Development of a National Forest Fire Danger System for Mexico

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Development of a National Forest Fire Danger System for Mexico[1]

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Abstract

This presentation introduces the project "Development of a Forest Fire Danger System for Mexico" funded by the Mexican Forest Agency CONAFOR. The goal of the 3-year project is to develop an operational fire danger system for mapping daily and forecasted fire risk occurrence and fire propagation danger in Mexico, which will be online for decision-making on fire management by CONAFOR and fire management actors in Mexico. The presentation summarizes the project goals and structure and the results from the first year of the project, including: 1) The development of a fire occurrence risk module for mapping expected number of fires based on vegetation type, weather and satellite information and 2) The development of an online interface for daily mapping of fire risk and danger in Mexico.

Keywords: fire danger, fire risk, fuel dryness indices, online decision support system, Mexico.

Introduction

No operational fire danger system is currently available in Mexico. This in contrast with countries such as USA, Canada or Brazil that have developed operational fire risk systems based on temporal and spatial quantification of fuel greenness and associated fire risk and danger (e.g. Deeming et al., 1977, Burgan et al., 1997, 1998,

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Preisler et al., 2004, 2008, 2011, Riley et al., 2013, Van Wagner, 1987, Sismanoglu and Setzer, 2012).

This lack of an operational fire danger system led the Forest National Commission (CONAFOR in Spanish) and the National Research Agency (CONACYT in Spanish) to fund the national scale project "Development of a Forest Fire Danger System for Mexico". The main objective of the study is the development of an operational fire risk and danger mapping system based on satellite and weather information for Mexico (Vega-Nieva et al., 2015). This document summarizes the project goals and structure and the results from the first year of the project, including:
1) The development of a fire occurrence risk module for mapping expected number of fires based on vegetation type, weather and satellite information and
2) The development of an online interface for daily mapping of fire risk and danger in Mexico.

Goals of the Project "Development of a Forest Fire Danger System for Mexico".

In Mexico, a system for near real-time mapping of fire Hotspots has been implemented by CONABIO (http://incendios1.conabio.gob.mx/), but no operational system for prediction of Fire Risk (probability of fire occurrence) or Fire Danger (expected fire behavior and difficulty of suppression) is currently available for Mexico. The Project 252620 in response to the call 3-C02-2014 by CONACYT-CONAFOR aims at developing an operational Fire Risk and Danger System to be used by the Mexican Government Forest Agency CONAFOR and relevant agents in decision making on fire management in Mexico. The Project is being conducted by a consortium of researchers from several institutions from Mexico, USA, Brazil and Spain.

The goals of the project are

1) To conduct a literature review of Fire Risk and Danger
2) To test existing Fire Risk and Danger systems for the prediction of fire occurrence in Mexico.
3) To develop a Mexican Fire Risk System for the prediction of fire occurrence.
4) To develop a Fire Weather forecast system for Mexico.
5) To develop a module for mapping Fire Area in Mexico.
6) To test existing Fire Danger systems in Mexico against fire area records.
7) To develop a Mexican Fire Danger System
8) To develop and transfer to CONAFOR a online software for mapping of current and forecasted Fire Danger in Mexico.

Modeling fire occurrence risk from monthly satellite fuel dryness by vegetation type and region in Mexico.

Within this national project, a study was conducted by Vega et al. (2016) with the goals of: 1) quantifying the monthly temporal trends of a MODIS satellite based fuel greenness index, DR, and the temporal trends of fire density (FD) by vegetation type and region in Mexico, 2) testing simple regression models for prediction of monthly FD by vegetation type and region from monthly DR values in Mexico. The methodology and the main results of this study are summarized below.

