EUMETSAT
SAF for Land Surface Analysis
(LSA SAF)

Algorithm Theoretical Basis Document
for
Fire Risk Map Product
(LSA-30)

Reference Number:	SAF/LAND/IM/ATBD_FRM/1.1
Issue/Revision Index:	Issue 1.1
Last Change:	13/05/2011

DOCUMENT SIGNATURE TABLE

	Name	Date	Signature
Prepared by :	T.J. Calado and Carlos C. DaCamara		
Approved by :	Land SAF Project Manager (IM)		

DOCUMENTATION CHANGE RECORD

Issue / Revision	Date	Description:
Version 0.1	01/06/2009	Version to be presented to PCR
Version 0.2	20/10/2009	Version to be presented to close-out meeting
Version 0.3	28/02/2010	Version to be presented to ORR Validation section removed.
Version 1.0	13/05/2011	Changes following the ORR meeting of April 2010: (1) The product name was changed throughout the document to "Fire Risk Map" with “FRM” as acronym; (2) Accuracy criteria were included in the document (p. 27); (3) The document mentions that the algorithm should provide estimates of fire risk for 24h, 48h and 72h ahead (pp. 8, 9 and 30); (4) Reference is made to an extended period of calibration (p. 9).

DISTRIBUTION LIST

Internal Consortium Distribution		
Organisation	**Name**	**No. Copies**
IM	Pedro Viterbo	
IM	Luís Pessanha	
IM	Isabel Trigo	
IDL	Carlos da Camara	
IM	Isabel Monteiro	
IM	Sandra Coelho	
IM	Carla Barroso	
IM	Pedro Diegues	
IM	Teresa Calado	
IM	Benvinda Barbosa	
IM	Ana Veloso	
IMK	Folke-S. Olesen	
IMK	Frank Goettsche	
IMK	Ewa Kabsch	
MF	Jean-Louis Roujean	
MF	Olivier Hautecoeu	
MF	Dominique Carrer	
RMI	Françoise Meulenberghs	
RMI	Arboleda Alirio	
RMI	Nicolas Ghilain	
FMI	Niilo Siljamo	
UV	Joaquin Melia	
UV	F. Javier García Haro	
UV/EOLAB	Fernando Camacho	
UV	Aleixander Verger	

External Distribution		
Organisation	**Name**	**No. Copies**
EUMETSAT	Frédéric Gasiglia	
EUMETSAT	Dominique Faucher	
EUMETSAT	Lorenzo Sarlo	
EUMETSAT	Lothar Schueller	
EDISOFT	Teresa Cardoso	
EDISOFT	Carlos Vicente	
EDISOFT	Cleber Balan	
SKYSOFT	Rui Alves	
SKYSOFT	João Canário	

Steering Group Distribution		
Nominated by:	**Name**	**No. Copies**
IM	Carlos Direitinho Tavares	
EUMETSAT	Lorenzo Sarlo	
EUMETSAT	Yves Govaerts	
EUMETSAT	François Montagner	
STG/AFG (USAM)	Luigi de Leonibus	
MF	François Bouyssel	
RMI	Alexandre Joukoff	
FMI	Tapio Tuomi	

Table of Contents

List of Tables

List of Figures

1. Introduction

1.1. Purpose

Rural fires are common events on ecosystems characterized by alternating rainy and drought periods, which inevitably lead to high levels of vegetation stress and to the accumulation of fuels during the dry phase (Chuvieco et al., 1997). This is particularly true in Mediterranean Europe, where the rainy and mild winters followed by warm and dry summers make the region especially prone to the occurrence of a large number of fire events (Ventura and Vasconcelos, 2006, Pyne, 2006). It is therefore not surprising that wildfire events are especially frequent over southern European countries, namely Portugal, Spain, France, Italy, Greece and Croatia, which present the largest number of fires and amounts of burnt area (Pereira et al., 2006, Barbosa et al. 2007). The large majority of fire episodes, and the most severe ones, take place during the summer months with dramatic consequences for the ecosystems and population; however late winter and spring fires should not be disregarded in some southern European areas.

Meteorological factors play a crucial role in the setting and spreading of wildfire and are an important factor in the resulting fire severity (e.g. Bovio and Camia, 1997). In fact, meteorological variables, alone or combined with vegetation and topographical information, are frequently used to develop fire risk indices, such as the ones that integrate the so-called Canadian Forest Fire Weather Index System (CFFWIS) (van Wagner, 1987). Fire risk indices may be based on single or combined use of meteorological station measurements, weather forecast model outputs and remote sensing estimations (Han et al., 2003).

In the above mentioned context, the SEVIRI instrument on-board the MSG satellite series has been identified as having an especially good potential in the domain of fire risk management (Pereira and Govaerts, 2001), namely in what respects to the identification of pre-fire indicators (e.g. signals of vegetation stress), which merged with meteorological parameters may lead to the formulation of indicators of fire risk.

Exploitation of the MSG potential is particularly suitable in the framework of the SAF on Land Surface analysis (LSA SAF) that is part of the Satellite Application Facility (SAF) Network. The aim of the LSA SAF is to take full advantage of remotely sensed data available from EUMETSAT sensors to describe/derive land surface properties/variables. For instance, the LSA SAF products are related with physical and biophysical properties of the land surfaces, and are especially relevant to estimating the surface radiative and energy budgets. The LSA SAF products are therefore expected to be relevant to a wide range of applications, including weather forecasting and climate modelling, renewable energy resource assessment, environmental management and land use, agricultural and forestry applications, and natural hazard management (DaCamara, 2006). In fact, the growing number of users in the latter topics together with the demands from environment monitoring and risk management communities (e.g., GMES requirements) supported the extension of biogeophysical parameters to wild fire related products (Trigo et al., 2009).

The LSA SAF is currently exploring (i) the capability of SEVIRI/MSG to detect and monitor active fires, particularly over Africa and Europe, leading to the operational generation, archiving and dissemination of the so-called Fire Detection and Monitoring (FD&M) product; and (ii) combining meteorological information with characteristics of vegetation to produce meaningful danger of fire rating for Southern Europe. In this respect the hereafter described Fire Risk Map (FRM) product may be viewed as representing the first attempt to make an integrated use of meteorological information from meteorological forecasts, vegetation data from land cover maps and observations of active fires and fire pixels as obtained from the FRM product of the LSA SAF in order to produce coherent maps of fire risk at the scale of MSG.

The purpose of the present document is to provide a detailed description of the methodology adopted for the version 0.2 of the LSA-SAF FRM algorithm. Section 2 provides a thorough description of the CFFWIS and of the statistical procedure to derive classes of fire risk, a brief description of the adopted methodology and the equations of the algorithm. Input and output data are then described in section 3. Validation procedures are discussed in section 4. Finally some constrains and limitations of the present version of the algorithm are addressed in section 5 and a brief description is given of the planned work in the near future.

1.2. Scope

This document describes the theoretical basis of the algorithms that generate the Fire Risk Map (FRM) product, namely the set of indices related to meteorological risk of fire and the associated levels of fire risk.

2. Algorithm Overview

2.1. Objectives

The main objective of the FRM algorithm is to compute daily values of the set of components of the Canadian Forest Fire Weather Index System (CFFWIS) for Mediterranean Europe together with levels of fire danger associated to probabilities of occurrence of fires exceeding specified magnitudes. The rationale is to provide the user community with information on meteorological risk that will allow adopting the adequate measures to mitigate fire damage. The FRM algorithm will accordingly compute levels of fire danger for within 24h, 48h and 72h.

2.2. Retrieval Strategy

Meteorological risk of fire may be evaluated by a wide range of methods, most of them relying on the evaluation of appropriate sets of meteorological indices. Viegas et al. (1999) compared five methods of evaluation of fire risk based on meteorological factors, on six different regions of France, Italy and Portugal for a period of 3-9 years. The five methods were tested using statistical data on daily number of fires and burned areas both for winter and summer fires. The methods used in the study were the above mentioned CFFWIS, the Numerical Risk (French method), the IREPI (Italian method), a modified version of the Nesterov index (Portuguese method) and the Spanish method. All methods, with the exception of the Spanish one, are cumulative and require daily meteorological variables, namely air temperature and relative humidity. Some methods also require precipitation, wind direction, wind speed, insolation and cloud cover. The methods provide a numerical index that grows with the danger conditions. The output values from the different methods were normalised in order to allow a proper comparison of number of fires and burnt area predicted by each method. The Mahalanobis distance was used to evaluate each method because it is a good discriminator of two samples from the same population and it was assumed that a danger method must provide a clear discrimination at least among those days with very low or very high fire risk. The authors concluded that CFFWIS as well as the modified Nesterov method were the ones presenting the best performance.

According to obtained results, the European Commission recommended in 1995 the community countries to adopt CFFWIS to predict fire danger. The use of a single method has, among others, the advantage of allowing a common language, with indices of easy recognition and interpretation by all users. The same decision was taken by the European Forest Fire Information System (EFFIS) network who adopted in 2007 the Fire Weather Index (FWI), one of the indices of CFFWIS, to assess fire danger over Europe.

