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SATELLITE APPLICATIONS IN MARINE AND LAND SURFACE ANALYSES FOR ENVIRONMENTAL RISK ASSESSMENT

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***Key words**: Meteorological and polar satellites, numerical modeling, diagnoses/ forecast, Black Sea coastal hazards, terrestrial hazards on vegetated land surface*

***Abstract:** The operational marine forecasting products for the Black Sea generated at NIMH-BAS using atmospheric model ALADIN and two spectral wave models WAVEWACH III and SWAN are presented. Satellite altimeter products are used as a reference for the verification and calibration of the operational wave models. The near real time significant wave height from radar altimeter instruments on the Jason-2/3, SARAL Altika and Sentinel-3 satellites are received, decoded, quality controlled and used for the wave model validation and calibration. Results from verification of the wave model WAVEWATCH III against the altimeter data from JASON-2/3 and SARAL Altika satellites are reported.*

Biogeophysical/ biochemical processes on vegetated land surface are quantified on the bases of three numerical models (meteorological 'SVAT_bg', thermodynamic, bioclimatic). Model outputs are combined used with ECMWF forecasts and satellite data in the developed Information System of Land Surface State and the anomalies related terrestrial hazards. The System includes development of meteorological products for territory of Bulgaria with following applications: thermal anomalies detection, assessment/forecast of agrometeorological drought, energetic bioclimatic resources and crop productivity, fire risk forecast, climate and five static fire risk.

Perspectives for SENTINEL missions use, together with available satellite information by EUMETSAT and other agencies for the region of southeastern Europe are discussed.

ПРИЛОЖЕНИЯ НА СПЪТНИКОВА ИНФОРМАЦИЯ ЗА ОЦЕНКА НА ПРИРОДНИ РИСКОВЕ ПРИ МОРСКА И ЗЕМНА ПОВЪРХНОСТ

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***Ключови думи**: Метеорологични и полярни спътници, числено моделиране, диагноза/прогноза, природни бедствия по крайбрежието на Черно море, природни бедствия на растителна повърхност*

***Резюме:** Представени са оперативните продукти за морски прогнози на Черно море, генерирани в НИМХ-БАН като се работи с атмосферния модел ALADIN и два спектрални вълнови модела WAVEWACH III and SWAN. Продукти от спътников алтиметър се използват като референтна информация за верификация и калибриране на оперативните вълнови модели. Данни за височината на вълнението, получени във време близко до реалното от радарни алтиметри на спътниците Jason-2/3, SARAL Altika и Sentinel-3 се декодират и след контролиране за качество се използват при валидилане и калибриране на вълновите модели. Докладват се резултати от верификацията на вълновия модел WAVEWATCH III посредством алтиметрични данни от спътниците JASON-2/3 и SARAL Altika.*

Биогеофизичните/биогеохимични процеси на растителна земна повърхността се описват количествено на базата на три числени модела (метеорологичен 'SVAT_bg', термодинамичен, биоклиматичен). Моделните резултати, комбинирани с прогнози от ECMWF и спътникова информация се използват в разработената информационна система за състоянието на земната повърхност и свързани с това природни бедствия. Системата включва метеорологични продукти за територията на България със следните приложения: детекция на термични аномалии, оценка/прогноза на агрометеорологична суша, енергетични биоклиматични ресурси и продуктивност, прогноза на пожароопасност; климат и пожароопасност.

Обсъждат се перспективите за използване на SENTINEL мисиите съвместно с наличната спътникова информация за региона на югоизточна Европа от EUMETSAT и други агенции.

Introduction: Weather and climate extremes result from the coupled interactions between atmosphere and the Earth system, comprising water and terrestrial land surfaces, by a number of biogeophysical and biochemical processes. Observations from geostationary and polar orbiting satellites provide valuable information for diagnoses/forecasts the Earth system process through its using in physically motivated concepts and numerical schemes, and on this bases for issuing early warnings of extreme events. The National Institute of Meteorology and Hydrology - Bulgarian Academy of Sciences (NIMH-BAS) has a long history in using satellite data for a variety of purposes, starting with synoptic applications in 1968 (1). We are working on use of satellites in marine meteorology since 1994, become a full member of EUMETSAT in 2014, and from 2017 we are members of the Consortium of the Land Surface Analyses Satellite Application Facilities (LSA SAF) program of EUMETSAT.

