Estimation of the tropical fire season

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Introduction

Wildfires in tropical rainforests degrade, among other essential functions, their carbon storage capacity, which plays a critical role in mitigating the effects of the ongoing climate crisis. Improved forecasting of the fire seasons in these forests would provide better data for decision-makers, supporting the development of adaptation policies to address issues such as excessive wildfire smoke and declining rainfall and drinking water availability. This study presents a pixel-wise estimation of the fire season in tropical forests, utilizing VIIRS fire hotspots and sigmoidal models.

Data

- The near real-time NOAA-20 Visible Infrared Imaging Radiometer Suite (VIIRS) Active Fire Detection product [NASA VIIRS Land Science Team 2020], processed by the University of Maryland with a three-month lag and distributed through the Fire Information for Resource Management System, provides active fire detection data at a nominal spatial resolution of 375 meters.
- The high resolution Köppen-Geiger maps based on constrained CMIP6 projections [Beck et al. 2023].
- The R package *sicegar* for fitting double-sigmoidal models to the data [Caglar et al. 2018].

Double Sigmoidal model

It is based on the logistic function (Equation 1) where $I(t)$ is the intensity as a function of time; I_{max} and t_{mid} are the maximum observed intensity and the time when it is reached; a_1 is the slope of $I(t)$ at t_{mid} given by the formula $\frac{d}{dt}I(t)t = t_{mid} = a_1 I_{max}/4$.

$$I(t) = f_{sig}(t) = \frac{I_{max}}{1 + exp(-a_1(t - t_{mid}))} \quad (1)$$

The double-sigmoidal is obtained by multiplying two sigmoidal functions (Equation 2).

$$f_{dsig-base}(t) = \frac{1}{1+exp(-a_1'(t-t'_{mid1}))}\frac{1}{1+exp(-a_2'(t-t'_{mid2}))} \quad (2)$$

And then let t^* be the time at which $f_{dsig-base}(t)$ is maximal and $f_{max} = f_{dsig-base}(t^*)$. In this way we can write:

$$I(t) = f_{dsig}(t) = \begin{cases} c_1 f_{dsig-base}(t) \text{ for } t <= t^* \text{(growth phase)} \\ c_2 f_{dsig-base}(t) + I_{final} \text{ for } t > t^* \text{(decay phase)} \end{cases}$$

Where $c_1 = \frac{I_{max}}{f_{max}}$ and $c_2 = \frac{(I_{max} - I_{final})}{f_{max}}$.

The features of this model are displayed in Figure 1.

