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## Reply on RC1

Adrián Cardíl et al.

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Author comment on "Characterizing the Rate of Spread of Wildfires in Emerging Fire Environments of Northwestern Europe" by Adrián Cardíl et al., Nat. Hazards Earth Syst. Sci. Discuss., <https://doi.org/10.5194/nhess-2022-47-AC1>, 2022

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Tapia et al. presented a new approach to cluster VIIRS hotspots and derive the rate of spread (ROS) for each fire in this manuscript. They applied this approach to landscape fires in northwestern Europe, and examined the relationship between ROS and land cover type, season, as well as geographical locations (countries). The ROS is closely related to other fire behavior and the impact of fires on ecosystems. So the documentation of ROS across northwestern Europe in this manuscript provided a good reference for future studies. However, there are some issues in the current manuscript that prevent me from recommending it to be accepted by NHESS.

- Need more complete description of the VIIRS data and the approach.

For VIIRS fire data, the authors need to provide some background information on the satellite, the remote sensor, the data product (including the name, resolution, uncertainty, etc.), as well as the data filtering approaches. For example, what exact fire product did you use, the monthly data or the near real time (NRT) data? Is the resolution 375 m for all the pixels?

**We have added more details about the VIIRS product in section 2.2. "We used data from the Visible Infrared Imaging Radiometer Suite that provides active fire data from the VIIRS sensor aboard the joint NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi NPP) satellite launched in 2011. The VIIRS 375 m active fire product is described in Schroeder et al., (2014) and uses a multi-spectral algorithm to identify fire activity through 5 imagery channels (I-bands), 16 moderate resolution channels (M-bands) and a Day/Night Band (DNB). Specifically, we used the VNP14IMGTDL\_NRT near-real time product which has been widely used in fire modeling applications, in part because of its higher spatial and temporal resolution and accurate response over fires of relatively small areas (Schroeder et al., 2014). Among VIIRS's greatest strengths is the ability to detect at moderate 375 m spatial resolution and provides global coverage approximately every 12 hours (Oliva and Schroeder, 2015); making it an ideal instrument for detecting the smaller fires we anticipated in our study area. VIIRS hotspot data were collected from the NASA Fire Information Resource Management System (FIRMS) portal (<https://firms.modaps.eosdis.nasa.gov/>) for the period of January 20th, 2012 to June 1st, 2020 as no earlier data was available."**

Some of the information on the fire clustering algorithm is also missing or not clear. How was the temporal grouping performed? How were the timing and the land cover of a fire determined? How did you verify whether a fire is real fire? See the 'Minor comments' below for detailed questions.

**We have added more details about both the temporal and spatial clustering we performed. Also, we have addressed all the minor comments raised by the reviewer below.**

**“The clustering in space was carried out using a grid-growing clustering algorithm. All hotspots are projected into a 5km cell size grid where clusters are defined as groups of interconnected cells in the grid (islands of cells containing hotspots). To identify these clusters we loop through the cells in the grid searching for an initial cell containing hotspots but with no assigned ID (not belonging to any cluster). The seed cell is assigned with an ID and then expanded (grown) among neighboring cells containing hotspots using a fast-marching method with 8 degrees of freedom, and assigning all found cells the ID of the initial seed cell. This process is done iteratively until all cells containing at least one hotspot have an ID. The method assures that any hotspot in the cluster has at least one neighboring point within  $2\sqrt{2}$  the cell size distance of the grid.”**

**“The clustering in time was conducted by splitting the initial cluster into subclusters whenever there was a time elapse of 48 hour or more without a hotspot. This threshold value is heuristic and could be slightly modified without significant changes in the final result. The combined process of clustering by space and time leads to the final group of fire incidents used in the rest of the analysis.”**

The approach to calculate ROS, which is the centerpiece of this study, also lacks important information. Sometimes the descriptions are contradictory or confusing (e.g. Which ROS statistics did you use? You mentioned maximum ROS, median ROS, and average ROS in the manuscript). The interpolation algorithm of vertices is also unclear to me.

**For statistical differences of ROS among land cover classes we used Mean ROS (Fig. 5). Graphical representation of ROS variation among months we used the median, as they were schematized as boxplots (Fig. 4)**

**We addressed this and edited the methodology section for a further explanation concerning about vertices and vector generation:**

**“With the fire progression multipolygons developed, the rate of spread vectors could be calculated. For each vertex of the polygon at time  $t+1$  the closest vertex of the parent polygon at time  $t$  was identified. Taking into consideration the distance and time between both points, we calculated the ROS of each spread vector (Fig. 2). To increase the accuracy of the spread vectors, the number of vertices at each polygon and time step was increased by adding one extra node between neighboring points.”**

- Concerns about methodology

The VIIRS active fire data represent the center location of each pixel. The pixel size is ~375m at nadir and varies with scan angle (can be much bigger at the edge). The current fire shape algorithm used these center locations directly, without considering the detection uncertainty of the data. Can this influence the calculated ROS? In the spatial grouping of fire pixels, 5km rasters were used. This leads to possible merging of fire pixels with distances at a maximum of ~14km. Is this too conservative? How does the variation in this value affect the clustering and ROS? For the Alpha value, why did you use 1km? Should you estimate the uncertainty related to this value?