The first step of the FRM product is to use gridded values of 24 h, 48 h and 72 h ECMWF forecasts of meteorological parameters (namely, temperature at 2 m, relative humidity, wind velocity at 10m and cumulated precipitation in 24 h) in order to compute the set of six fire indices that constitute CFFWIS. These values are computed on a pixel basis over the EUR window and are disseminated everyday at 12 UTC. Classes of fire danger are finally obtained by combining, at each MSG pixel, daily values of FWI with vegetation classes as derived from GLC2000. Risks of fire occurrence (for specified levels of severity) are associated to each class of fire danger by crossing FWI and vegetation cover information with active fires as detected by the FD&M algorithm during July and August of 2008 and 2009. Calibration of fire danger classes will be extended to the period of June to September 2005-2009 as soon as data from the RFM product become available. To the best of our knowledge, this method of estimating risks of fire occurrence has never been used before and may be viewed as the innovation brought by the FRM product.

2.3. Delivered products

For each processed pixel in EUR window the FRM algorithm computes all fire indices of FFWIS: the Fuel Moisture Codes, *i.e.*, FFMC, DMC and DC and the Fire Behaviour Indices, *i.e.,* ISI, BUI, FWI and DSR. The FRM algorithm also computes classes of fire risk. The list of fields given by the product is given in Annex A.

3. Algorithm Description

3.1. Theoretical Description

3.1.1. Rationale

The above-mentioned CFFWIS (van Wagner, 1987) consists of six components that account for the effects of fuel moisture and wind on fire behaviour. Figure 1 provides an overview of the FWI System. The first three components, *i.e.* the Fine Fuel Moisture Code (FFMC), the Duff Moisture Code (DMC) and the Drought Code (DC) respectively rate the average moisture content of surface litter, decomposing litter, and organic (humus) layers of the soil. Wind effects are then added to FFMC leading to the Initial Spread Index (ISI) that rates fire spread. The remaining two fuel moisture codes (DMC and DC) are in turn combined to produce the BuildUp Index (BUI) that is a rating of the total amount of fuel available for combustion. BUI is finally combined with ISI to produce the Fire Weather Index (FWI) and the Daily Severity Rating (DSR) that respectively rate fire intensity and the difficulty of controlling fires.

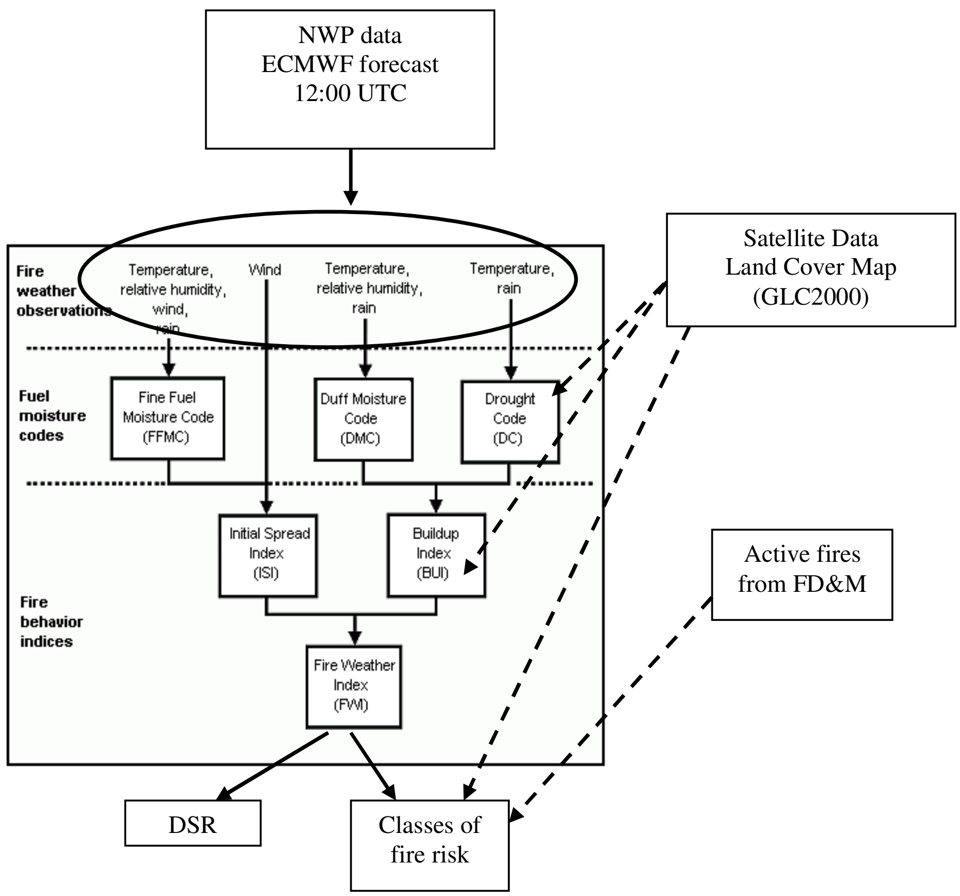


Figure 1. Diagram of the components of the FWI System (*source*: CFS, 2007, with changes).

Using a statistical approach, classes of fire danger are finally defined for a given region by calibrating the FWI System against wildfire activity as defined by the recorded number of active fires and of fire pixels over a given period of time (Bovio and Camia, 1998).

3.1.2. Mathematical Description of the Algorithm

The FRM algorithm is based on the CFFWIS, as described by van Wagner (1985). A schematic overview of the procedure is given hereafter.

I. Computation of FFMC

The Fine Fuel Moisture Code (FFMC), hereby denoted as F, is a numeric rating of the moisture content of litter and other cured fine fuels. This code is an indicator of the relative ease of ignition and the flammability of fine fuel (CFS, 2007). FFMC of a given day is defined as:

$$F = \min\left[59.5(250-m)/(147.2+m), 101\right] \quad (1)$$

In the above equation, m denotes the so-called fine fuel moisture content after drying defined as:

$$m = \begin{cases} E_d + (m_0^* - E_d)\times 10^{-k_d}, & m_0^* > E_d \\ E_W - (E_W - m_0^*)\times 10^{-k_W}, & m_0^* < E_W < E_d \\ m_0^*, & E_d \geq m_0^* > E_W \end{cases} \quad (2)$$

where m_0^*, E_d, k_d, E_w and k_w respectively represent the fine fuel moisture content from the previous day, the fine fuel Equilibrium Moisture Content (EMC) for drying, the log drying rate, the fine fuel EMC for wetting and the log wetting rate, all of which will be defined hereafter.

The fine fuel moisture content from the previous day, m_0^*, is defined as:

$$m_0^* = \begin{cases} m_0 = 147.2(101-F_0)/(59.5+F_0), & r_0 < 0.5\text{mm} \\ \mathrm{m_r} = \min(m_0 + \Delta m,\ 250), & r_0 \geq 0.5\text{mm} \end{cases} \quad (3)$$

where m_0 is the fine fuel moisture content as estimated from the FFMC of the previous day, F_0, m_r is the fine fuel moisture content after rain and r_0 is the cumulated precipitation at 12:00 [in mm].

The fine fuel moisture content after rain, m_r, is essentially a corrected m_0 by rainfall, which is obtained by adding the correction factor Δm given by:

$$\Delta m = \begin{cases} 42.5\, r_f \left(e^{-100/(251-m_0)} \left(1-e^{-6.93/r_f}\right) \right), & m_0 \le 150 \\ 42.5\, r_f \left(e^{-100/(251-m_0)} \left(1-e^{-6.93/r_f}\right) \right) + 0.005\,(m_0-150)^2\, r_f^{0.5}, & m_0 > 150 \end{cases} \quad (4)$$

where r_f is the so-called FFMC effective rainfall, defined as:

$$r_f = r_0 - 0.5 \quad (5)$$

The fine fuel EMC for drying, E_d, is given by:

$$E_d = 0.942\, H^{0.679} + 11 e^{(H-100)/10} + 0.18\,(21.1-T)\left(1-e^{-0.115H}\right) \quad (6)$$

where H is relative humidity at 12:00 [in %] and T is the 2m air temperature at 12:00 [in ºC].

The log drying rate, k_d [in $\log_{10}$(m/day)] is given by:

$$k_d = k_0 \times 0.581 e^{0.0365T} \quad (7a)$$

where

$$k_0 = 0.424\left[1-(H/100)^{1.7}\right] + 0.0694\, W^{0.5}\left[1-(H/100)^{8}\right] \quad (7b)$$

is the intermediate step for the computation of k_d, and W is the wind speed at 12:00 [in km/h].

