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The Forest Fire Danger Prediction System of Mexico

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Introduction

The Forest Fire Danger Prediction System of Mexico is an operational decision-support tool for forest fire management in Mexico. Maps are updated daily from weather, active fire and fire suppression information. It allows to monitor near-real time fuel greenness and associated fire risk and danger to support decision making in fire management. In particular, it offers information about fuel dryness, expected number and location of ignitions, and expected fire spread potential. The maps allow to support decision making for fire detection planning, suppression prioritization, optimizing number and location of fire suppression resources, allowing to assign most appropriate fire suppression resources to each fire and to orient prescribed and agricultural burn timing, fire management plans and fuel treatment and long-term strategic fire suppression resources allocation. It is publically available online at: http://forestales.ujed.mx/incendios

The current publication synthesizes the structure and components of the fire danger system.

Methods

Figure 1 summarizes the structure of the Forest Fire Danger Prediction System of Mexico. The fuel dryness index (FDI) is calculated following the calibration from Vega-Nieva *et al.* (2018, 2019a) of the FPI index from Burgan et al. (1998) for Mexican vegetation types, based on daily weather and MODIS-based fuel greenness information daily supplied by CONABIO and the Mexican National Weather Service (SMN-CONAGUA). Expected number of active fires per vegetation type and region is calculated daily from the FDI and the observed MODIS and VIIRS active fires from the previous days, based on the active fire ignition density index developed by Vega-Nieva *et al.* (2018), combined with the spatial active fire distribution models of Vega-Nieva *et al*. (2019b, under review).

In addition to fuel dryness and vegetation types, fire occurrence in Mexico is strongly influenced by human factors, with more than 90 % of all fires caused by human ignition, according to COANFOR statistics (CONAFOR, 2018). The fire ignition density index is combined with a human fire occurrence risk map (Monjarás-Vega *et al*., 2019), based on distance to roads and urban areas and historical suppression registers, to produce a fire danger index that combines the expected ignition density from fuel dryness and presence of active fires with the human ignition spatial pattern. Finally, a forecast of expect number of fires by state for the next week is calculated from the weather-based fire index and the active fire suppressions, based on the forecast models developed by Vega-Nieva *et al*. (2019c, under review).

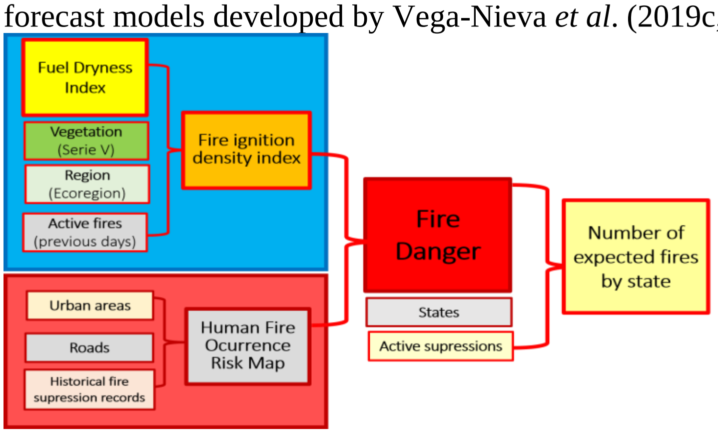

Figure 1: Structure of the Forest Fire Danger Prediction System of Mexico.

Results

The fire ignition density index has shown a good agreement with observed active fire density by vegetation type and region in the country. Figure 2 shows example of observed and predicted active fire density for three regions (NW, C and NE) from the study of Vega-Nieva *et al.* (2018). Differences in weather and human factors between the regions result in different ignition temporal trends, which can be modeled with percentile regression from the fuel dryness index and the previously observed active fires.