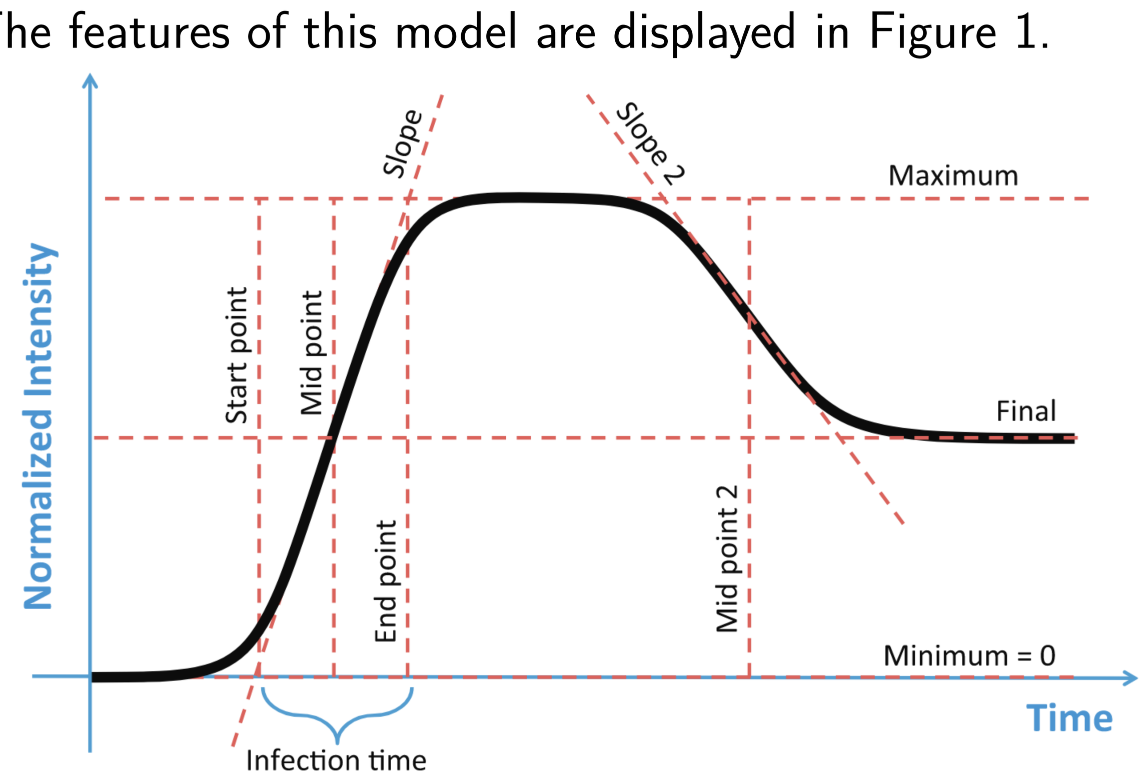

Figure 1: Double-sigmoidal model. Their midpoints are assumed as the start and end of the fire season. Source: [Caglar et al. 2018].

Method

- We aggregated VIIRS Active Fire data (from 2012 to 2020) using a regular grid made of 0.25-degree-month cells over a WGS84 Coordinate Reference System.
- Then we estimated the 9-year monthly mean for each pixel.
- Then we fitted a double-sigmoidal function, assuming that their mid-points are the start and end of the fire season and their durations are the time intervals between midpoints.
- Finally, our results were cropped using the Köppen-Geiger tropical monsoon and rainforest zones for the period 1991-2020 [Beck et al. 2023].

Results

Our results show that the fire season in the tropical forests lasts between one and three months. Additionally, both the start and end of the season displays a horizontal striping pattern, depending on the latitude and relative position to the equatorial line (Figures 2, 3, and 4).

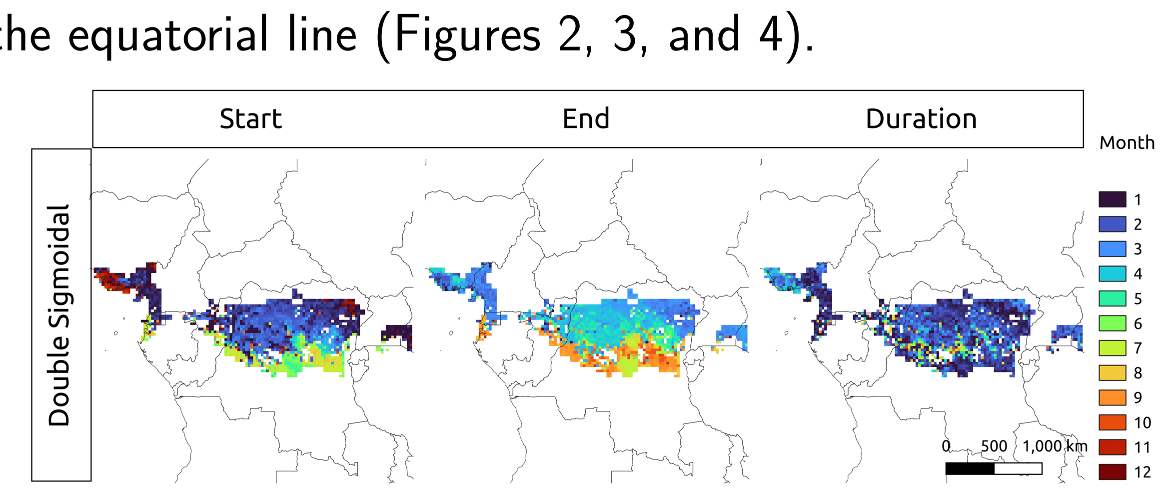

Figure 2: Fire season in the African tropical rainforest.