The fine fuel EMC for wetting, E_W, is given by:

$$E_W = 0.618\, H^{0.753} + 10 e^{(H-100)/10} + 0.18\,(21.1-T)\left(1-e^{-0.115H}\right) \quad (8)$$

and the log wetting rate, k_W [in $\log_{10}$(m/day)] is given by:

$$k_W = k_1 \times 0.581 e^{0.0365T} \quad (9a)$$

where

$$k_1 = 0.424\left[1-\left(\frac{100-H}{100}\right)^{1.7}\right]+0.0694W^{0.5}\left[1-\left(\frac{100-H}{100}\right)^{8}\right] \quad (9b)$$

is the intermediate step for the computation of k_W

II. Computation of DMC

The Duff Moisture Code (DMC), hereby denoted as P, is a numeric rating of the average moisture content of loosely compacted organic layers of moderate depth. This code gives an indication of fuel consumption in moderate duff layers and medium-size woody material (CFS, 2007). DMC of a given day is defined as:

$$P = \begin{cases} P_0 + 100\,K, & r_0 \le 1.5\,\text{mm} \\ P_r + 100\,K, & r_0 > 1.5\,\text{mm} \end{cases} \quad (10)$$

where P_0 is simply the DMC of the previous day and where P_r and K, respectively represent the DMC after rain and the log drying rate in DMC, which will be defined hereafter.

The DMC after rain is given by:

$$P_r = \max\left[244.72 - 43.43\ln\left(M_r - 20\right),\, 0\right] \quad (11)$$

where M_r is the duff moisture content after rain defined as:

$$M_r = M_0 + 1000\,r_e/\left(48.79 + b\,r_e\right) \quad (12)$$

In the above expression M_0 is the duff moisture content from the previous day given by:

$$M_0 = 20 + e^{\left(5.6348 - P_0/43.43\right)} \quad (13)$$

r_e is the effective rainfall for DMC given by:

$$r_e = 0.92\,r_0 - 1.27 \quad (14)$$

and b is the slope variable in DMC rain effect defined as:

$$b = \begin{cases} 100/\left(0.5 + 0.3\,P_0\right), & P_0 \le 33 \\ 14 - 1.3\ln P_0, & 33 < P_0 \le 65 \\ 6.2\ln P_0 - 17.2, & P_0 > 65 \end{cases} \quad (15)$$

Finally, the log drying rate in DMC, K [in $\log_{10}(M/day)$] is given by:

$$K = 1.894 \times \max(T + 1.1, 0)(100 - H)L_e \times 10^{-6} \tag{16}$$

where L_e is the effective day length in DMC [in hours] as defined in Table 1.

Table 1. Annual cycle of effective day length in DMC [in hours].

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
L_e	6.5	7.5	9.0	12.8	13.9	13.9	12.4	10.9	9.4	8.0	7.0	6.0

III. Computation of DC

The Drought Code (DC), hereby denoted as D, is a numeric rating of the average moisture content of deep, compact organic layers. This code is a useful indicator of seasonal drought effects on forest fuels and the amount of smoldering in deep duff layers and large logs (CFS, 2007). DC of a given day is defined as:

$$D = \begin{cases} D_0 + 0.5V, & r_0 \le 2.8\,\text{mm} \\ \mathrm{D_r} + 0.5V, & r_0 > 2.8\,\text{mm} \end{cases} \tag{17}$$

where D_0 is simply the DC of the previous day and where D_r and V respectively represent the DC after rain and the potential evapotranspiration, which will be defined hereafter.

The DC after rain is given by:

$$D_r = \max\left[400 \ln(800/Q_r), 0\right] \tag{18}$$

where Q_r is the moisture equivalent after rain defined as:

$$Q_r = Q_0 + 3.937\, r_d \tag{19}$$

In the above expression Q_0 is the moisture equivalent of previous day's DC, given by:

$$Q_0 = 800\, e^{-D_0/400} \tag{20}$$

and r_d is the effective rainfall for DC, given by:

$$r_d = 0.83 r_0 - 1.27 \quad (21)$$

Finally, the potential evapotranspiration [in units of 9.254 mm water/day] is given by:

$$V = \max\left[0.36 \times \max\left(T + 2.8, 0\right) + L_f, 0\right] \quad (22)$$

where L_f is the day length adjustment in DC [in hours] as defined in Table 2.

Table 2. Annual cycle of day length adjustment [in hours].

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
L_f	-1.6	-1.6	-1.6	0.9	3.8	5.8	6.4	5.0	2.4	0.4	-1.6	-1.6

IV. Computation of ISI

The Initial Spread Index (ISI), hereby denoted as R, is a numeric rating of the expected rate of fire spread. It combines the effects of wind and the FFMC on rate of spread without the influence of variable quantities of fuel (CFS, 2007). ISI is given by:

$$R = 0.208 f\left(W\right) f\left(F\right) \quad (23)$$

where $f\left(W\right)$ and $f\left(F\right)$ are the wind function and the fine fuel moisture function, respectively defined as:

$$f\left(W\right) = e^{0.05039W} \quad (24)$$

where W is the wind speed at 12:00 [in km/h] and

$$f\left(F\right) = 91.9 e^{-0.1386m} \left[1 + m^{5.31} / \left(4.93 \times 10^{7}\right)\right] \quad (25)$$

V. Computation of BUI

The BuildUp Index (BUI), hereby denoted as U, is a numeric rating of the total amount of fuel available for combustion. It combines the DMC and the DC (CFS. 2007). BUI is given by the following expression:

$$\begin{cases} U = 0.8\,PD/(P+0.4\,D), & P \le 0.4\,D \\ U = P - [1-0.8\,D/(P+0.4\,D)][0.92+(0.0114\,P)^{1.7}], & P > 0.4\,D \end{cases} \quad (26)$$

VI. Computation of FWI

The Fire Weather Index (FWI), hereby denoted as S, is a numeric rating of fire intensity. It combines the Initial Spread Index and the BuildUp Index. It is suitable as a general index of fire danger throughout the forested areas (CFS, 2007). FWI is given by:

$$S = \begin{cases} e^{2.72(0.434\ln B)^{0.647}}, & B > 1 \\ B, & B \le 1 \end{cases} \quad (27)$$

where B is the so-called intermediate form of FWI, given by:

$$B = 0.1R\,f(D) \quad (28)$$

In the above expression, $f(D)$ is the duff moisture content, given by:

$$f(D) = \begin{cases} 0.626U^{0.809} + 2, & U \le 80 \\ 1000/25 + 108.64\,e^{-0.023U}, & U > 80 \end{cases} \quad (29)$$

VII. Computation of DSR

The Daily Severity Rating (DSR), hereby denoted as Z, is a numeric rating of the difficulty of controlling fires. It is based on the Fire Weather Index but more accurately reflects the expected efforts required for fire suppression (CFS, 2007). DSR is given by:

$$Z = 0.0272(S)^{1.77} \quad (30)$$

3.1.3. Classes of fire risk

FRM also estimates classes of fire danger for a sub region of the MSG EUR window (Figure 2), defined as the area comprehended between 9.5ºW and 45ºE in longitude and between 34ºN and 48ºN in latitude.

Figure 2. Sub region of EUR where classes of fire risk are retrieved.

Classes of fire risk are assessed by associating, for different types of vegetation cover (Table 3), pixel values of FWI with number of active fires, as identified during July and August 2008-2009 (Figure 3) by the FD&M product. It may be noted that the FD&M product relies on FiDAlgo (Fire Detection Algorithm), an operational procedure that allows active fire detection in near real time, based on information from Meteosat-8/SEVIRI. FiDAlgo is based on contextual algorithms that have been successfully developed for different sensors, namely NOAA-AVHRR and MODIS (see Doc: SAF/LAND/IM/ATBD_FD&M).

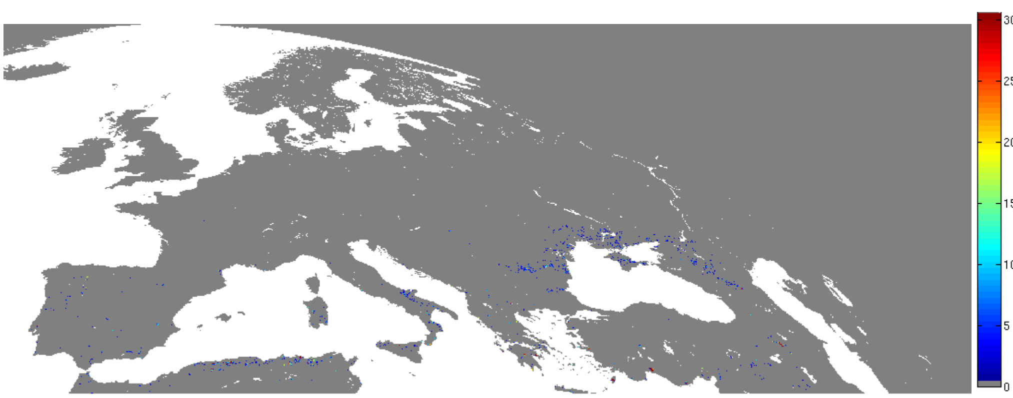


Figure 3. Number of active fires in July and August 2008-2009 as identified by FiDAlgo. Red pixels represent number of fires greater or equal to 30.

Analysis of spatial distribution of fire pixels and active fires showed that most fires occur in the following types of vegetation according to GLC2000 land cover classification (see Figure 9): shrub, tree cover broad-leaved, tree cover needle-leaved, cultivated and managed areas. The remaining types of vegetation did not show significant fire activity and were therefore grouped into a single type. Conditional probabilities of occurrence of fires above a certain threshold for specified ranges of FWI were finally computed for each of the selected types of vegetation (Table 3).