Methodology

Area of study

The area of study was the Mexican Republic. Figure 1 shows the vegetation types present in the country according to the National Institute of Geography and Statistics (INEGI in Spanish) most recent land use map **(**INEGI Land Use Map Series V, 1:25000 http://www.inegi.org.mx/geo/contenidos/recnat/usosuelo/) Four geographical regions , Northwest (NW), Northeast (NE), Center (C), and South (S), were established (figure 1), considering both the potential fire regimes zoning for Mexico (Jardel et al. 2014), based on vegetation types and climatic zones (Holridge, 1996), together with a visual observation of the temporal and spatial patterns of clustering in fire hotspots on the period of study.

Satellite hotspots and fuel dryness indices.

Considering the availability of MODIS fire hot spots information for Mexico we selected the period of 2003-2014 for our study. We compiled monthly MODIS fire hotspots for the 12 years of the study period from CONABIO (http://incendios1.conabio.gob.mx/).

The monthly NDVI composite images with a spatial resolution of 1 x 1 km (MODIS product MOD13A3) from the study period were downloaded from http://modis.gsfc.nasa.gov/data/dataprod/mod13.php.

Following Burgan et al. (1998), Dead Ratio (DR) values were calculated for each pixel based on the values of NDVI for each monthly image, on the maximum and minimum NDVI values for each pixel and on the absolute maximum and minimum NDVI observed values in the area of study for the whole study period. Dead ratio is an empirical index representing the fraction of fuel that is not live (DR= 100- Live Ratio), reaching 100 in a fuel that is completely cured with no live biomass, and with lower values representing fuels with a higher fraction of live biomass (Burgan et al., 1998).

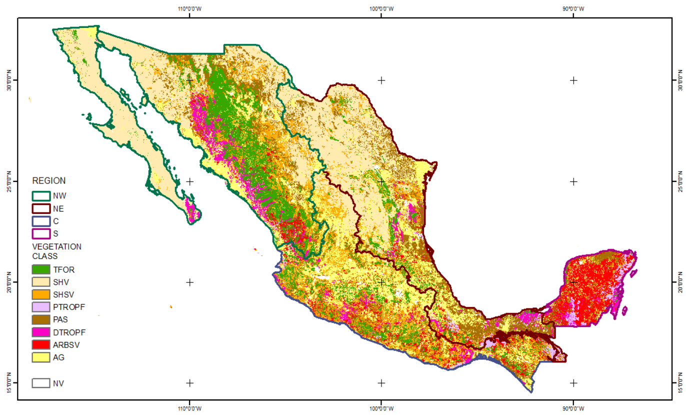

Figure 1. Map of vegetation types and regions considered in the analysis. Where: TFOR: Temperate Forest, SHV: Shrubland Vegetation, SHSV: Shrubby Secondary Vegetation, PTROPF: Perennial Tropical Forest, PAS: Pastureland, DTROPF: Deciduous Tropical Forest, ARBSV: Arboreous Secondary Vegetation, AG: Agriculture, NV: No Vegetation; and NW: North West, NE: North East, C: Centre, S: South regions. Source: INEGI land use map (series V)

Fire Density Index.

For each of the 28 vegetation types and regions considered, monthly Fire Density (FD) was calculated by dividing the number of fires in the area by the surface (km^2) of the vegetation/region considered. Monthly FD values for each vegetation type and region were scaled to a Fire Density Index (FDI) as follows:

FDI= Number of fires / Surface (km^2) x 5000

The FDI index is defined so that a FD of 0.01 fires /km ^{2} – e.g. 1 fire / 100 km ^{2} – is equivalent to an FDI value of 50. Accordingly, a FD of 2 fires / 100 km ^{2} is equivalent to an FDI value of 100, which might be considered an indicator of a high fire density.

Modeling monthly FDI from DR.