This paper presents the research and operational activities at NIMH-BAS for diagnoses and forecast of environmental constrains and risk assessment over the two components of the Earth surface – marine (Black Sea) and vegetated land for the region of Bulgaria.

A. Satellites in support to Black Sea Surface Analyses and related coastal hazards

The coastal zones are areas of high vulnerability to natural hazards. The combination of strong winds and high waves is associated with extreme events: coastal erosion, overtopping and flooding. NIMH-BAS is responsible for the wind and wave forecasts in the Black Sea. The operational Numerical Weather Prediction (NWP) and wave models are used to identify the hazard zones of strong winds and high waves along the coastal zone and in the deep waters. The accuracy of numerical models is of great importance. Satellite altimetry plays an important role in predicting waves and have been used at NIMH-BAS to assess the quality of wind and wave forecasts in the Black Sea.

Methodology: The wave forecasts verification for the Black Sea is a difficult task because of lack of conventional wave data from buoys and weather ships. The recent advances in satellite technology have created a possibility to use remotely sensed wave data for wave model verification. Significant wave height (SWH) are determined using the satellite altimeter measure that have been used to validate and calibrate the wave models**.** The satellite and model data represent different time and space resolution. The data collocation procedure is applied to match the satellite and model data.

Development of the operational system for marine forecasts at NIMH-BAS

The Black Sea wave forecasts system is in operational use at NIMH since 1994. The system is a result of the bilateral cooperation between the NIMH-BAS and Meteo-France. The state of the art numerical wave models were implemented and cutting edge satellite technology was applied at NIMH (2). The ERS-1/2 and TOPEX-Posseidon altimeter data were used for validation the forecasts results from the NWP and numerical spectral wave models for the Black Sea (3, 4). Twenty years later the system is fully upgraded with the new versions of the atmospheric and marine numerical models (5, 6) and near real time altimeter data from Jason2/3, Saral Altika and Sentinel-3 satellites. The core of the current Black Sea operational wave forecast system is based on the SWAN (7) and WAVEWATCH-III (8) numerical wave models The operational wave forecast system runs two times daily (at 06 and 18 UTC) using atmospheric data (wind speed and direction etc.) from the NWP model ALADIN (9). The wave models cover the geographical area of Black Sea with a spatial resolution of 0.125° x 0.125° (WW3) and 0.0833 degree (SWAN) and issues 72-hour forecasts of SWH and mean wave direction. The results from forecasts are presented as maps of wind and wave parameters (Figs.1b and c). Marine forecasts distributed through the INTERNET to the end-users: the regional office of NIMH-BAS in Varna; executive Agency Maritime Administration, Maritime Rescue Co-ordination Centre and Bulgarian Ports Infrastructure Company in Varna. The System is used for issuing "warnings of danger" disseminated through the web-based service Meteoalarm (Fig.1a), to warn people in Bulgaria of severe weather and hydro-meteorological hazards along the Bulgarian coastal zone of Black Sea.

(a) (b) (c)

