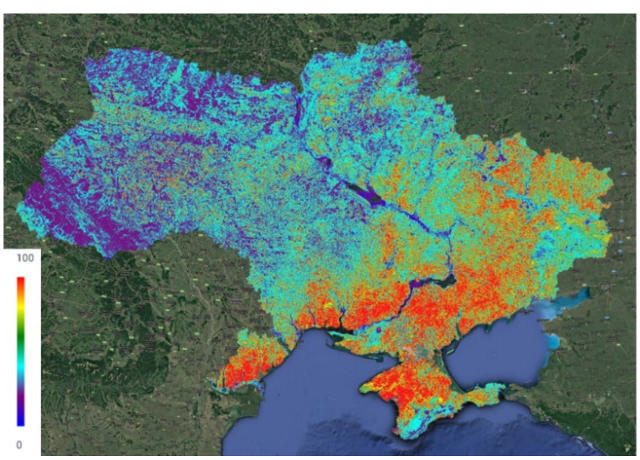

Fig. 3. Improved Fire Weather Index (FWI_{impr}) for summer, 01.06-31.08.2021

The study of dependence evaluation of the fires number according to the SES information with the FWI_{impr} index value (for the summer period Pearson's correlation coefficient 0.65) showed that the index correlates well with real fires in areas observed at different times of the year. According to the results of FWI_{impr} comparison for the summer period, the dependence of the number of active fires in the regions of Ukraine was estimated according to satellite data and the average index for this period. As with satellite data and the fire danger index, most fires are located in the southern and south-eastern parts of Ukraine, as shown in Fig. 3 and Fig. 4. The dependence of such fires on oblasts is shown in Fig. 5 (each point corresponds to one oblast).

Fig. 4. Probability of fire according to FIRMS 01.06-31.08.2021

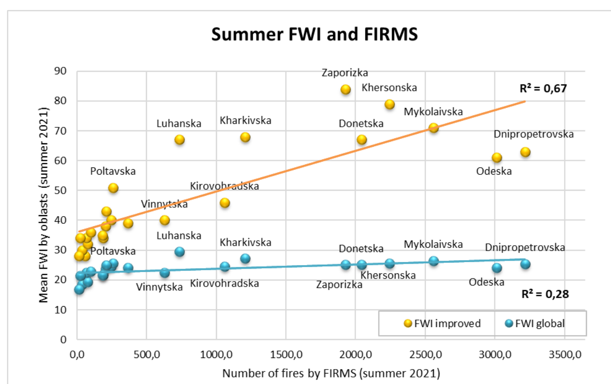

Fig. 5. Estimation of dependence of the active fires number by regions according to FIRMS data on the Improved Fire Weather Index in summer

The obtained resulting dependency allows us to state that the combination of weather and satellite data, especially for the summer period, makes it possible to assess fire danger with a coefficient of determination greater than 0.6, which is much better than existing global data (0.28). The Table 2 provides the information on correlation between global data, SES data, satellite fires and the improved fire risk index. The improved fire safety index correlates best with FWI_{Global}

(0.77) and FIRMS (r = 0.82). The best correlation is between the FWI_{impr} index and the improved active fires according to satellite data.

Table 2. Correlations between data

	SES	FWI_{Global}	FWI_{impr}	FIRMS
SES	1	0,48	0,65	0,76
FWI_{Global}	0,48	1	0,77	0,52
FWI_{impr}	0,65	0,77	1	0,82
FIRMS	0,76	0,52	0,82	1

5. DISCUSSION AND CONCLUSIONS

The problem of fire risk assessment in Ukraine is analyzed and the necessary sources and characteristics of satellite, ground and statistical data for a new approach to fire risk assessment are determined. Based on the modified FWI_{impr} index methodology, a new method of fire danger assessment has been developed. Modification of the basic FWI_{Global} method involves, in particular, the involvement of the index of moisture deficit in the soil in addition to the established six components (sub-indices) of the FWI system, which are predictors of daily potential fire. Their calculations include weather data from the CAMS service, which have higher spatial resolution compared to global data from NASA Power. The new method with the use of satellite, weather geospatial data allows to obtain the FWI_{impr} index with a spatial resolution of 250 m. The fire danger assessment method has been adapted for all types of land cover in Ukraine. The assessment of the accuracy of the obtained index is confirmed by the obtained dependences on the basis of real fires according to the SES data and active fires hotspots from satellite data. In view of this, the above estimates of comparison look quite encouraging for the continued use of the approach.

6. AKNOWLEDGEMENTS

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