It is worth noting that cultivated and managed areas present distinct characteristics in what respects to number of fires and FWI values in the Iberian Peninsula and France when compared to other regions. For this reason, classes of risk in this type of vegetation were separately assessed for these two areas.

3.2. Practical considerations

3.2.1. Input data

3.2.1.1. Numerical Weather prediction data

Meteorological auxiliary data needed by the FRM algorithm are derived from ECMWF forecasts. Originally defined on a 0.25°×0.25° lat-lon grid, meteorological data are mapped onto the MSG grid and spatially interpolated for 2-meter air temperature (Figure 4), 2-meter dew point temperature (Figure 5), 10-meter wind speed (Figure 7) and 24-hour cumulated precipitation (Figure 8). Dew point temperature is used together with temperature to compute air relative humidity, H (Figure 6). According to Magnus' expression, H is given by:

$$H = 100\left(e/e_w\right) \tag{31}$$

where e [in hPa] and e_w [in hPa] are respectively, the environmental vapour pressure and saturation vapour pressure given by:

$$e = \exp\left(\ln\alpha + \beta T_d/\left(\lambda + T_d\right)\right) \tag{32a}$$

$$e_w = \exp\left(\ln\alpha + \beta T/\left(\lambda + T\right)\right) \tag{32b}$$

where $\alpha = 6.112\,hPa$ is the reference saturation vapour pressure, $\beta = 17.62$ and $\lambda = 243.12\,°C$.

3.2.1.2. Vegetation data

The land cover map used in the FRM algorithm was the Global Land Cover 2000 (GLC2000). Over the EUR window, GLC2000 was reprojected from its original regular latitude×longitude grid onto the MSG projection, *i.e.* onto the Normalized Geostationary Projection (NGP), using the most frequent value in the resampling of the data (Figure 9).

3.2.2. Exception Handling

The algorithm operates in two different modes: 0 and 1.

If it is the first time that the algorithm is going to run, or if there is some problem with input data or the system and there are no input data, then the program will run in mode 0. In this mode the three fuel moisture codes are initialised as $FFMC = 85$, $DMC = 6$ and $DC = 15$.

Table 3. Relative frequencies (in %) of occurrence of active fires exceeding specified thresholds (0, 5, 10, 20, 30, 50) for different classes of FWI, for MSG EUR window, for tree cover, broad-leaved tree, shrub, cultivated and managed areas characteristic of Iberian Peninsula and of central and eastern Europe, tree cover needle leaved and other types of vegetation, such as tree cover mixed leaf type and herbaceous cover.

Broad-leaved Tree

		FWI		
		<=10	]10, 15]	>15
N Fires	0	60	71	84
	5	40	46	63
	10	20	39	54
	20	20	30	44
	30	0	18	40
	50	0	9	33

Shrub

		FWI		
		<=35	]35, 45]	>45
N Fires	0	50	70	82
	5	17	36	59
	10	17	16	50
	20	8	9	36
	30	0	5	25
	50	0	4	21

Cultivated Area (I. Penins.+France)

		FWI		
		<=30	]30, 40]	>40
N Fires	0	67	73	83
	5	24	50	83
	10	15	42	83
	20	6	27	83
	30	3	17	67
	50	0	13	50

Cultivated Area

		FWI		
		<=15	]15, 20]	>20
N Fires	0	35	76	82
	5	13	33	54
	10	3	14	35
	20	0	5	21
	30	0	0	7

Needle-leaved Tree

		FWI		
		<=25	]25, 35]	>35
N Fires	0	0	19	84
	5	0	13	63
	10	0	11	54
	20	0	8	44
	30	0	6	40
	50	0	4	33

All but BL, NL, Shrub and CA

		FWI		
		<=20	]20, 35]	>35
N Fires	0	6	43	70
	5	1	18	60
	10	0	11	40
	20	0	7	40
	30	0	4	30
	50	0	2	30

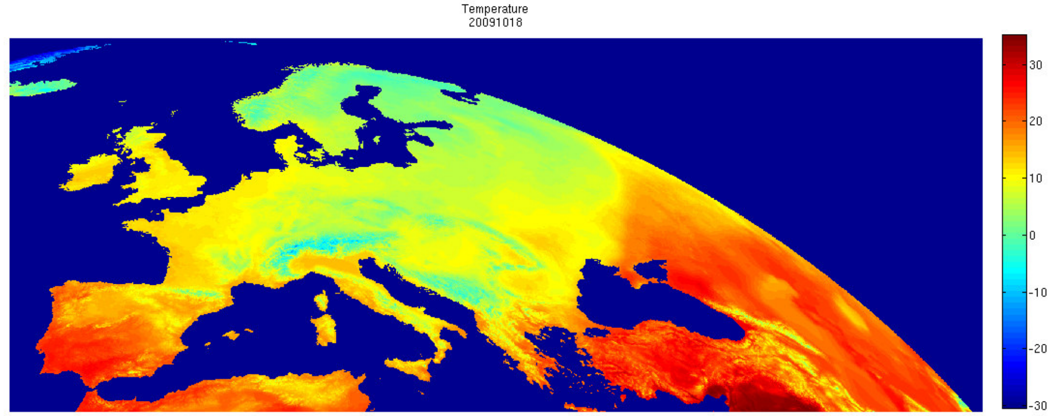


Figure 4. ECMWF forecast of 2-meter air temperature [in ºC], at 12Z of 18/10/2009 over the LSA SAF European window (EUR).

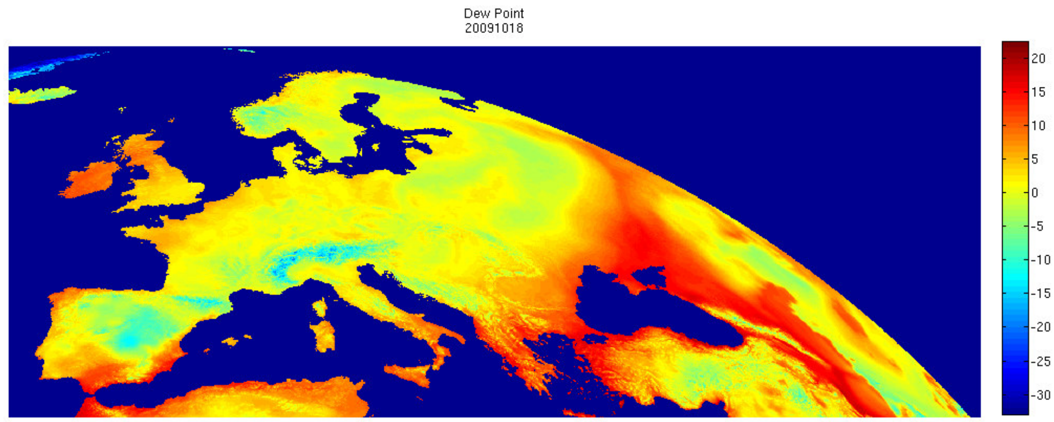


Figure 5. As in Figure 4, but respecting to 2-meter dew-point temperature [in ºC].

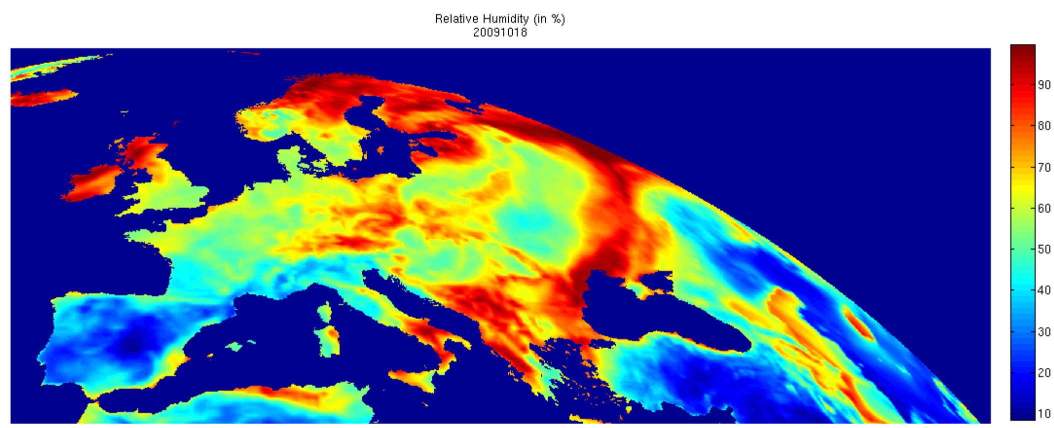


Figure 6. As in Figure 4, but respecting to relative humidity [in %].