Fire season concentrated on the first 6 months of the year for all vegetation types considered. Consequently, all land uses were modeled for the period January-June. We tested linear and nonlinear power equations as regression models. Table 1 summarizes the equations tested. Each month or group of months was allowed to have distinct coefficients by multiplying the observed DR by a dichotomous variable (0 or 1) so that each month or group of months would obtain an individual parameter, both in the lineal and nonlinear models (eqs. 1 and 7, table 1). After observing the coefficients obtained in this approach, several groups of months were tested as candidates for grouping with the same coefficients (eqs. 2-6 8-12). Statistical and graphical analyses were used to evaluate the performance of the equations. The goodness-of-fit of each model was evaluated using the adjusted coefficient of determination (R^2) and root mean squared error (RMSE).

Table 1. ***Equations tested for prediction of monthly Fire Density Index from Dead Ratio values. Where: FDI: monthly Fire Density Index, DR: monthly Dead Ratio, a and b are model coefficients, J: January, F: February, M: March, A: April, My: May, Ju: June, Jl: July, Ag: August, S: September, O: October, N: November, D: December.***

Eq. Num.	Fit type	Grouped months	Equation
1	Linear	-	$FDI = a + (b_J DR_J + b_F DR_F + b_M DR_M + b_A DR_A + b_{My} DR_{My} + b_{Ju} DR_{Ju})$
2	Linear	J&F	$FDI = a + (b_{JF} DR_{JF} + b_M DR_M + b_A DR_A + b_{My} DR_{My} + b_{Ju} DR_{Ju})$
3	Linear	J,F&M	$FDI = a + (b_{JFM} DR_{JFM} + b_A DR_A + b_{My} DR_{My} + b_{Ju} DR_{Ju})$
4	Linear	J,F&M, A&My	$FDI = a + (b_{JFM} DR_{JFM} + b_{AMy} DR_{AMy} + b_{Ju} DR_{Ju})$
5	Linear	J,F&M, A&Ju	$FDI = a + (b_{JFM} DR_{JFM} + b_{AJu} DR_{AJu} + b_{My} DR_{My})$
6	Linear	J,F,M&A, My&Ju	$FDI = a + (b_{JFMA} DR_{JFMA} + b_{MyJu} DR_{MyJu})$
7	Non linear	-	$FDI = (a_J DR_J + a_F DR_F + a_M DR_M + a_A DR_A + a_{My} DR_{My} + a_{Ju} DR_{Ju})^b$
8	Non linear	J&F	$FDI = (a_{JF} DR_{JF} + a_M DR_M + a_A DR_A + a_{My} DR_{My} + a_{Ju} DR_{Ju})^b$
9	Non linear	J,F&M	$FDI = (a_{JFM} DR_{JFM} + a_A DR_A + a_{My} DR_{My} + a_{Ju} DR_{Ju})^b$
10	Non linear	J,F&M, A&My	$FDI = (a_{JFM} DR_{JFM} + a_{AMy} DR_{AMy} + a_{Ju} DR_{Ju})^b$
11	Non linear	J,F&M, A&Ju	$FDI = (a_{JFM} DR_{JFM} + a_{AJu} DR_{AJu} + a_{My} DR_{My})^b$
12	Non linear	J,F,M&A, My&Ju	$FDI = (a_{JFMA} DR_{JFMA} + a_{MyJu} DR_{MyJu})^b$
13	Linear	-	$FDI = a + (b_J DR_J + b_F DR_F + b_M DR_M + b_A DR_A + b_{My} DR_{My} + b_{Ju} DR_{Ju} + b_{Jl} DR_{Jl} + b_{Ag} DR_{Ag} + b_S DR_S + b_O DR_O + b_N DR_N + b_D DR_D)$
14	Non linear	-	$FDI = (a_J DR_J + a_F DR_F + a_M DR_M + a_A DR_A + a_{My} DR_{My} + a_{Ju} DR_{Ju} + a_{Jl} DR_{Jl} + a_{Ag} DR_{Ag} + a_S DR_S + a_O DR_O + a_N DR_N + a_D DR_D)^b$
15	Non linear	All but My	$FDI = (a_{JFMAJuJlAuSOND} DR_{JFMAJuJlAuSOND} + a_{My} DR_{My})^b$

Results and discussion

Table 2 shows the models that better fitted the data for each vegetation type and region and the goodness of fit statistics for the best models. With the exception of the deciduous and perennial tropical forests of the NE, the nonlinear models described better the data than linear models for all vegetation types and regions, suggesting that the relationship of DR with fire occurrence is not linearly proportional –e.g. fire occurrence risk increases very rapidly with increasing DR.