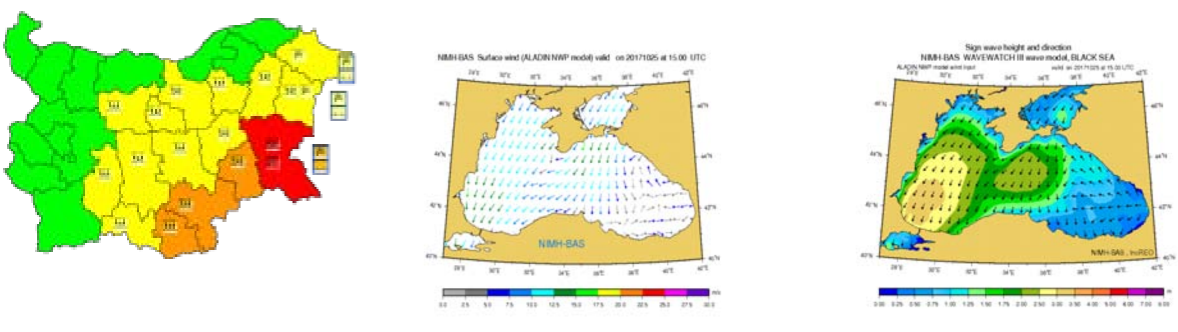
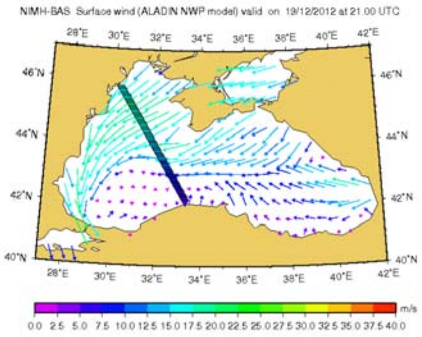


Fig. 1. (a) Meteoalarm (red-cod: strong winds 20-24 m/s and high waves 4-5 m), (b) wind forecast ALADIN model and (c) wave forecast WW3 for the storm situation in the Black Sea on 25.10.2017

Satellites in support to verification the Numerical Weather Prediction Models: The wind forecasts (at 10m) is used for atmospheric forcing of the wave models and their quality influences the wave model results. The altimeter derived wind data from satellites Jason2/3 are used for the verification of NWP model ALADIN. The map of surface wind field during the storm in the Black Sea on 19.12.2012 produced by the ALADIN model is presented in Fig. 2a with the along track altimeter data and the comparison of model-satellite wind data Fig. 2b. There is a good agreement between model ALADIN and the along Jason-2 track satellite wind data. Trough the bilateral cooperation between NIMH-BAS and Russian Federal Service for Hydrometeorology and Environmental Monitoring, ROSHYDROMET provides NIMH with wind data from the Advanced Scatterometer (ASCAT) on board the Metop-A satellite.

(a)



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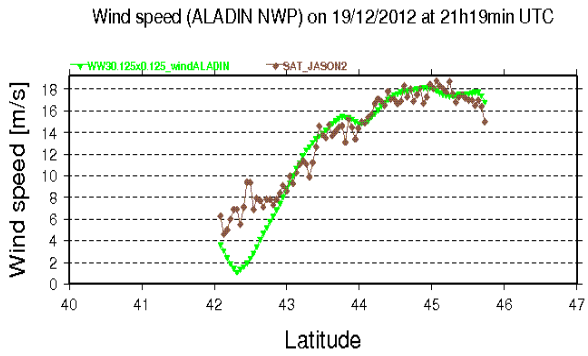
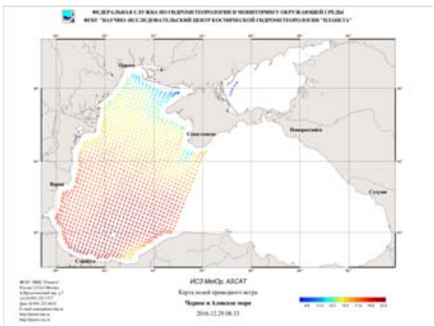


Fig. 2. (a) Surface wind field from ALADIN model and the along track wind speed from Jason-2 above the Black Sea on 19 December 2012 at 21h19min (storm situation), (b) collocated model-satellite wind data

(a)



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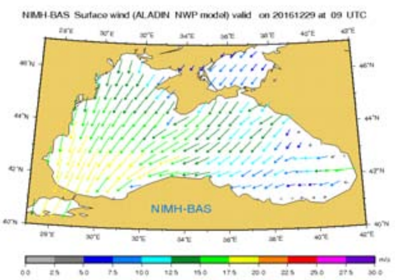
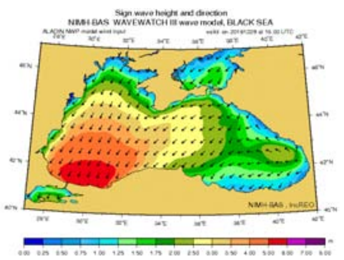