**We addressed this and edited the methodology section for a further explanation of this process:**

**“Basically, the value of  $\alpha$  determines the maximum distance it is assumed hotspots could define a perimeter edge. In practice,  $\alpha$  controls the “porosity” of the final shape since high values lead to a convex hull polygon while lower values increase the concavity of the perimeter. In this analysis the value of  $\alpha$  was tested with different values (1, 3, 5 and 10 km), being 10 km the optimal solution to create the fire spread polygons throughout the fire growth. The fire perimeters are now defined by the outer edges of the remaining mesh. These edges can be extracted by noticing that outer edges only belong to one triangle in the mesh while internal edges are shared between two triangles. Extracted edges are then ordered to form valid geometrical polylines and then aggregated together to form the final polygons representing the fire perimeters.**

**Notice that in this process the perimeter exactly connects the input hotspots without considering the actual VIIRS spatial resolution. This could be easily fixed by applying an external buffer to the perimeter equal to half the resolution distance of VIIRS (around 375 m). In any case, it is important to notice that this does not affect the ROS calculation since the same procedure is used at each time step, and therefore the distance between consecutive perimeters is not affected.”**

- Statistical robustness

The other issue I’m concerned about is whether some of the analyses (and results) are statistically robust. The total number of fires you used for analysis in this manuscript is only 254. While this number may be sufficient for whole-regional statistical analysis, you further divided the fires into different seasons, land cover types, and countries. I doubt the sample number is enough for all the categories.

**Sample size relates to every time step within individual fires (e.g. A single fire that has 4 time steps must have the same number of maximum spread vectors) Hence, the sample size is greater than the number of fires. It is important to note that statistical analysis was carried out just for cover types.**

**The analysis was redone. Now we have 102 fires with a total number of 327 vectors. Figures were edited and now all indicate the sample size for each cover/month. For the statistical analysis, land covers with a sample size lower than 10 were excluded and reclassified as "Others" (Figure 5).**

- More analysis on ROS

It's good to see the ROS variations across different land covers and seasons. But I expect the authors to do more analysis to support the usefulness of the dataset. Some examples include, but not limited to, the relationships between burned area increment and ROS; the influences of weather variables on ROS; the statistical relationship between ROS and fire size.

**New hypothesis and post-hoc test was carried out. We did a new analysis to assess the relationships between burned area and ROS as suggested.**

Minor comments;

Line 23: "suggesting that may present the extent of the fire season"

What does the 'that' refer to? May change to something like 'this period' or 'these months'.

**Addressed. We have used "these months".**

Line 38: "Moritz et al. ((Moritz et al., 2012)". Some citations (such as this example) are not formatted correctly.

**Done.**

Lines 39-40: "in the last quarter of the 21st century (2070–2099)". 2070–2099 has 30 years and is more than a quarter of a century.

**This is true. Addressed.**

Lines 117-118: "its higher spatial and temporal resolution compared to other satellites such as MODIS". Some satellites have higher spatial or temporal resolution than VIIRS. Need additional defining words for 'other satellites'

**We agree with the reviewer. We have changed the sentence.**

Lines 134: "VIIRS detections are points scattered in time and space"

This is not quite true. A location record in the VIIRS fire data file does not represent the exact burning location, which could be anywhere within a pixel of the VIIRS footprint (which also varies with scanning angle).

**We agree with the reviewer. We have removed this sentence from the manuscript.**

Line 143-145: "The clustering in time was conducted by ordering the space clusters by time and creating divisions or break points if there was a time difference greater than 48 hours in between consecutive points."

The clustering method at the temporal axis is not clear for me. How did you determine which space clusters should be tested temporally? What do 'consecutive points' mean? Individual fire center locations, or the 5km pixels?

**Thanks for the commentary. We have edited the methodology section and further explain this process:**

**"...clustering in time was conducted by splitting the initial cluster into subclusters whenever there was a time elapse of 48 hour or more without a hotspot. This threshold value is heuristic and could be slightly modified without significant changes in the final result given that the fire frequently in the study area is usually low. The combined process of clustering by space and time leads to the final group of fire incidents used in the rest of the analysis."**

**Clusters were tested spatially for different alpha values. The optimal solution for this was to establish a 10 km value. Thereafter, temporal clusters were generated from spatial clusters. Consecutive points are considered centered-points data.**

Line 183-184: "Copernicus Land Monitoring Service's Corine Land Cover Map 2018 ((2019a)) to distinguish landscape fires from other heat sources such as active volcanoes, artifacts of heated plumes". Can the Copernicus Land Cover Map be used to distinguish volcanic eruptions from fires?