Table 2. ***Coefficients and goodness of fit of the best fit equations for the prediction of monthly Fire Density Index from Dead Ratio values for each vegetation type and region. Where: Veg_Reg: Vegetation and region; Eq: best fit equation from table 1, a and b are model coefficients, J: January, F: February, M: March, A: April, My: May, Ju: June, Jl: July, A: August, S: September, O: October, N: November, D: December coefficients for the corresponding month or group of months. RMSE: Root Mean Standardized Error; R^2adj: Adjusted R^2; TFOR: Temperate Forest, PAS: Pastureland, PTROPF: Perennial Tropical Forest, ARBSV: Arboreous Secondary Vegetation, SHSV: Shrubby Secondary Vegetation, DTROPF: Deciduous Tropical Forest, NV: No Vegetation; and NW: North West, NE: North East, C: Centre, S: South regions.***

Veg_Reg	Eq	a	JF	M	JFM	A	JFMA	My	AMy	Ju	AJu	MyJu	b	RMSE	R^2_{ADJ}
TFOR_C	8		0.019	0.021		0.024		0.026		0.023			7.771	33.3	0,75
TFOR_NE	8		0.016	0.018		0.019		0.021		0.019			10.438	15.4	0,62
TFOR_NW	12						0.015					0.017	11.371	32.4	0,62
TFOR_S	9				0.016	0.016		0.015		0.014			25.706	11.7	0,68
PAS_C	8		0.019	0.022		0.028		0.032		0.027			5.276	18.2	0,95
PAS_NE	8		0.019	0.021		0.024		0.026		0.023			5.668	9.3	0,86
PAS_NW	8		0.011	0.011		0.012		0.012		0.013			13.729	3.3	0,60
PAS_S	8		0.059	0.110		0.178		0.197		0.082			2.243	92.3	0,79
PTROPF_C	9				0.024	0.034		0.041		0.034			4.817	35.7	0,79
PTROPF_NE	3	-102.96			2.278	2.794		3.388		2.266			0.000	19.1	0,67
PTROPF_NW	12				0.015							0.020	5.662	9.1	0,67
PTROPF_S	8		0.019	0.021		0.023		0.026		0.023			7.018	7.5	0,70
DTROPF_C	11				0.023			0.052			0.048		3.234	19.5	0,91
DTROPF_NW	9				0.013	0.017		0.024		0.022			5.245	9.8	0,89
DTROPF_NE	2	-219.92	3.503	3.882		4.767		5.615		5.368			0.000	78.6	0,46
DTROPF_S	8		0.037	0.044		0.050		0.049		0.036			3.923	28.0	0,76
ARBSV_C	8		0.019	0.024		0.031		0.035		0.028			5.361	26.5	0,90
ARBSV_NE	8		0.022	0.025		0.028		0.034		0.028			6.131	10.7	0,94
ARBSV_NW	9				0.016	0.024		0.030		0.027			4.706	28.6	0,70
ARBSV_S	8		0.034	0.059		0.080		0.080		0.034			2.956	37.0	0,79
SHSV_C	8		0.017	0.020		0.026		0.030		0.025			5.590	17.8	0,93
SHSV_NE	10				0.017				0.022	0.019			7.257	14.6	0,73
SHSV_NW	9				0.012	0.014		0.015		0.015			11.690	18.9	0,65
SHSV_S	8		0.033	0.048		0.060		0.061		0.033			3.722	59.4	0,79