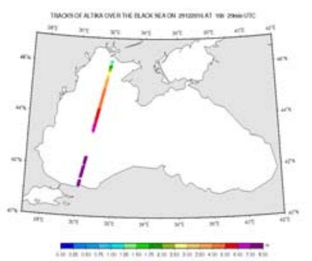
Fig. 3. (a) Wind speed from ASCAT MetOp and (b) ALADIN wind forecast in Black Sea storm on 29.12.2016

Satellites in support to verification the Numerical Wave Models: Jason-2 and Jason-3 satellites continuously provide full-orbit measurements with a 10-day recurring cycle, produced and disseminated by EUMETSAT in NRT. The altimeter data has been routinely streamed through the Global Telecommunication System (GTS) to NIMH-BAS since July 2012, SARAL Altika since May 2014 and Jason-3 since April 2016 and are used for the improving forecasts quality. The altimeter-derived wave heights SARAL Altika and Jason-2/3 are available along the satellite ground track. The wave parameters are derived from the satellite altimeters measurements. Fig. 4a illustrates SWH forecast from wave model WW3 for the storm on 29.12.2016 and available satellite information.

(a)



(b)



(c)

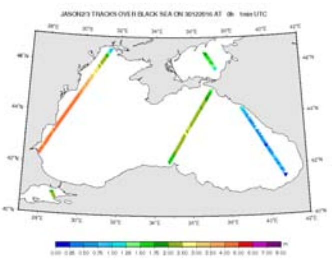


Fig. 4. Map of WW3 SWH: (a) in the Black Sea (the arrows indicates the mean wave directions), the colored line (b) along the track of SARAL Altika satellite over the Black Sea during the storm on 29.12.2016

Additional information on the wind and waves from the Copernicus Sentinel-3 satellite is planned for operational use at the NIMH-BAS from December 2017.

B. Satellites in support to Land Surface State Analyses and related terrestrial hazards

Compared to the ocean, the interactions between land surface and the atmosphere are far more complex and diverse. This complexity comes from a number of reasons: Land surface topography influence the irradiance distribution; The soil characteristics determine together with topography the highly variable spatial distribution of soil moisture availability for transfer into the atmosphere; Vegetation penetrates into both, soil and atmosphere, and further complicates the exchange processes by additional interaction modes and interdependencies. Moreover, these exchange processes take place on almost infinitively small scales due to the multi-fractal structure of the interface between the systems. Land surface heterogeneity additionally complicates the problem of quantification of atmosphere-terrestrial biosphere interface.

Methodology: Due to the spectral characteristics of sensors and high space/time resolution of contemporary satellite information available for the region of southeastern Europe it is a valuable tool for LSA. Research is based on integrating land surface simulations, observations from SYNOP network, NWP ECMWF forecasts and satellite observation methods to accurately determine land surface energy and moisture states. For land surface simulation three types of models are used: a) meteorological model for quantification of Soil-Vegetation-Atmosphere Transfer processes, 'SVAT_bg' (10); b) thermodynamic model of ecosystem functioning (11, 12); c) regional bioclimate classification model (13). Operational satellite information received trough EUMETCast, MSG, Aqua/Terra (available till Feb 2017) fire products and LSA SAF products *(https://landsaf.ipma.pt/)* are used. All these sources of information are combined for development of meteorological products/systems for operational use to assess/forecast the land surface state anomalies and related natural hazards.

Development of Information System for Land Surface State (ISLSS) at NIMH-BAS: Land surface modeling seeks to predict the terrestrial water, energy, and biogeochemical processes by solving the governing equations from the standpoint of vegetation cover and up scaling of knowledge within the soil-plant-atmosphere continuum between regimes of increasing spatial scale. This work is based on our experience from laboratory-controlled environment (e.g. 12) and landscape analyses using satellite information in characterizing space-time anomalies and their variability.

