

# **Monitoring and Early Warning Systems for Potentially Dangerous Vegetation Fires in Cuba**

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## **Abstract**

The early warnings alert is a result of the agrometeorological monitoring system that includes information on the content of soil moisture, living vegetation, and dead biomass. Starting from this, the danger potential conditions can be inferred to originate and to spread vegetation fires. The alert system was designed to operate at different temporal scales at the national level (early warnings alert) and provincial level (advanced and immediate warnings alert). The resulting information flow of the danger-potential alert conditions of vegetation fires surveillance is explained. Some results of the practical application of this potential danger index in long-term early warnings alerts are reported. The index was evaluated with forest fire reports during 2001 and 2002, for the early warnings alert of the occurrence of danger conditions of vegetation fires. This system has allowed the Cuban Body Keepers to strengthen preventive activity and to achieve operative efficiency during the high-danger occurrence period of forest fires in Cuba.

## **Introduction**

During the last decades, the world has observed a remarkable tendency toward an increase in forest fires and the area affected by them. The Cuban forests have not been an exception in this tendency.

According to the investigative results of the Meteorological Institute Climate Center, in the last three decades, the average air temperature has increased by 0.6 °C, the presence of severe storms has increased (accompanied by strong winds and electric discharges), and the frequency and intensity of south winds and droughts has risen (Centella, et al., 1997). All of these events contribute to a greater occurrence of vegetation fires. The general increase in temperatures has been accompanied by a reduction of annual total rainfall from 10 to 20 percent and an increase in the interannual variability from 5 to 10 percent. Another feature noted is diminishing rainfall in the rainy period (May - October) and increased rainfall in the drier period of the year (Lapinel, et al., 1993).

According to Gutiérrez, et al., (1999), the expected combination between the generalized decrease of biomass potential density and the forest net primary productivity caused by the effect of the climatic change during the current century, specifically in the eastern region of the country, bring as a consequence a progressive reduction of forest sustainability and an evolution to more dry forests, very dry forests, or savannas. These drier ecosystems, in presence of higher temperatures and higher air saturation deficit, will see considerably more exposure to forest fire danger than the current ones (Ávila, et al., 1985).

The general objective of this work was to use the more novel agrometeorological knowledge in the international literature, adapt them to the Cuban conditions, and to formulate a theoretical framework. The necessary algorithms were used to simulate the effect that the

climatic conditions produce on the vegetation and other aspects related with the environment where they grow. Finally, advanced techniques of data prosecution and geographical information systems (GIS) were used to apply this knowledge to evaluate the danger potential conditions of vegetation fires.

The specific objectives were: 1) to obtain an evaluation method that describes, using objective methods, the danger potential conditions of vegetation fires in an appropriate scale for an exploratory purpose; and 2) to apply the results obtained in the operational agrometeorological services and in the future generation of a database that allows developing new agrometeorological investigations and risk studies for vegetation fires.

## Materials and Methods

The alert system based on the integration of different indexes containing elements that initiate the beginning and the propagation of the forest fires (Solano, 2001). Contributing in its elaboration, the different meteorological components according to the temporary scale warning are as follows.

<i>Index</i>	<i>Danger condition</i>	<i>Condition to evaluate</i>
0	None	Presence of humid conditions during the last three 10-day periods.
1	Little	Humid conditions don't exist during the last three 10-day periods or dry periods.
2	Moderate	Agricultural drought process in evolution but with some humid or lightly dry decades during the last three 10-day periods.
3	Much	Agricultural drought process in evolution. The modified humidification index during the three or last four 10-day periods has been very dry or severely dry.
4	Extreme	Established agricultural drought process. The modified humidification index during the last five 10-day periods has been very dry or severely dry.

Table 1. Weather and climate characteristics used to evaluate the danger conditions expressed in the agrometeorological danger potential vegetation fires index.

The meteorological and agrometeorological information used in the danger potential conditions of vegetation fire surveillance comes from the meteorological networks of the Institute of Meteorology (ground, radar, aerological, and satellite stations) and the rain gauge networks belonging to the Institute of Meteorology and the National Institute of Hydraulic Resources.

To evaluate the long-term danger potential conditions of vegetation fires, an index determined by Solano (2001) was used, modified to a five-values scale and described in Table 1.