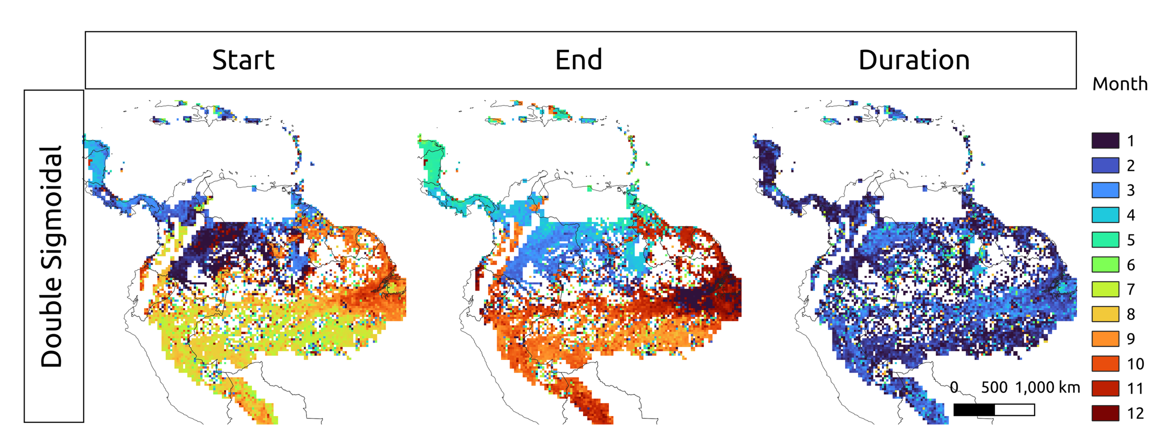

Figure 3: Fire season in the American tropical rainforest.

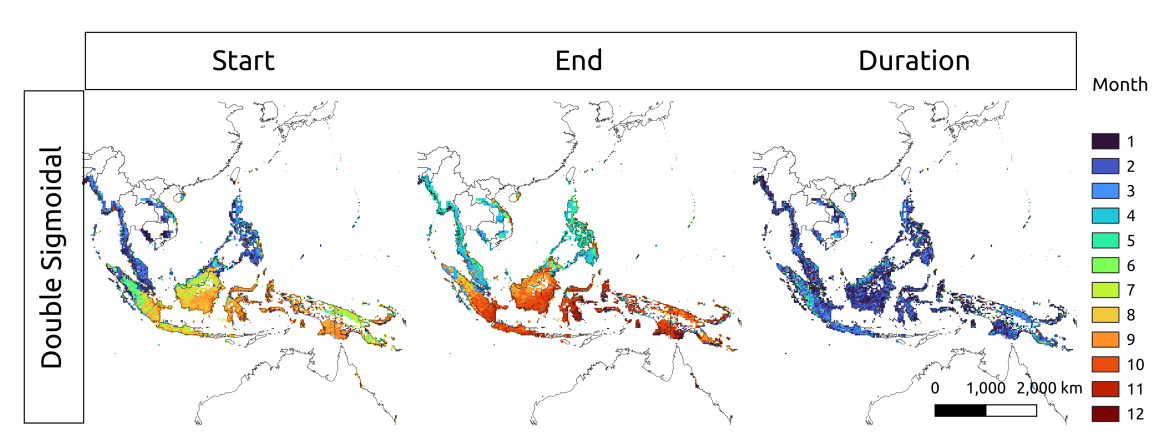

Figure 4: Fire season in the Asian tropical rainforest.

Figure 5 (left) clearly shows the differences between the Northern and Southern Hemispheres regarding the fire season start. This pattern has already been observed in the Amazon region using climatological variables rather than Active Fire data [Carvalho et al. 2021].