(a) Satellite system for detection/monitoring of thermal anomalies and vegetation fires:

An operational System based on using information from geostationary Meteosat satellites and NASA/NOAA polar orbiting Aqua/Terra (available via EUMETCast up to Feb 2017, now replaced with S-VIIRS 750m) for active fire monitoring has been developed since 2007. It is used for meteorological services of State Forest Agency and Ministry of Inner Affairs of Bulgaria. In parallel validation of fire products is performed (for accuracy, sensitivity, vegetation type, fire at/down the canopy etc.).

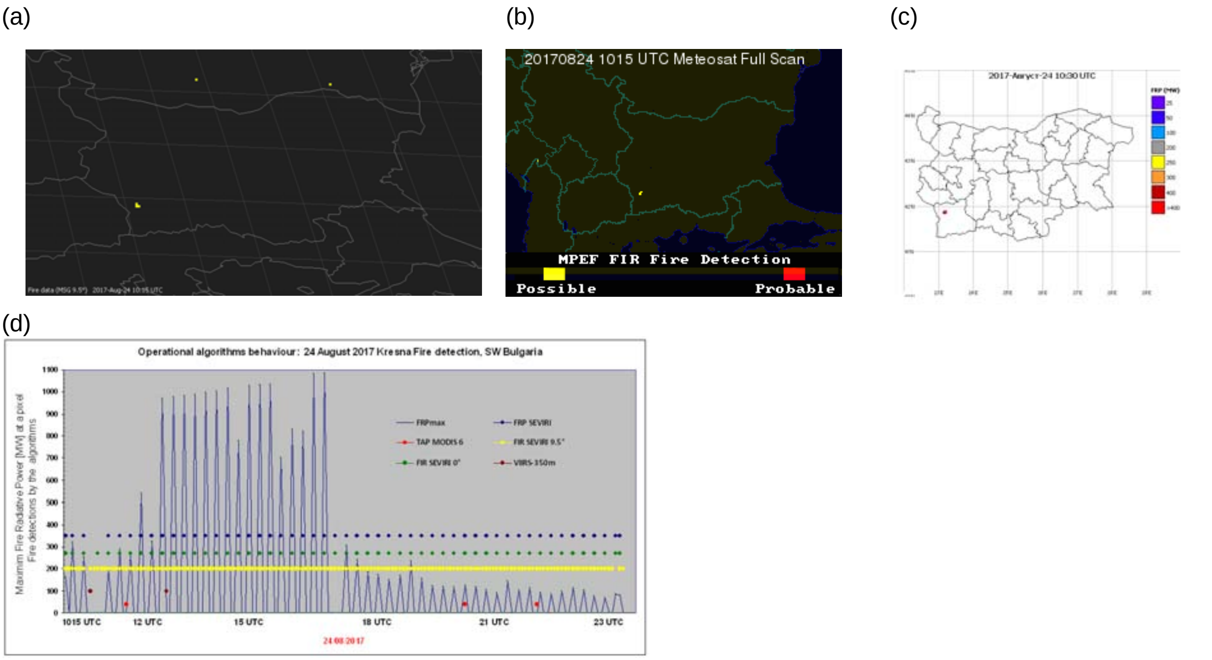


Fig. 5. Active fire detection at Kresna gorge on 24 Aug 2017 by available satellite products (a) MPEF FIR Rss; (b) MPEF FIR Full Scan; (c) LSA SAF FRP; (d) Summary of satellite monitoring of active fire development

Geostationary and polar orbiting fire detections complement each other in fire behavior evaluation for developing an efficient fire warning system for the region of southeastern Europe, illustrated on Fig. 5. This is an example of the early warning provided by our System for the large fire on 24-28 August 2017, Kresna, SW Bulgaria, giving the first signal at 10:15 UTC, and evaluation of its dynamics.

(b) Agricultural drought warning system: Here we accent on agricultural drought that is defined as a combination of meteorological and hydrological droughts, resulting in reduced supply of moisture levels for crops, i.e. Soil Moisture Availability (SMA). SMA being the main determinant of plant systems development is a basic parameter in mesoscale atmospheric circulation models, and at the same time might serve as information source for “warnings” for environmental constrains. A model approach for quantification of SMA in root zone depth has been developed (10). This approach together with thermodynamic modeling of ecosystem fuctioning (11, 12) is used as a methodological background for development of a Drought Warning System (DWS). DWS comprises three levels of warnings: Watch – Warn, indicating different levels of agricultural drought severity, and Alert, indicating risk of yield reduction (13). The System is in a pre-operational phase of development.