The index was evaluated with the forest fires information that occurred in the whole country during “January, first 10-day period 2001 to July, third 10-day period 2002,” and also the agrometeorological information corresponding to the previous 10-day period was used “December, third 10-day period 2000 to July, second 10-day period 2002” (Solano, et al., 2003). For this particular purpose, a Cuba Body Keepers fire database was prepared, with extracted information: occurrence day, municipality name, the degree of catastrophe, and the

affected area. This information was organized by 10-day periods (decades) for each one of the municipalities studied. Required ground station climatic data for reference evapotranspiration by Penman-Monteith method according to Menéndez, et al., (1999), and their analysis and spatial distribution in the country according to Solano, et al., (1999), were organized. The soil-water balance was made according to Solano, et al., (1999); the calculation of the modified humidification index and their spatial distribution was made according to Solano, et al., (2000) and Solano and Vázquez (1998); and the evaluation of the agricultural drought was made according to Solano, et al., (2000). With this information, the vegetation fires danger index according to Solano (2001) was evaluated for each one of the municipalities and decades used.

To issue the early warnings alert on vegetation fires potential, the traditional agrometeorological prediction method was used. It was based on the vegetation, formed by inertia of agrometeorological conditions at the end of a 10-day period, and the dependence of the current inertia in the vegetation with regard to the present and past meteorological conditions. Also used was the potential danger of vegetation fires index determined by Solano (2001) calculated at the end of a particular decade, to calculate the explosiveness of potential danger conditions of vegetation fires in the next 10-day period.

## **Results**

An alert system was designed that included the issuance of warnings for three different temporal scales and the analysis of different agrometeorological indices and meteorological elements, which are described below:

- *Alert early warnings* are elaborated using information of the climatic risk and the surveillance of the following weather parameters: precipitation; meteorological elements that intervene in the calculation of the evaporative power of the atmosphere, (such as temperature and humidity air), the speed of the wind and the solar radiation, observation of agrometeorological index obtained of the soil water balance (such as the reserve of soil productive humidity), conditions of vegetation, agricultural drought potential, and conditions of potentially dangerous vegetation fires. These warnings are designed to cover a temporal scale of 10 days or more.
- *Alert advanced warnings* are made including the previous information and the existence of weather systems. Short-term and medium-term forecasts are provided for: rainfall, air temperature and air humidity, direction and speed of wind, and behavior of the weather for the following 5 days. These warnings cover a temporal scale from 1 to 10 days.
- *Alert immediate warnings* are elaborated from the previous information and rainfall information, dry-bulb and wet-bulb air temperatures at 13:00 hours of the 75° W meridian, the speed and direction of wind, the Nesterov danger integral index, information provided by meteorological radar on cloud cover, rain and movement of weather systems, and sounding information of atmospheric stability. These warnings cover a temporal scale up to 6 hours.

The alert early warnings are produced by the Agricultural Meteorology Department of the Institute of Meteorology and the alert advanced and immediate warnings are made by the Provincial Meteorological Centers.

Alert early warnings, supported by a system of specialized observations, guarantee an effective supply of accurate and authorized information for decision makers at the national, provincial, regional, or local levels.

The alert system has allowed Cuba National Body Keepers to keep its specialists informed about the danger conditions caused by weather and climate extremes; strengthen preventive activity and improve operational efficiency in fire monitoring surveillance; and more effectively combat forest fires.

Risk Category <u>1/</u>	Fires of potentially dangerous conditions in vegetation in the 10 days before the fires happened									
	<b>4</b>		<b>3</b>		<b>2</b>		<b>1</b>		<b>0</b>	
	Decadal Alerts	Days with reported fires <u>2/</u>	Decadal Alerts	Days with reported fires <u>2/</u>	Decadal Alerts	Days with reported fires <u>2/</u>	Decadal Alerts	Days with reported fires <u>2/</u>	Decadal Alerts	Days with reported fires <u>2/</u>
Jan-Dec. 2001	652	126	468	43	1 601	84	1 880	27	979	5
Jan.-Jul. 2002	830	160	465	53	769	60	880	13	311	16
Jan 2001-Jul 2002	1 482	286	933	96	2 370	144	2 760	40	1 290	21

Table 2. Number of advanced alert warnings by risk level and number of fires occurring in the decadal period following the alert, for all Cuban municipalities, 2001 and 2002.