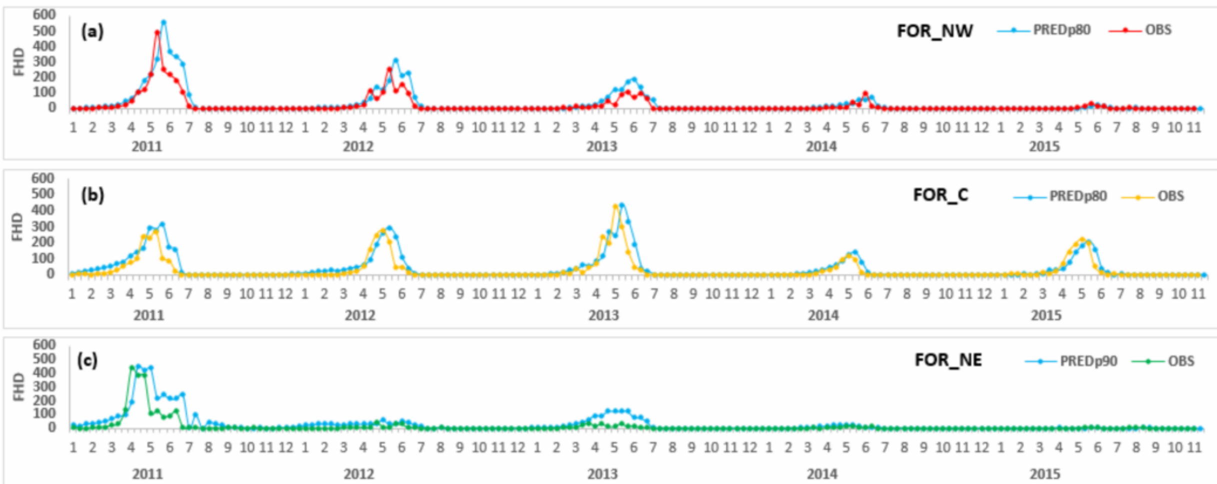

Figure 2: Example of predicted (PRED) against observed (OBS) active fire hotspot density (FHD) for temperate forests of three regions: NW (a) C (b) and NE (c). Source: Vega-Nieva *et al*. (2018).

Furthermore, models for predicting the spatial distribution of active fires from the fuel dryness index have shown good potential to map the expected ignition distribution for each vegetation type and region. An example of observed (left) and predicted (middle figure) MODIS active fire distribution against FDI from the study of Vega-Nieva *et al.* (2019b, under review) is shown in figure 3.

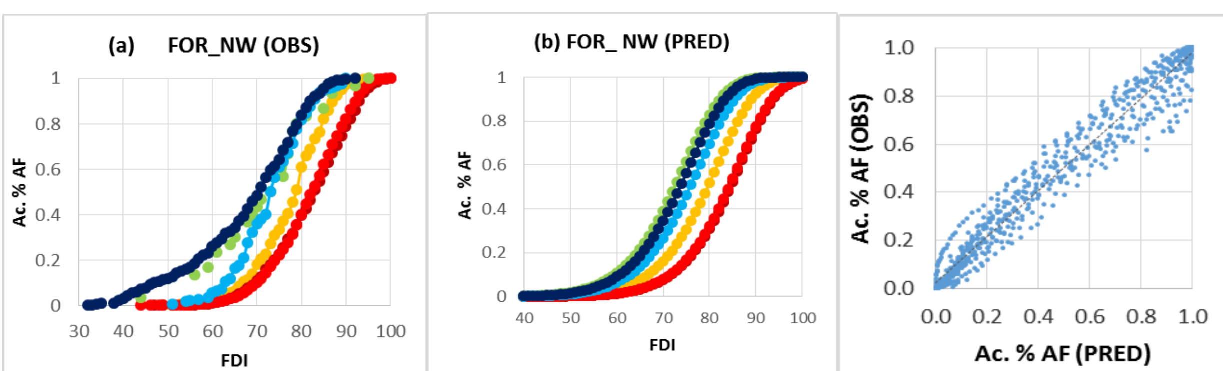

Figure 3: Observed (OBS) (a) and predicted (PRED) (b) accumulated distributions of MODIS active fires (Ac % AF) by fuel dryness (FDI) for the months of 03-05 in the wet year 2014 (blue and green lines) and in the dry year 2011 (orange and ref lines) for the temperate forests of the NW (FOR_NW). Observed against predicted Ac % AF is shown in the right figure. Source: Vega-Nieva *et al.* (2019b, under review).

The system daily maps the weather-based fuel dryness index (figure 4, top left), and calculates the expected ignition density from fuel dryness and previous MODIS and VIIRS active fires for each vegetation type (figure 4, top right) based on the mentioned temporal and spatial models of fire ignition risk.

The fire ignition risk maps are combined with a human fire occurrence risk map (Monjarás-Vega *et al*., 2019), to result in a daily fire danger index that combines the predictions of expected ignition density from fuel dryness with the human-based spatial patterns of fire occurrence (figure 4, bottom left). This map allows to visualize, of all the areas that are dry enough to sustain a fire, which ones are more likely to ignite because of human factors such as vicinity to an urban areas and access by road. It also allows to consider the accessibility by road and vicinity to urban areas potentially at risk into the fire suppression prioritization decision-making.

Additonally, in order to support fire suppression allocation decision-making, maps of expected number of fires are produced by state (figure 4, bottom right), combining the fire ignition density predictions with the active fire suppression data daily supplied by CONAFOR.

The fuel dryness index, expected ignition density, fire danger index and expected number of fires maps (figure 4) are produced daily and shown in a publically available GIS interface, which also shows the MODIS and VIIRS active fire data –daily supplied by CONABIO-, to aid in fire suppression decision-making by CONAFOR and all agents involved in fire management in Mexico. It can be accessed at: http://forestales.ujed.mx/incendios