Satellite information is used in the context of the model developed conceptual DWS scheme. Due to its close relationship to soil moisture, the Land Surface Temperature (LST) is an important parameter for monitoring changes in surface conditions. As indicator optimized for characterizing vegetation water stress and drought, which is related to energy and water cycles, the temperature difference between MSG LSA SAF LST product and air temperature (T2m) at 2 m height is used. Based on a set of thresholds linking root zone SMA and the level of this temperature difference, agricultural drought (severity) is scaled in three levels. On this bases, maps for diagnoses and two days ahead forecast of drought severity are daily, operationally produced. Using (LST – T2m) Index as a proxy of entropy production in canopy leaves (that can quantify climatic bioenergetic resources according 11,_12), analytical description of its relation to crop yield has been developed and applied for predictions. Fig. 6 illustrates the DWS concept and the set of indexes for real drought situations over Bulgaria based on using Meteosat information.

(a) (b) (c)

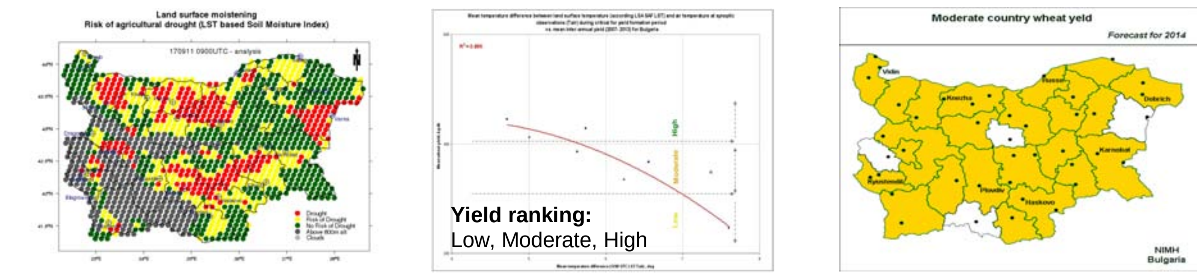


Fig. 6. Satellite information in support to agricultural drought assessment based on (LSA SAF LST-T2m) temperature difference index. Examples: (a) Diagnostic map of spatiotemporal distribution of drought in a 3- level scale. Calculations at ECMWF model resolution; (b) Analytical description the link between climatic bioenergetic resources and crop yield (NIMH agro database yield estimates); (c) Predicted mean country yield of winter wheat for 2014 (kg/dk), (coincides with the announced by Ministry of Food and Agriculture in Bulgaria).

(c) Satellites in support to fire risk assessment and forecast: Available information for short-term fire weather forecasting includes indexes developed (at NIMH-BAS) for operational use. Results are applied in support to short-term fire weather forecasting, issued in public domain. Example of operational system for fire risk warnings is presented on Fig. 7 and it includes:

(a) (b) (c)

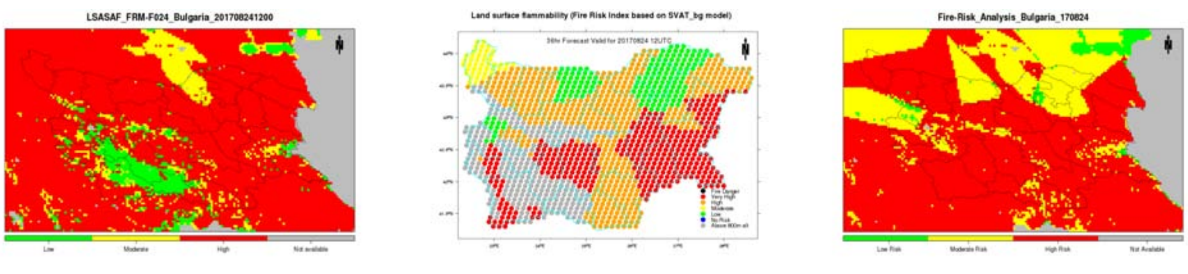


Fig. 7. Fire risk diagnoses/forecast, example maps for 24/08/2017: (a) Meteorological fire risk after LSA SAF FRM 24 h forecast; (b) Spatiotemporal distribution of SMD/fuel dryness and related fire risk; (c) CoFRI