1/ = no danger, etc.

2/ = fires occurring in decade following alert decade.

**0** = No danger

**1** = Little danger.

**2** = Moderate danger

**3** = Much danger

**4** = Extreme danger

Note: Taking into account the dimensions of the Havana City Province, which has been considered as a municipality.

Table 2 shows, for categories of potential vegetation fire danger (for the year 2001 and for the period January to July 2002), the total fires that occurred in Cuban municipalities and the number of times the danger category was issued in the previous decade to the occurrence of the fire. There was a tendency for the number of forest fires to increase as the index increased. It is necessary to point out that fires can happen even when present conditions for fire risks are low or absent. This explains the differences between the number of evaluated decades and the days with fires reported in those decades.

Evaluating the distribution of the fires and the categories of potential danger from January to July 2002 (Table 3), out of 1,290 cases 21 cases were reported with zero fire potential in the next decade, with an error rate of 1.6 percent. Nevertheless, 86 percent of the fires were in Pinar del Río Province, where the frequency of fires originated by electric discharge is highest. The average affected area of the fires rose in this category (two ha) shown in the Table 3, suggesting that the same ones did not have very favorable conditions for their propagation. The 21 fires occurred in the following municipalities: Guane (6), Mantua (8), Minas de Matahambre (2), Viñales (1), La Palma (1), Martí (1), Moa (1), and Buey Arriba (1).

Of a total of 587 forest fires reported in January 2001 through July 2002, 566 (96 percent) happened in decades following alerts in categories of danger 1 to 4 (Table 3).

Danger level	FIRES		Average fire area (hectares).
	Number	Percent of total	
0 None	21	3.6	2.0
1 Little	40	6.8	14.1
2 Moderate	144	24.5	19.2
3 Much	96	16.4	65.5
4 Extreme	286	48.7	67.8
Total	587	100.0	

Table 3. Distribution of fires and average fire area by alert risk level in Cuba, January 2001-July 2002.

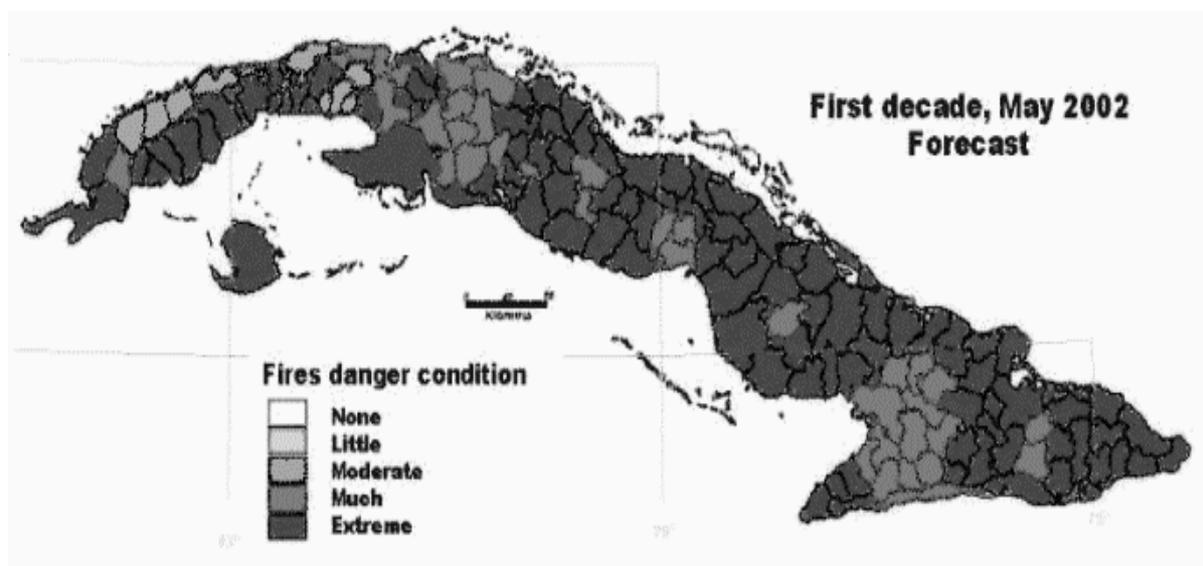


Figure 1. Prediction of potential danger conditions for the occurrence of forest fires predicted for first 10 days of May 2002.