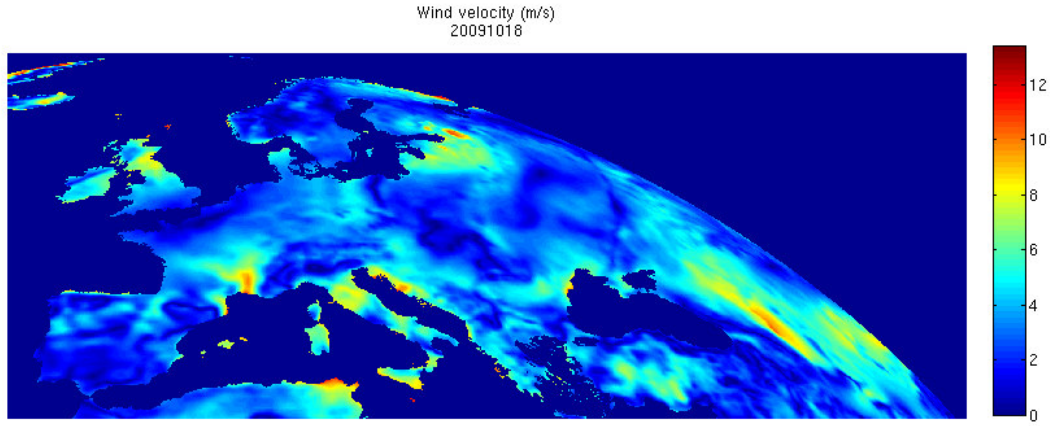


Figure 7. As in Figure 4, but respecting to wind speed [in m/s].

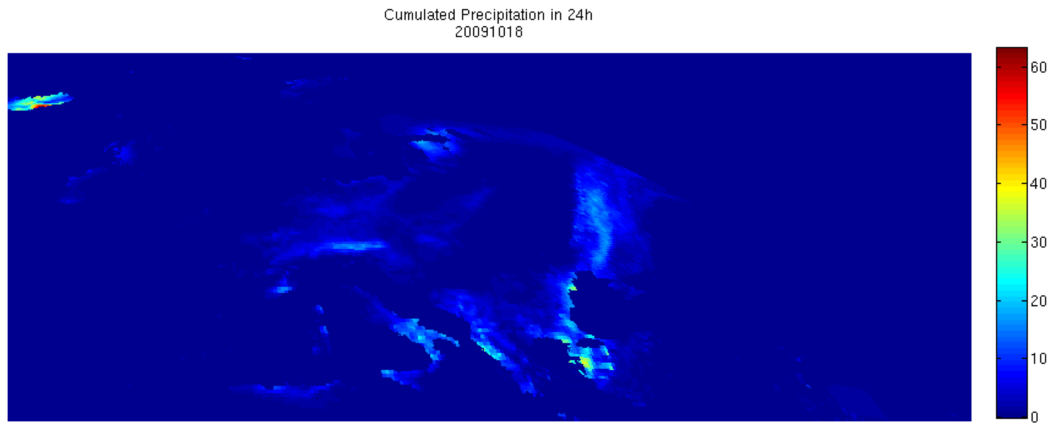


Figure 8. As in Figure4, but respecting to cumulated precipitation in 24 h [in mm].

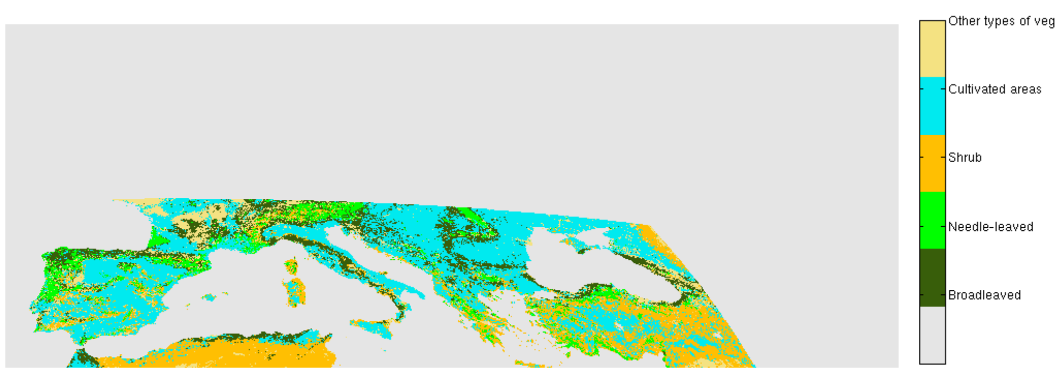


Figure 9. Land Cover map as identified by GLC2000, for the types of vegetation with interest for the retrieval of fire risk, for Europe, from -9.5ºW to 45ºE in longitude and from 34ºN to 48ºN in latitude.

3.2.3. Output data

3.2.3.1. Fire indices

The FRM algorithm also uses as input, fire indices that are obtained from output files from the previous day, namely Fine Fuel Moisture Code (FFMC), Drought Code (DC) and Duff Moisture Code (DMC), as shown in Figures 10, 11 and 12, respectively.

Figures 13 and 14, 15 and 16 present examples of the remaining output files of the FRM algorithm, namely the Initial spread Index (ISI), Build-Up Index (BUI), Fire Weather Index (FWI) and Daily Severity Rating (DSR).

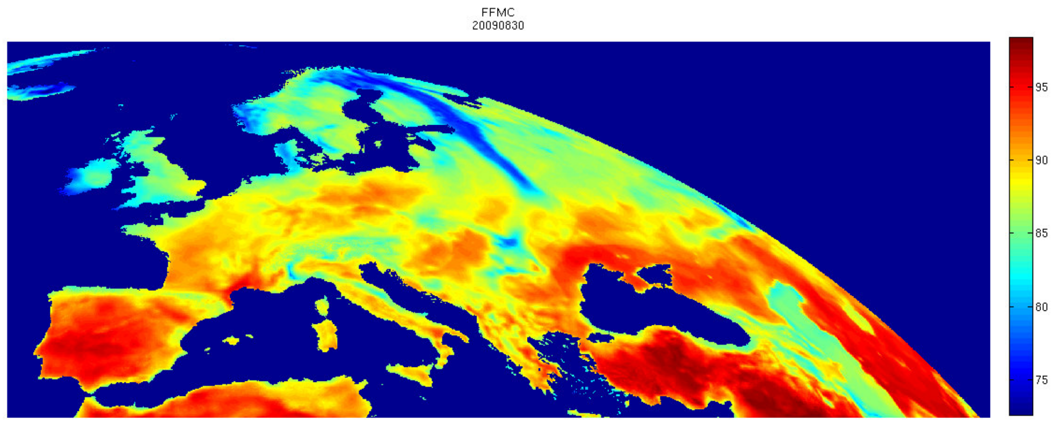


Figure 10. Fine Fuel Moisture Code (FFMC) at 12Z of 30/08/2009 over the LSA SAF European window (EUR).

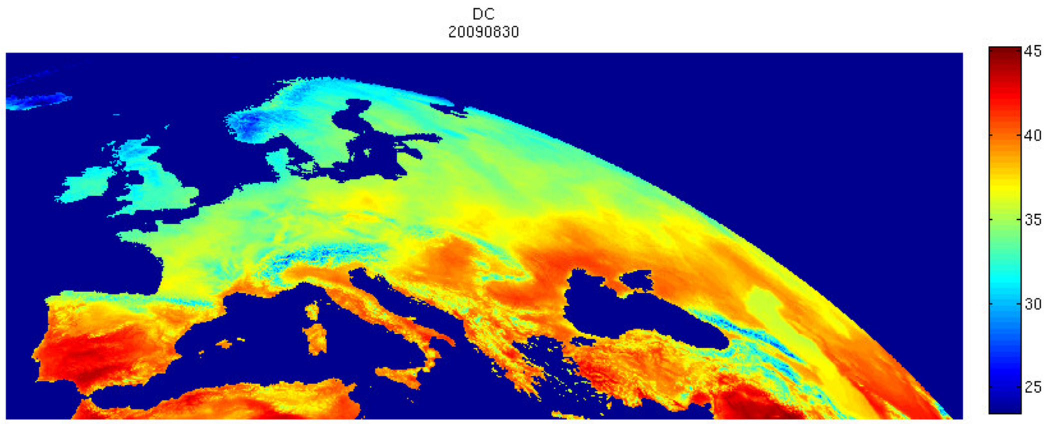


Figure 11. As in Figure 10, but respecting to Drought Code (DC).

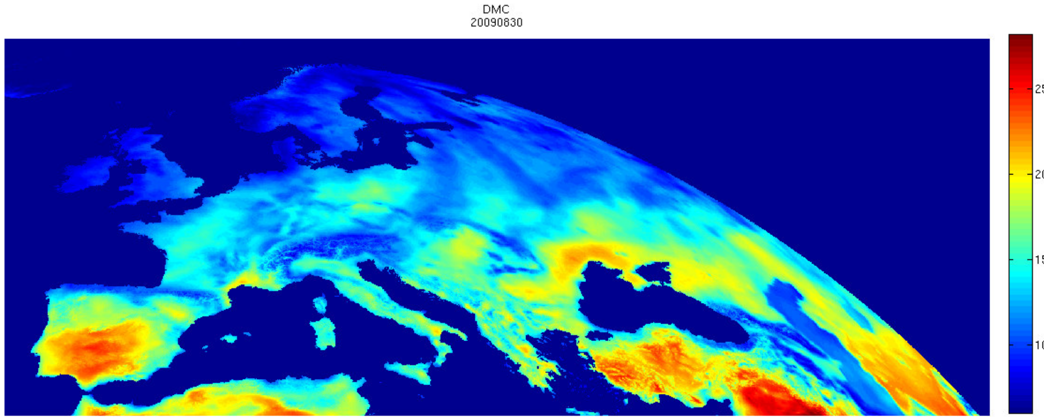


Figure 12. As in Figure 10, but respecting to Duff Moisture Code (DMC).