Different patterns of FDI and DR relationships were observed for different vegetation types and regions, agreeing with observations that point to a variety of fire regimes resulting from combinations of climatology and fuel types in the country (e.g. Rodríguez et al., 1996, 2008, Morfin et al., 2007, 2012, Avila et al., 2010, Jardel et al., 2009, 2014, Perez-Verdin et al., 2014). Derived model coefficients for months and groups of months may offer information about the patterns of timing of fire season and their relationships with DR patterns in different vegetation types and regions. Most of the vegetation types in the south and center region showed an earlier start of fire season (1 month earlier) compared to the NW region, suggesting that either longer periods of accumulated drought in that latter region are required for fire to start, or perhaps reflecting different patterns of agricultural burns timing in the different regions of the country. Within regions, tropical forest showed latter starts of fire season compared to other vegetation types in the same region (1 or 2 more months in the NW), suggesting that longer accumulated drought periods are required in those more humid ecosystems for fire to start.

Development of an online interface for the Mexican Fire Danger System

In the first year of the project, UJED programmed an online test interface for the Forest Fire Danger System of Mexico, freely available online at the link:
http://fcfposgrado.ujed.mx/incendios/inicio/index.php

The interface includes several layers for current situation (figure 2) and a section with evolution of fuel dryness and risk indices. (figure 3), available at:
http://fcfposgrado.ujed.mx/incendios/inicio/historicos_animaciones.php
The layers included in the GIS interface for current situation include observed daily layers for fire hotspots, fuel dryness index, and fire occurrence risk (figure 2).

A number of thematic layers in included in the GIS interface, including: CONAFOR fire priority areas, Regional Fire Management Centers, Type of land cover, Natural Protected Areas, Limits of States, Municipalities and Forest Management Units (figure 1). A base map containing towns, roads and topography from three online sources (Bing Maps, ArcGis Online 1, ArcGis Online 2) is also included .The user can zoom in/off using base maps as a spatial reference. The user can turn on/off any layer in the GIS interface, including the possibility of simultaneously visualizing a combination of layers (e.g. fire risk and a topography/roads map from Bing maps) by regulating the layers level of transparency.