Figure 1 shows the early-warning alerts of potential danger for the occurrence of forest fires that were forecast for the first decade of May 2002. Figure 2 shows the actual danger conditions for the same decade. Comparing the forecast and actual potential danger conditions for each municipality in the second 10 days of May 2002, 95 percent of these forecasts were accurate for the remaining 3 percent (5 municipalities). Real danger conditions were a little more severe than the foreseen ones, raising the risk to a superior category beyond what had been predicted.

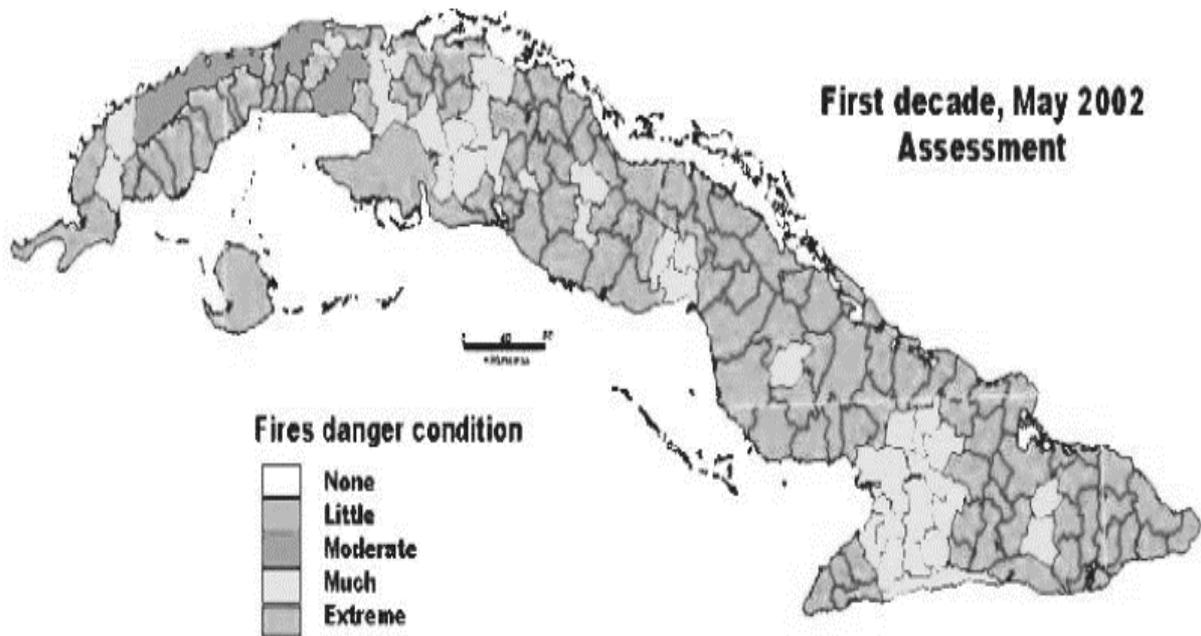


Figure 2. Assessment of potential danger conditions for the occurrence of forest fires during the first 10 days of May 2002.

