Forest Fire Risk Based on Historical Data and Numerical Simulations

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January 8, 2021

Description of the Problem

- Many areas affected by forest fires.
- Big environmental and economic losses per year.
- Mathematical-computational method for the quantification of current and future risk.

Figure: Forest fire "*Agua Fría*", February 2020, Chile.

Objectives:

1. Understand and contribute to the formulation of fire occurrence models.
2. Understand the outputs of the numerical simulation and how these are combined with the ignition rates.
3. Review of computational implementation.

Description of the Problem

The tools used were:

Figure: *SPARK*.

Figure: *Jupyter*.

Figure: *Python*.

Mathematical Description

To quantify the risk of forest fires, the risk is interpreted as the product between the probability of the occurrence and the consequence.

Supposed

The stochastic processes of ignition and propagation depend on the geographical location and instantaneous meteorological conditions of the fire.

Mathematical Description

Categorizations

- Division of the territory, in a set of cells K, where each cell $k \in K$ is $2\ km \times 2\ km$.
- A set of phases is defined, where each phase $p \in P = \{3, 4, 5\}$ is as following:
  - 3, if 0 to 10 Ha have been consumed by the fire.
  - 4, if 10 to 100 Ha have been consumed by the fire.
  - 5, if more than 100 Ha were consumed.
- The meteorological condition $c \in \mathcal{C} = \{F, S\} \times \{H, L\}$, is composed of the following form:
  - $\{F, S\}$, is the categorization of wind speed, where F is fast and S is slow. To pass from S to F, it must exceed $15 \frac{km}{h}$.
  - $\{H, L\}$, is the categorization of temperature, where H is high and L is low. To pass from L to H, it must exceed $25^\circ C$.

Calculating the Probability of Occurrence

Historical data is considered to consist of a period of L fire seasons.

Definitions

1. Let $\hat{H}_{kc}$ and $\hat{Q}_{kc}$ be the number of ignitions and total duration of time observed in cell k under conditions c.
2. Let $\hat{S}_{kcp}$ be the proportion of fires in k under conditions c and reaching phase p.
3. Let $\hat{h}_{kc}$ be the fire ignition rate in k under conditions c.
4. Let $\hat{N}_{kcp}$ be the expected number of fires per season in k, with phase p and conditions c.

Calculating the Consequence

Definitions

1. Let m_{kcp} be the total number of simulations in k, under conditions c, that end in phase p.
2. For each simulation $j \in \{1, ..., M\}$ the weight is $\hat{W}_j$
3. Then, the loss map is calculated on an impact grid with cells i, which do not necessarily coincide with ignition cells k, λ_i which depends on f_{ij} and ρ, where f_{ij} is the intensity of the line of fire in cell i, associated with simulation j, and $\rho : \mathbb{R}^+ \to [0, 1]$ maps the intensity of de line of fire.

Results and Analysis

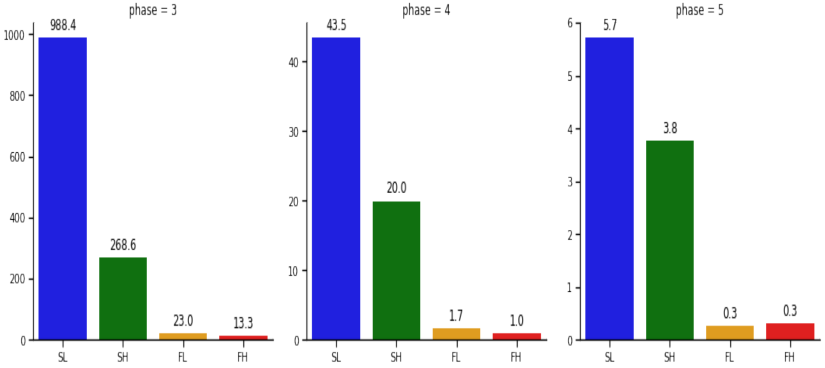

Figure: Expected number of ignitions over the entire territory, $\sum_{k\in K} \hat{N}_{kcp}$, $\forall c \in \mathcal{C}$, $\forall p \in P$.

Results ans Analysis

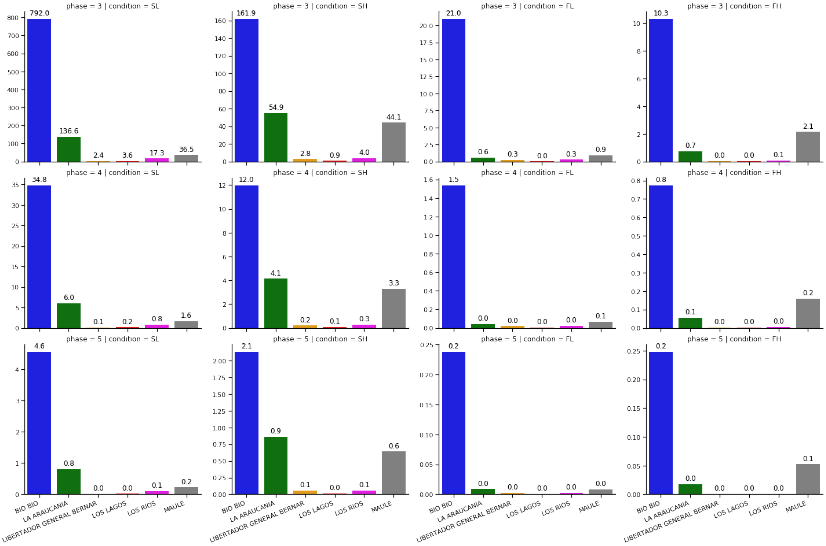

Figure: Expected number of ignitions per region, separated by condition and phase.

Results ans Analysis

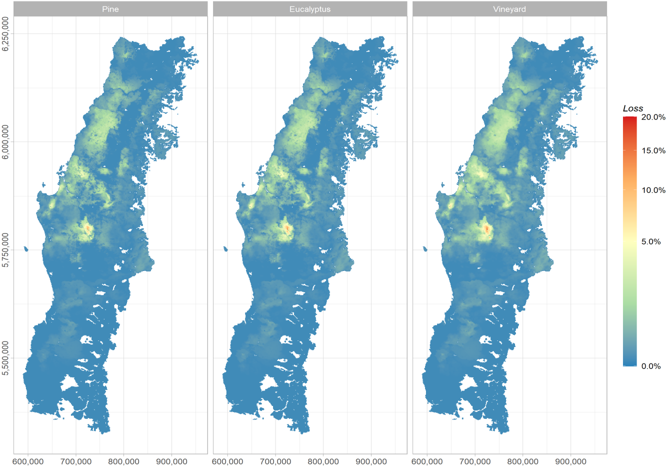

Figure: Loss maps for pine, eucalyptus and vineyard plantations, given by λ_i.

Conclusions

- Analyze which are the most favorable conditions (factors) for ignition to occur.
- Analyze the proportion of fires with the highest phase.
- It is possible to identify areas most affected by fires, thanks to maps of losses.

A future extention from the presented methods consists of predictive models that integrate new spatial covariates such as the number of inhabitants in the areas where intentional fires occur, in line with what was proposed in [4].

Bibliography

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