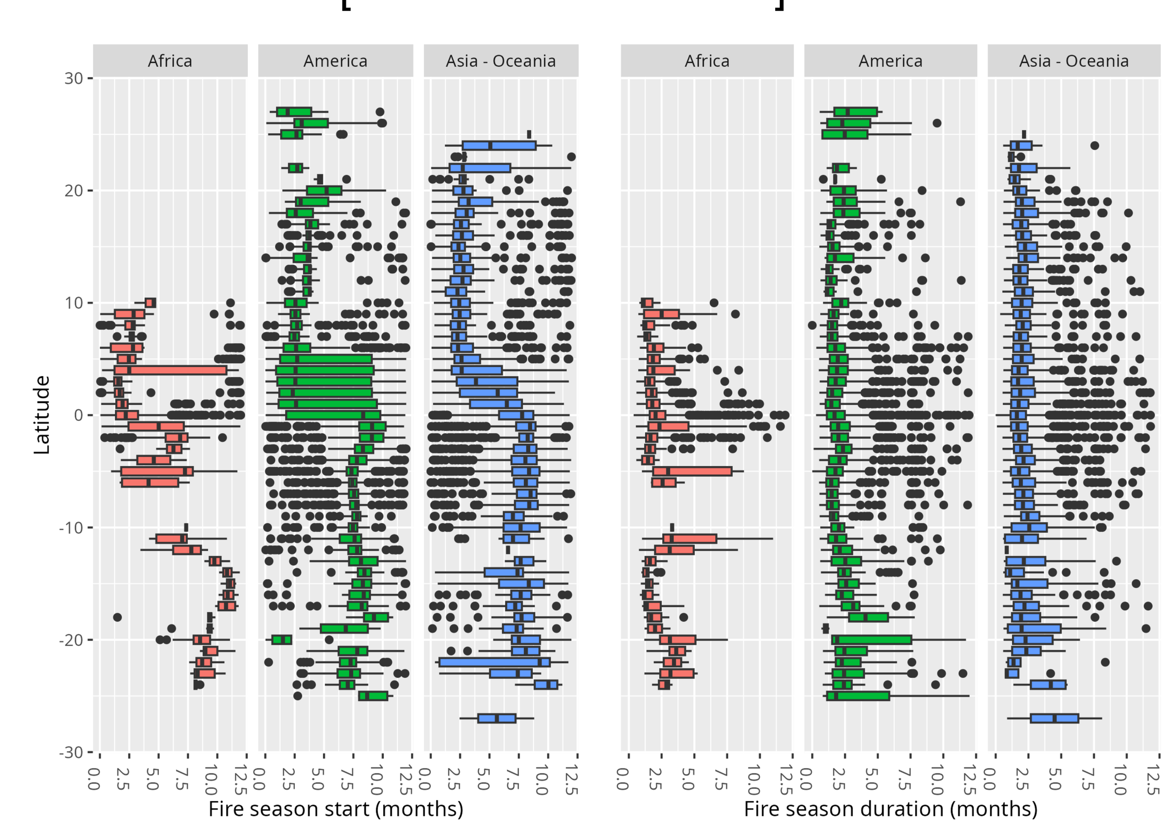

Figure 5: Start and duration of the fire season aggregated by latitude.

Reproducibility

To ensure the reproducibility of our results, we used only publicly available data and software. Besides the previously introduced datasets, we used the R programming language for statistical computing and data visualization [Ihaka and Gentleman 1996]. We also the R packages *sf* and *terra* for handling vector and raster data and the *sicegar* for fitting double-sigmoidal models [Pebesma 2018, Hijmans 2020, Caglar et al. 2018].

Future work

We view our results as a starting point to addressing the question: *Is the fire season changing?* To find an answer, we will:

- Switch from VIIRS to MODIS active fire data to get longer time series.
- Run the analysis presented here on a time series longer than 20 years and use it as a baseline.
- Compute yearly deviations from the baseline.
- Test for patterns in the deviations, particularly changes in the start and duration of the fire season.
- Compare our estimation of the fire season to the dry season. This could point to human-behavior changes since most of the rainforest fires are anthropogenic.

References

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Links

Email. Code.