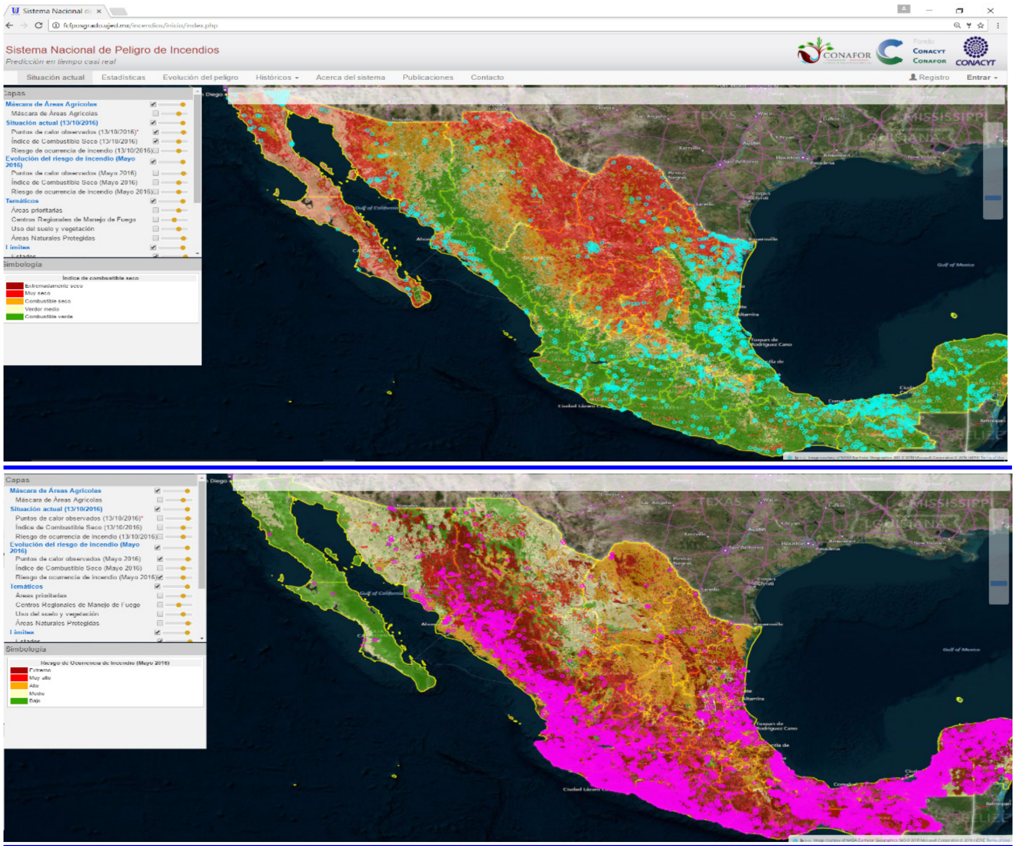

Figure 2. Online interface of the Mexican Forest Fire Danger System: current situation. Top figure shows current fuel dryness index and observed fire hotspots (in blue) in October 2016. Colors represent fuel dryness, with green being very wet fuel and red and light pink being dry and very dry fuel conditions. Bottom figure shows the predicted fire occurrence risk map and observed fire hotspots (in bright pink) in May 2016. Colors represent risk of fire occurrence, with green meaning low probability of fire occurrence and red and dark red representing high and very high fire occurrence risk. http://fcfposgrado.ujed.mx/incendios/inicio/index.php

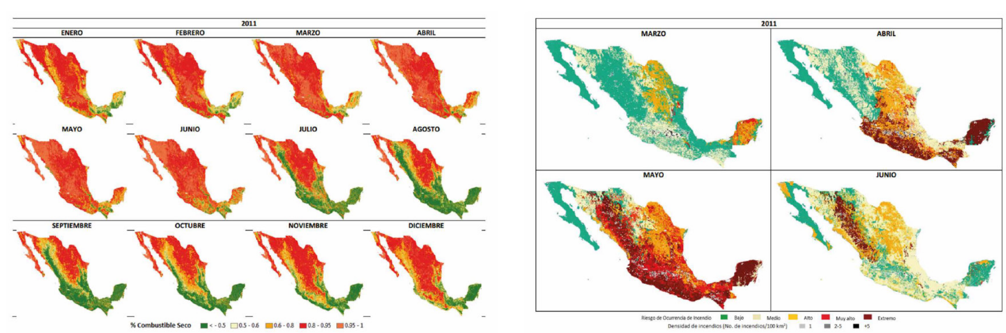

Figure 3. Examples of Fuel Dryness Index (left figure, monthly fuel dryness for 2011) and Fire Ocurrence Risk maps (right figure, march to june 2011). Animations of fuel dryness and fire risk for historic years in Mexico can be consulted at the link: *http://fcfposgrado.ujed.mx/incendios/inicio/historicos_animaciones.php*

Summary and conclusions.

The Project "Development of a Forest Fire Danger System for Mexico", funded by the Forest National Commission (CONAFOR in Spanish) and the National Research Agency (CONACYT in Spanish) aims at developing an operational fire risk and danger mapping system based on daily satellite and weather information, to be used by the Mexican Government Forest Agency CONAFOR and relevant agents in decision making on fire management in Mexico. During the first year of the project, several weather and satellite based indices have been tested, with first results for prediction of fire occurrence risk based on a satellite fuel dryness index for Mexico. Future work in the project will include the development of probabilistic fire risk based on daily weather-based fire danger indices together with spatial factors such as distance to roads and locations. These daily fire risk models will be included in the online platform which will provide daily assessments of fuel drought and expected fire risk occurrence. This operational tool will be used for improving the planning of fire extinction and for strategic fire management decision making in Mexico.

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