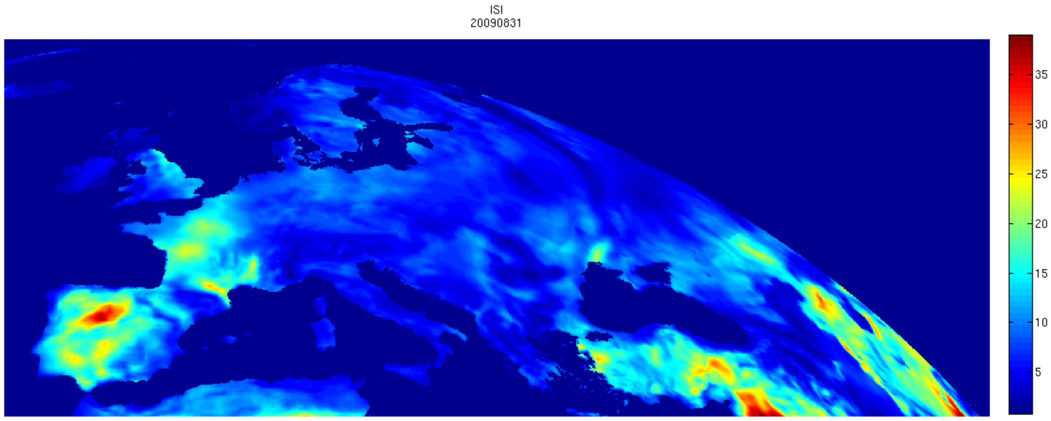


Figure 13. Initial Spread Index (ISI) at 12Z of 31/08/2009 over the LSA SAF European window (EUR).

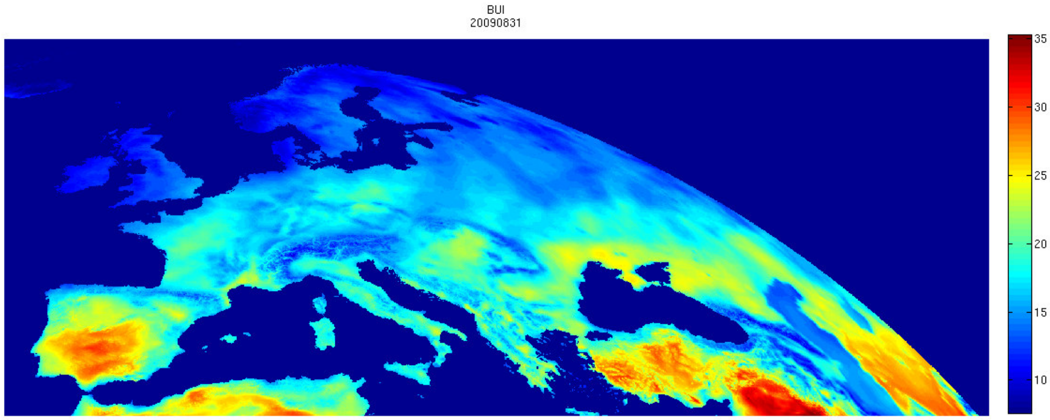


Figure 14. As in Figure 13, but respecting to Build-Up Index (BUI).

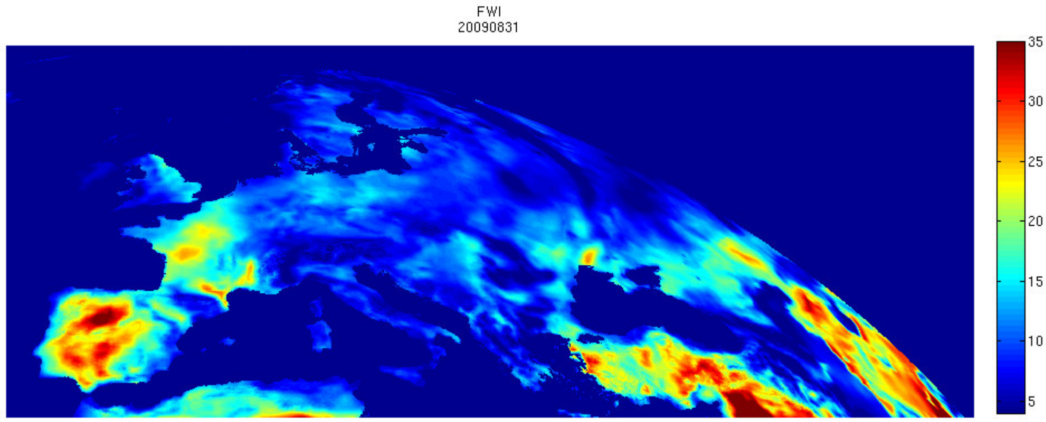


Figure 15. As in Figure 13, but respecting to Fire Weather Index (FWI).

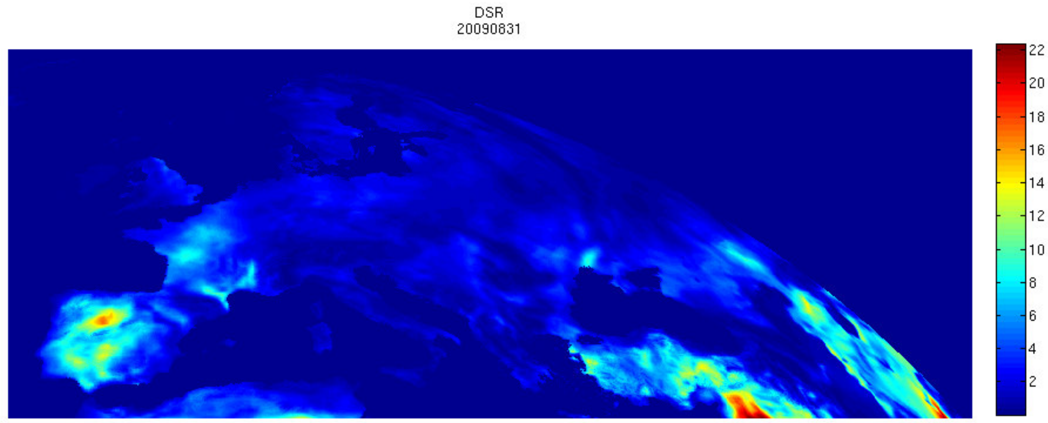
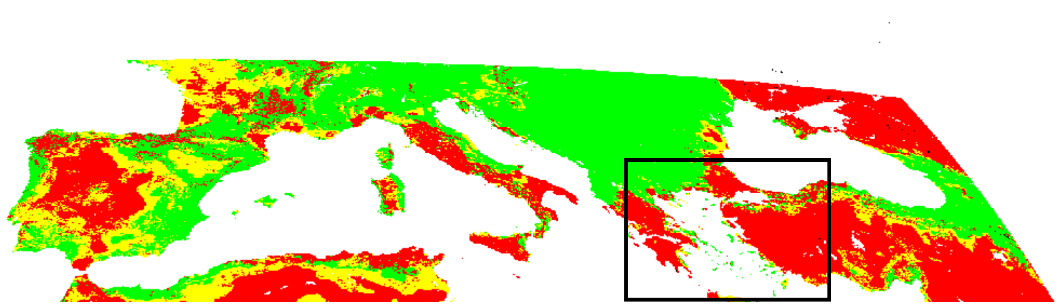


Figure 16. As in Figure 13, but respecting to Daily Severity Rating (DSR).

3.2.3.2. Maps of fire risk

Figure 17 shows an example for July 23 2008 of an output map of classes of fire risk. Pixels in green, yellow and red represent low, moderate and high risk, respectively. For comparison purposes, the corresponding map produced by EFFIS is also shown. Pixels in green, yellow, orange, red and brown represent very low, low, moderate, high and very high risk of fire. The similarities between the patterns of the FRM and the EFFIS products is worth being stressed.



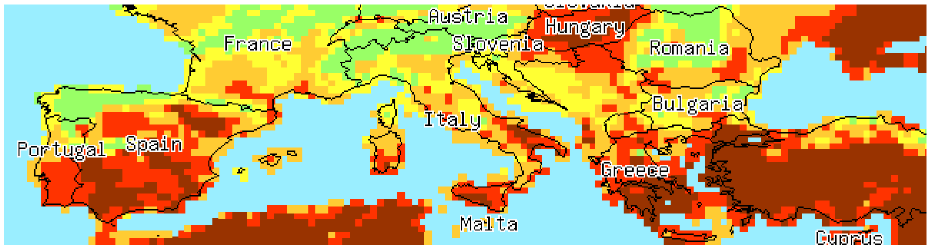


Figure 17. Upper panel; example, for July 23 2008, of a map of classes of fire risk for the sub-area of the MSG EUR window. Green, yellow and red correspond to low, moderate and high risk of fire. Lower panel; corresponding map produced by EFFIS. Green, yellow, orange, red and brown correspond to very low, low, moderate, high and very high risk of fire. The rectangular frame in the upper panel delimits the study area of Greece and part of Turkey.