- Fire weather forecast according LSA SAF Fire Risk Map (FRM) product for 1 to 3 days ahead using weather forecast data of ECMWF and provided warnings in 3 classes of fire risk (low, moderate, high) with a spatial resolution of about 5 km (MSG resolution). The FRM algorithm computes the set of components of the Canadian Forest Fire Weather Index System; prognostic levels of fire danger over the European area are updated everyday at 12 UTC, and disseminated through EUMETCast (Fig.7a).
- Terrestrial Fire Risk diagnosis/forecasts for 2 days ahead is derived by Soil Moisture Deficit Index of Fire Danger (SMDIFD) using weather forecast data of ECMWF and provided warnings in 5 classes of fire risk with a spatial resolution of the ECMWF model grid (Fig.7b).
- Composite Fire Risk Indicator (CoFRI, Fig.7c) for 2 days ahead with MSG resolution in 3 classes of fire risk (low/moderate/high) combining atmosphere (Fig.7a) and land surface (Fig.7b).

(d) Satellites in support to characterise fire-forest-climate relations: To account for gradient in static fire risk and fire regime we apply the Bulgarian developed bioclimatic scheme for regional classification of the natural land cover in functional units (Forest Functional Types, FFTs), (14) together with the Fire Radiative Approach based on MSG information. Appling the concept for S-SE Bulgaria, three functional units of static equilibrium between forest and climates are discriminated (Fig. 4 (a)), which are also distinguished based on satellite information (LST and FVC LSA SAF products). Vulnerability of FFTs to fire hazard is characterized using capabilities of LSA SAF FRP product (5 years dataset). Accumulating all pixel detections and biomass-burning effects (total fire radiative energy and fire-carbon equivalent emitted), the ranking of natural forest cover regarding susceptibility to fire ignition and spread on a regional scale is made. An example of the ranking of bioclimate regimes in terms of fire occurrence is illustrated for 2011 (Fig. 8). The most fire prone is FFT2 area (broadleaved xerophytes), followed by native coniferous FFT3 and the less fire-prone ecosystem is the area of FFT2 (mesophytes). This ranking is confirmed by the ground observations of national SFA.

(a) (b) (c)

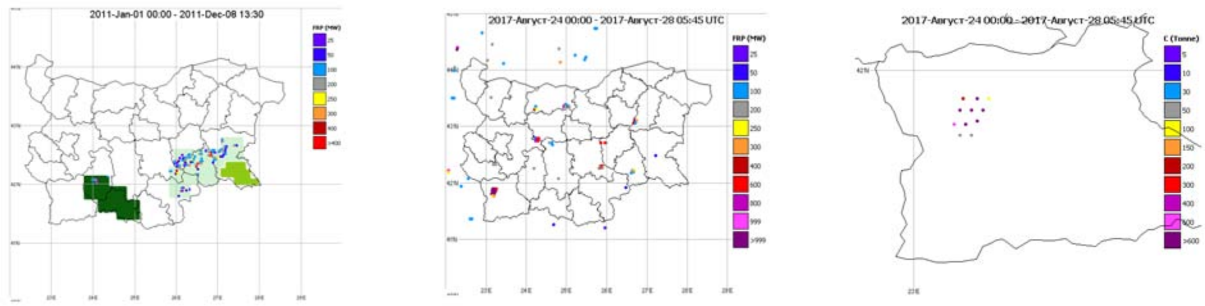


Fig. 8. Use of MSG LSA SAF FRP-PIXEL product in characterizing climate-fire relationships and static fire risk: (a) Regional characterization of biomass-burning pattern for 2011; Accumulated effects from biomass burning during fire in Kresna, 24–28/08/2017 in terms of (b) total fire radiative energy and (c) Total Carbon-Eq. emitted.

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