**We have changed the sentence. Copernicus Land cover Map was used to remove hotspots within urban/industrial areas and not for volcanic eruptions. Hotspots from volcanoes are not relevant in our study area.**

Line 192: "As each timestep also featured data on land cover"

What land cover product did you use for this purpose? Still Copernicus Land Monitoring Service's Corine Land Cover Map 2018? Please also describe how you determined the land cover type for each fire when the fire is big enough to cover different land cover pixels.

**That sentence was related to analyzes on each vector, not for individual fires/polygons. When we evaluated ROS variation over land covers, it was at the vector level and the most abundant land cover type passing through each.**

Line 198: "ANOVA and Tukey statistical analysis"

This statistical method may not be familiar to many readers. Please add a reference.

**Reference is added now**

Line 204-205: "of which 254 were verified to be "real" landscape fires"

Please specify the details about the way you verified the real fires.

**The filtering was carried out for VIIRS hotspot with a buffer of 375m. We removed those hotspots that intersected with the urban/industrial areas of the CORINE Land Cover.**

Line 209: "timing of the fire, the burnt area, the land cover, and the maximum ROS"

For a fire covering multiple raster pixels and time steps, how did you determine the 'timing of the fire' and 'the land cover' for the whole fire?

**Algorithm clusterization process outputs several timestep-polygons for each fire and every timestep has its own time footprint. Each timestep generated is a clusterization of near-time pixels.**

**As mentioned above, land cover analyses were carried out at a vector level, not for entire polygons.**

Line 219-221 : "On the other hand, fires less than 0.01 km<sup>2</sup> were rarely detected with our satellite-based analysis, comprising approximately 0.002% of the total burned area and 1% the total number of fires. Fires between 0.01–0.1 km<sup>2</sup> were also seldom observed with 0.3% of the burnt area set by 10.2% of total fires."

In the method section (Line 136), you mentioned you "filtering out clusters with less than 20 VIIRS hotspots". This filtering will reduce the number of small fires (in <0.01km<sup>2</sup> and 0.01-0.1km<sup>2</sup> bins) for certain. So the fraction of the number of fires in different size groups can be artificial.

**Thanks for the commentary, we have addressed it in the re-edited version. We agree with the reviewer, we discuss this since new improvements in technology may allow enhancing the recognition and ROS characterization of small fires.**

Line 229: "It was during this period that the median ROS was the greatest"

In the Method section (Line 192), you said you used 'maximum ROS', here you said you used 'median ROS'. Did you calculate the maximum ROS for a single fire (at a single time step, or for all time steps?), and then calculate the median ROS from all fires? The description needs to be clear in the Methods section.

**We only used the mean and median ROS to discuss our results. Note that "maximum ROS" is not used as a statistical metric. Each fire may have different time steps during the fire growth and each time step has different ROS vectors. We selected the vector with the highest ROS to consider the spread of the head of the fire.**

Line 278-280: "The lack of fires smaller than 1 km<sup>2</sup> can likely be explained by the fact that the VIIRS satellite was unable to capture fires of this magnitude due to limitations of the temporal and spatial resolution."

Again, is this because you filtered fires with less than 20 VIIRS hotspots?

**More than 20 hotspot points are needed to derive consistent vectors. Hence, we are grateful for your commentary as we added this limitation in the sentence you indicated.**

Line 330: "our study did not yield any significant effect of land cover on ROS"

This conclusion is not consistent with that shown in Figure 5, where we can see the obvious differences in the RoS for different land cover types.

**We agree with the reviewer. The new analysis shows statistically significant differences among land cover types.**

Line 369: "lie within the methodology implemented, which produced average spread rates."

Now you say 'average spread rates'. So it's not the 'maximum ROS' you mentioned in line

192?

**This was mentioned for every raw ROS vectors generated, before the maximum was selected for each time step for further analysis, as we mentioned above.**

Figure 1. The caption says "b) VIIRS hotspots retrieved from the area of interest". But I didn't see hotspots in this panel. I only see land cover types shown on the map.

**Thank you for this comment. It was a mistake that we have addressed.**

Figure 4. Considering there are only 254 fires in total, the number of samples in each country-month bin is expected to be small (It's also good to show this number in the Figure). The statistical robustness needs to be addressed.

**Now we have a total number of 102 fires and 327 vectors. For every new figure presented in the new version, the number of observations for each category is indicated.**

Figure 5. What are the 'n' values referred to? I don't think they are numbers of fires, since the total is way above 254 (the total fire number).

**Every fire has several time steps. Every time step has several ROS vectors and we selected the vector with the highest ROS by time step. The number of observations (n) is related to the number of maximum ROS values for each time step. In this new version, 102 fires were clusterized with 327 maximum vector values.**