Figures 18, 19 and 20 respectively present the spatial distribution of land cover types, active fires and fire risk over the study area delimited by the rectangular frame in the upper panel of Figure 17. Figure 20 presents a sequence of maps of fire risk for July 23, 24 and 25 2008 with active fires (pixels in black) superimposed. There is a net increase of risk with time, which is in good agreement with the occurrence of a very large number of fires at island of Rhodes (pixels in black limited by the circle) that consumed thousand of acres of pine forest. Taking into account that the predominant types of vegetation in the island are shrub and tree cover needle leaved (Figure 18), Table 3 indicates for these cases that there is a jump from class 2 (moderate risk) to class 3 (high risk) for fires above 30. This result is in very good agreement with the amount of fires recorded in Rhodes on July 24 and 25.

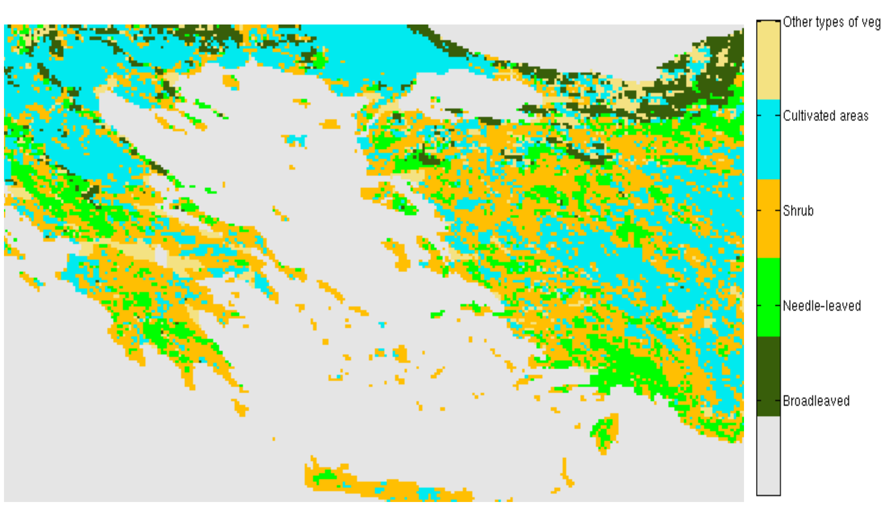
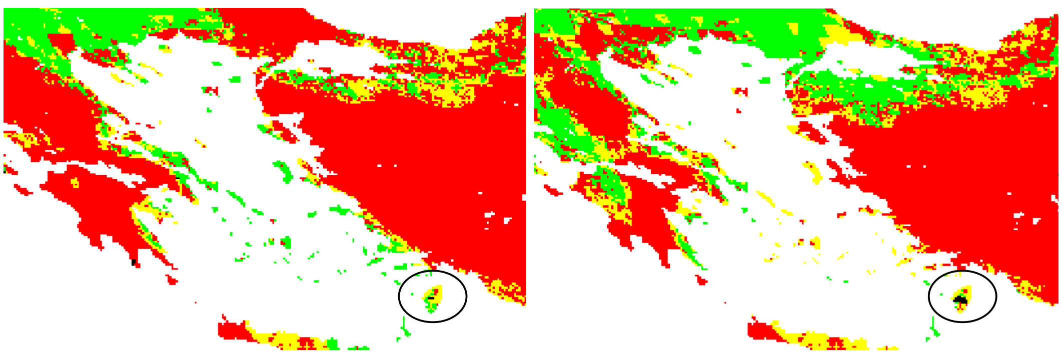
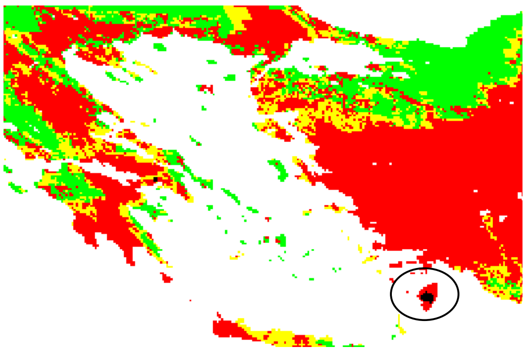


Figure 18. Types of vegetation as identified by GLC2000 present in the selected area.

Figure 19. Active fires, as identified by the FD&M algorithm for July and August 2008 for the selected area.



(a) (b)



(c)

Figure 20. Classes of fire risk for with superimposed active fires in the Island of Rhodes (limited by the black circle), for (a) July 23, (b) 24 and (c) 25 2008.

3.2.3.1. Accuracy of risk of fire

The levels of fire risk given by FRM will be verified by comparing time-series of SEVIRI fire pixels as detected by the FD&M product against estimated risk. When FD&M will become operational, the RFM product will be further assessed against the FD&M product as a source of verified pixels.

The product accuracy is defined in accordance to the following criteria:

i) Threshold accuracy:
The FRM estimates of fire probability should improve over a priori probability based on relative fire frequency distributions;

ii) Target accuracy:
The class of lowest risk should indicate the virtual absence of highly active fires (larger than 30/35 fire pixels) and a relative frequency lower than 1/3 of moderate fires (between ~10 and ~30 fire pixels); the class of highest risk should indicate a relative frequency higher than 2/3 for large fires (larger than 30/35 fire pixels);

iii) Optimal accuracy:
The class of lowest risk should indicate a virtual absence of active fire pixels; classes of intermediate risk should indicate the virtual absence of highly active fires (larger than 30/35 fire pixels) and a relative frequency lower than 1/4 of moderate fires (between ~10 and ~30 fire pixels); the class of highest risk should indicate a relative frequency higher than 3/4 for large fires (larger than 30/35 fire pixels)

4. Constrains and limitations

As pointed out by Chuvieco and Congalton (1989), structural risk is generally assessed by means of a set of variables related to long-term fire hazard. Choice of relevant variables involves studying statistical relationships between long-term records of variables and fire events. In this particular, assessing the heat and water stress of vegetation involves the development of statistical models that relate the amount of burnt area during the fire season with averages of relevant meteorological parameters over a certain period prior to the fire season (Calado et al., 2009). In fact, about 50% of observed inter-annual variability of the logarithm of cumulated burnt area in July and August over Continental Portugal is explained by the average temperature and the cumulated precipitation in the previous months of May and June (DaCamara et al., 2007). On the other hand, other factors have to be taken into account when refining the levels of fire risk. These factors range from fuel structure and terrain characteristics up to human activities and climate variability.

Taking into account the above-described constrains and limitations, it is currently planned to refine the levels of fire risk by taking into account indicators of vegetation stress (e.g. daily cycle of LST, FVC, LAI as obtained from LSA SAF products) and by considering the fact that different weather regimes in spring may lead to different levels of thermal and water stress of vegetation at the beginning of the fire season.

5. References

[1] AFN, 2007: Defesa da floresta contra incêndios. Relatório 2007. Direcção-Geral dos Recursos Florestais, Lisboa (in portuguese). Available from http://www.afn.min-agricul tura.pt/portal/dudf/Resource/ficheiros/relatorios/DGRF-DFCI-2007-RELATORIO –FIN AL-IF.pdf

[2] Barbosa P., Amatulli G., Boca R., Camia A., Kucera J., Libertà G., San-Miguel Ayanz, J., Schmuck G,. Schulte E., and Dierks H-H., 2007: *Forest Fires in Europe 2006*. EUR 22931 EN – Joint Research Centre – Institute for Environment and Sustainability, Luxembourg: Office for Official Publications of the European Communities, EUR – Scientific and Technical Research series – ISSN 1018-5593.

[3] Bovio, G., and Camia, A., 1997: Meteorological Indices for Large Fires Danger Rating. In: "*A review of remote sensing methods for the study of large wildland fires*", Ed. by E. Chuvieco, Megafires Project ENV-CT96-0256, Alcalà de Henares (Spain), 73-90.

[4] Bovio, G., and Camia, A., 1998: An analysis of large forest fire danger conditions in Europe. In "*Proc. 3rd Int. Conf. on Forest Fire Research & 14th Conf. on Fire and Forest Meteorology*", Viegas, D.X. (Ed.), Luso, 16-20 Nov., ADAI, 975-994.

[5] Calado M.T., DaCamara C.C.and Gouveia C., 2009: The regime of summer wildfires: How can it be anticipated. In: "*33rd International Symposium on Remote Sensing of Environment (ISRSE)*", May 2009, Stresa, Italy.

[6] CFS, 2007: Canadian wildland fire information system. Available from: http://fire.nofc.cfs.nrcan.gc.ca/en/background/bi_FWI_summary_e.php.

[7] Chuvieco, E., and Congalton, R.G., 1989: Application of Remote Sensing and Geographic Information Systems to Forest Fire Hazard Mapping. *Remote Sensing of Environment*, 29, 147-159.