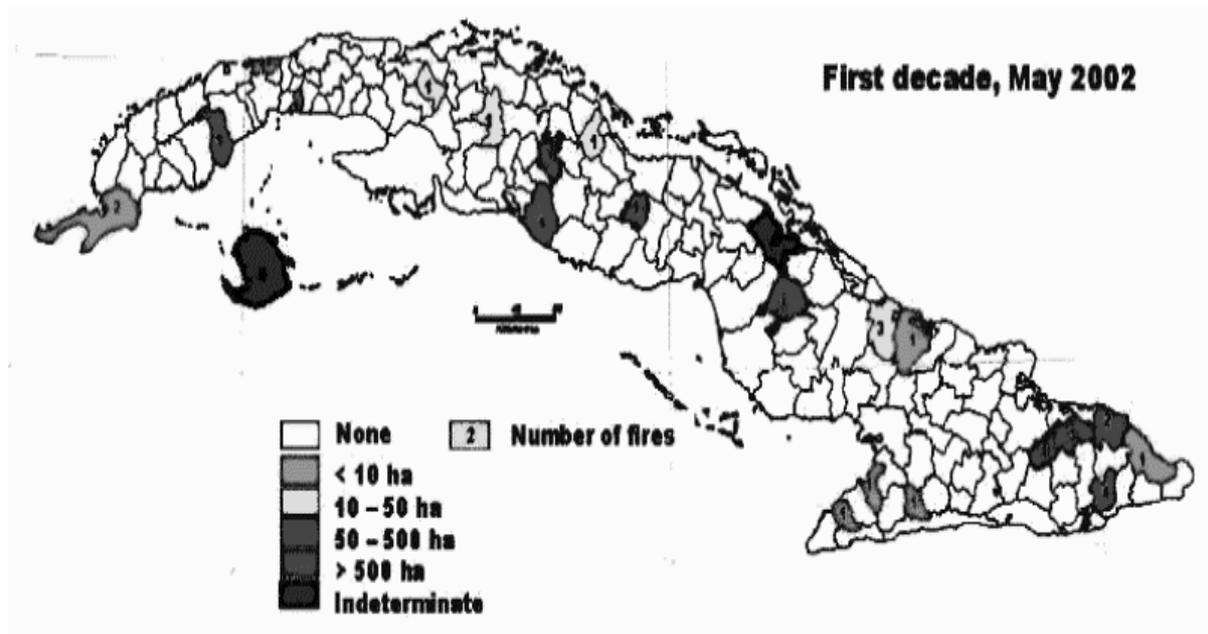


Figure 3. Fires during the first 10 days of May 2002.

Figure 3 shows the municipalities in which forest fires were reported during the first decade of May 2002. A total of 41 fires occurred in that period in 23 municipalities of the country. The number that appears inside the municipality indicates the number of fires and the background shade indicates extent of area damaged, in ha. Of the 41 fires, there was one in the category of moderate danger covering less than 10 ha, and four in the category of the severe danger (two covering less than 10 ha, one between 10 and 50 ha, and one covering more than 500 ha). The remaining 36 forest fires happened in the extreme hazard category. Five fires were smaller than 10 ha, three were between 10 and 50 ha, five were between 50 and 500 ha, three were more than 500 ha, and for two the covered area was not determined.

The results obtained from agrometeorological observation of potential danger conditions of fires in vegetation have been very encouraging. Nevertheless, better results in the system of alert early warnings of potential fire danger conditions could be obtained. For the spatial distribution of this index in municipalities, provinces, and country, the danger index could be improved by modifying the mean value of the danger index for municipalities used at the present time. The results obtained to date in predicting potential fire danger conditions, using the method of the inertia of the agrometeorological conditions formed in it, suggest that acceptable predictions could be achieved for periods between 10 and 20 days or more. Another possible improvement would be to combine the forecast based on the inertia of the conditions formed in the vegetation with other models that include the rain prediction for larger temporal period. Lastly, combining the indexes obtained from information observed in terrestrial stations with those of high spatial resolution (remotely sensed data), would improve the information on agrometeorological conditions; especially in those areas where the surface meteorological information is insufficient.

The forest fires danger conditions observation system has been used by the Cuban National Body Keepers forces to strengthen prevention. For example, forest fire occurrences declined by 6 percent (52 fires) compared with the same period 3 years earlier. The early warning alerts make it possible to concentrate forces and resources on the more fire-prone danger areas; optimize the use of aviation resources used in observation, optimize specialized forces to combat these catastrophes; and inform the population about the potential hazard.

The results shown in this work have great importance for the planning activities in preventing fires in both cattle and agriculture sectors under sustainable conditions and non-irrigated land.

### **Conclusions**

A system for assessing the danger of vegetation fires has proven effective in all the Cuban regions. This system makes it possible to monitor conditions and issue alert warnings for three different temporal scales, helping the Body Keepers to strengthen preventive activity and aid operational efficiency during the period of high fire danger in Cuba.

Early warning alerts with a 10-day forecast period explained 96 percent of the fires during the decade under consideration. This indicates the efficiency of this system for making early warnings of fire danger, and it provides valuable index to determine danger conditions for vegetation fires under tropical conditions in Cuba.

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