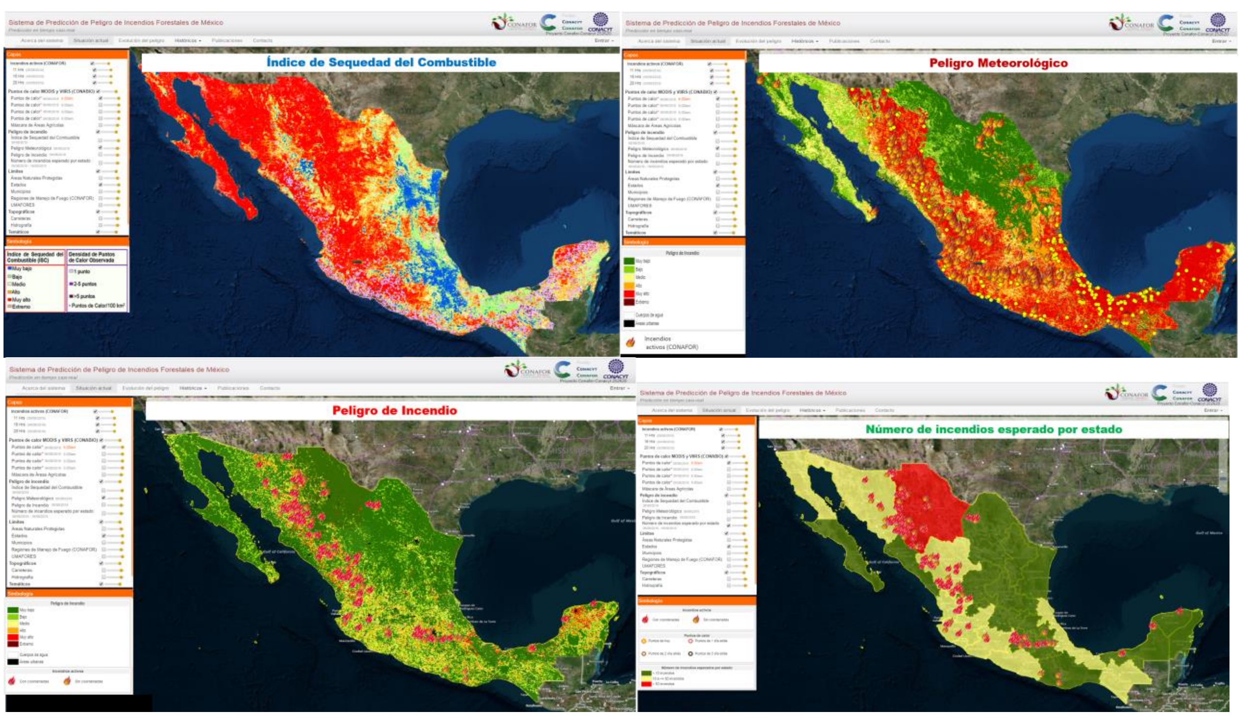

Figure 4: Examples of the main fire danger information daily shown by the Forest Fire Danger Prediction System of Mexico. From top left to bottom right: Fuel Dryness Index (with active fire density shown in purple), weather-based fire ignition density index -with MODIS and VIIRS active fires shown as yellow circles- (top right), fire danger index (bottom left) and expected number of fires by state (bottom right). Flames represent fire suppression records daily supplied by CONAFOR.

Conclusions

The Forest Fire Danger Prediction System of Mexico is an operational decision-support tool to aid in decision making in fire management from near-real time information about fuel dryness, active fire, fire suppression, and forecasted number and location of forest ignitions. It is being utilized operationally by CONAFOR and other agents involved in fire management in Mexico, to support in decisions of fire suppression and strategic fuel and fire management planning.

Several improvements are forecasted for expanding the capabilities of the system. The maps of fire occurrence risk will be improved with the consideration of additional factors, such as distance to agriculture, because of the relevance of agricultural activities in fire ignition risk the country, and Landsat-based aboveground forest biomass, which has been found to influence forest fire occurrence in the country (Briones-Herrera *et al.*, 2019).

In its current version, the system only considers a vegetation type maps. Because of the recent availability of a national fuel type map (Jardel *et al.*, 2019), fuel types will be utilized both for updated fire ignition risk maps, and to develop forecasts of fire spread potential and fire intensity, considering topographically corrected wind, fuel dryness and fuel types. The use of active fire radiative power, which has shown to be linked to fire suppression difficulty (Jolly and Freeborn, 2017), together with burned area products and/or interpolated active fire perimeters will be explored for these future fire behavior predictions.

Current predictions focus on active fire ignition density and expected number of fire suppressions by state. Because of the relevance of large fires on fire suppression costs, forecasts of large fire probability (Presiler *et al.*, 2011, 2016) will also be explored. Other potential variables to be predicted from fire danger indices -integrating fuels, dryness and topographically corrected wind speed-, could be total area burned by state, and number of high intensity fires -based on fire radiative power-, to aid in fire suppression allocation planning.

Other areas of future technological development for the system are the automated active fire cluster delineation (Jolly and Vega, 2018) and rapid automated perimeter interpolation from active fires (e.g. Caraviglio *et al.*, 2016, Veraverbeke *et al.*, 2014, Artés *et al.*, 2017) to aid in decision making of fire suppression allocation at the national, regional and state fire management centers of CONAFOR, among other agents involved in fire suppression in the country.

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