[8] Chuvieco, E., Salas, J., and Vega C., 1997: Remote sensing and GIS for longterm fire risk mapping. In "*A review of remote sensing methods for the study of large wildland fire*", Ed. by E. Chuvieco, Megafires Project ENV-CT96-0256, Alcalà de Henares (Spain), 91–108.

[9] DaCamara, C.C., 2006: The Land Surface Analysis SAF: one year of pre-operational activity. The 2006 EUMETSAT Meteorological Satellite Conference, Helsinki, Finland, 12-16 June 2006, EUMETSAT P.48, ISBN 92-9110-076-5, 8pp. (available from http://www.eumetsat.int/Home/Main/Publications/index.htm).

[10] DaCamara, C.C., Calado T.J., Amraoui M. and Pereira J.M.C, 2007: The SAF for Land Surface Analysis: wildfire applications. In "*2007 EUMETSAT Meteorological Satellite Conference and the 15th Satellite Meteorology & Oceanography Conference of the American Meteorological Society*", Amsterdam, Netherlands, 24 - 28 September. EUMETSAT P.50, ISBN 92-9110-079-X.

[11] Han, K. S., Viau, A. A., and Anctil, F., 2003: *High-resolution forest fire weather index computations using satellite remote sensing*. *Can. J. For. Res*. **33(6)**: 1134-1143.

[12] Pereira J.M.C. and. Govaerts, Y, 2001. Potential fire applications from MSG/SEVIRI observations. EUMETSAT Programme Development Department, Technical Memorandum No. 7.

[13] Pereira, J.M.C., Carreiras, J.M.B., Silva, J.M.N. and Vasconcelos, M.J., 2006: Alguns conceitos básicos sobre os fogos rurais em Portugal. In J.S. Pereira, J.M.C. Pereira, F.C. Rego, J.M.N. Silva and T.P. Silva (Eds.), Incêndios Florestais em Portugal – Caracterização, Impactes e Prevenção (pp 133-161). ISA Press (in portuguese).

[14] Pyne, S.J., 2006: Fogo no jardim: compreensão do contexto dos incêndios em Portugal. In J.S. Pereira, J.M.C. Pereira, F.C. Rego, J.M.N. Silva and T.P. Silva (Eds.), Incêndios Florestais em Portugal – Caracterização, Impactes e Prevenção (pp 115-131). ISA Press (in portuguese).

[15] Trigo I., DaCamara, C., Viterbo, P., Roujean, J.L., Olesen, F., Barroso, C., Camacho-de Coca, F., Carrer, D., Freitas, S., García-Haro, F., Geiger, B., Gellens-Meulenberghs, F., Meliá, J., Ghilain, N., Pessanha, L., Siljamo, N. and Arboleda, A., 2009: The Satellite Application Facility on Land Surface Analysis. *Int. J.Rem Sens.* (in press).

[16] Ventura, J. and Vasconcelos, M.J., 2006: O fogo como processo físico-químico e ecológico. In J.S. Pereira, J.M.C. Pereira, F.C. Rego, J.M.N. Silva and T.P. Silva (Eds.), Incêndios Florestais em Portugal – Caracterização, Impactes e Prevenção (pp 93-113). ISA Press (in portuguese).

[17] van Wagner, C.E. and Picket, T.L., 1985: Equations and FORTRAN program for the Canadian Forest Fire Weather Index System. Canadian Forestry Service, Government of Canada, Forestry Technical Report 33.

[18] van Wagner, C.E., 1987: Development and structure of the Canadian Forest Fire Index System. Canadian Forestry Service, Ottawa, Ontario, Forestry Technical Report 35, 37 pp.

ANNEX A

The output file has the name

HDF5_MSG_LSASAF_FRMX_Euro_YYYYMMDDHHmm

Where

X is 1, 2 or 3 depending on the ECMWF forecast used in the algorithm is 24h, 48h or 72h, respectively.

YYYY is the year

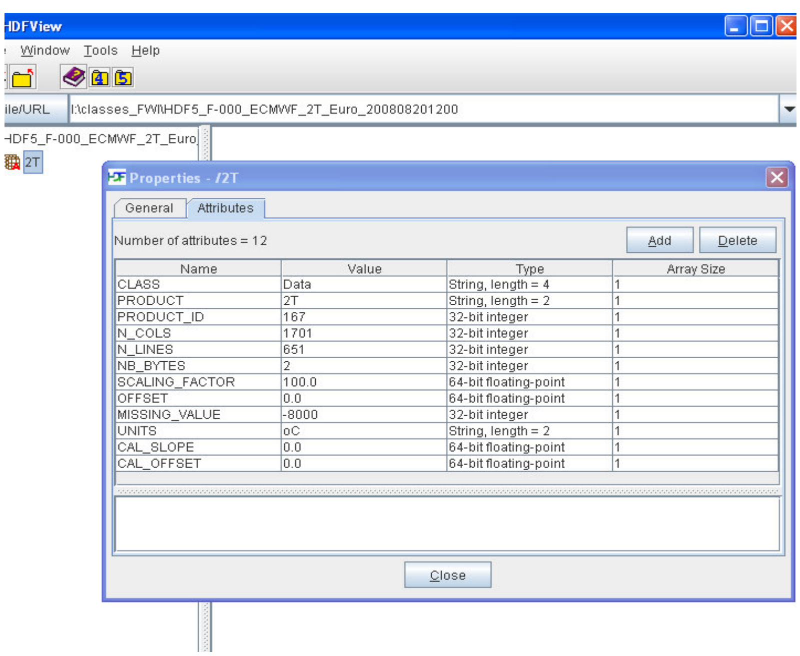
MM is the month

DD is the day

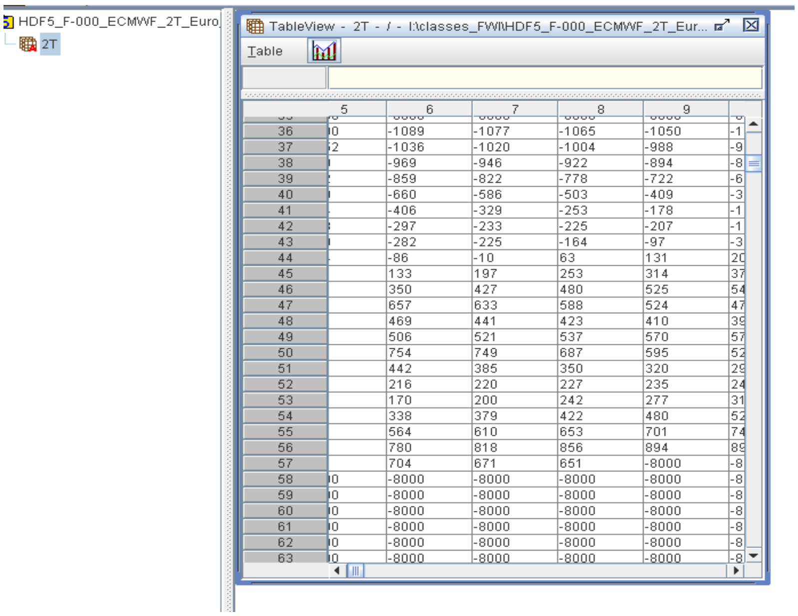
HH is the hour

mm are the minutes

The HDF5 file has 10 fields: the three fuel moisture codes (FFMC, DMC, DC), the three fire behaviour indices (ISI, BUI, FWI), the Daily Severity Rating (DSR), the Risk (low, moderate and high, corresponding to risk values of 10, 20 and 30, respectively), the Table_Ref (10, 20, 30, 41, 42, 43 and 50 for shrub, tree cover broad-leaved, tree cover needle-leaved, cultivated and managed areas for Iberian Peninsula and France, cultivated and managed areas for the remaining regions and all other types of vegetation, respectively) and a flag indicating processed pixels (pixels in land) and non-processed pixels (water pixels or pixels out of MSG disk). This flag further indicates in which mode the algorithm ran. Figure 28 presents an example of HDF5 file attributes and data values.



(a)



	6	7	8	9
36	-1089	-1077	-1065	-1050
37	-1036	-1020	-1004	-988
38	-969	-946	-922	-894
39	-859	-822	-778	-722
40	-660	-586	-503	-409
41	-406	-329	-253	-178
42	-297	-233	-225	-207
43	-282	-225	-164	-97
44	-86	-10	63	131
45	133	197	253	314
46	350	427	480	525
47	657	633	588	524
48	469	441	423	410
49	506	521	537	570
50	754	749	687	595
51	442	385	350	320
52	216	220	227	235
53	170	200	242	277
54	338	379	422	480
55	564	610	653	701
56	780	818	856	894
57	704	671	651	-8000
58	-8000	-8000	-8000	-8000
59	-8000	-8000	-8000	-8000
60	-8000	-8000	-8000	-8000
61	-8000	-8000	-8000	-8000
62	-8000	-8000	-8000	-8000
63	-8000	-8000	-8000	-8000

(b)

Figure 21. Example of an HDF5 file as displayed by the HDFView, namely (a) the file attributes and (b) the data values.