Author's Response

Author Comment 1:
Hi Carolina,

Thank you very much for reading our paper, your feedback is very much appreciated. All changes mentioned here are implemented and will appear when the next version of the document is uploaded.

I'll just go over the points that you mentioned.

1. We have removed the paragraph: "In this paper sections 1 and 2 will give an overview of existing research on wildfires and wildfire modelling. Section 3 will describe the resources that were necessary to model wildfire propagation. Section 4 explains how these resources were used to build the IGS. Section 5 compares different gird types produced using the IGS, while section 6 compares the IGS to ForeFire. Sections 7 and 8 discuss these results." from the abstract as recommended.

2. We have reviewed the paper again and have made some minor changes to the English language used. Would it be possible provide more details on which parts of the paper were difficult to read so we can alter them?

3. We have shortened the (2 Overview of wildfire propagation models) section removing the lines 99 – 120, as suggested. We believe the (3 Resources) section is important to readers as it provides an insight into the parameters both platforms require to operate, so we have retained it in the document for now. We also think it might be best to keep it in the separated (3 Resources) section as the input parameterisation is not the same for every platform mentioned in the (2 Overview of wildfire propagation models) section. We have made this clearer at the start of the (3 Resources) section.

4. We originally did have sections (5 Comparison of Grid Types), (6 Comparison of IGS and ForeFire) and (7 Results) as a singular results section but a reviewer before submission suggested we change this. Sections 5 and 6 build towards the results but contain methods used for the comparison in Section 7, therefore the reviewer suggested that it would be best not to include the content from sections 5 and 6 in section 7. In section (7 Results) we only stated facts pertaining to finding the results, we have added further discussion to (8 Conclusions). We are not sure how we could include text from (3 Resources) and (6 Comparison of IGS and ForeFire), would it be possible to provide more details on this so we can review the suggestion?

5. The IGS we adapted by an emergency event management system (DecaMap), we have added further information about this to the conclusion as suggested.

Thank you for your time reading our paper and providing valuable suggestions. I hope the above changes can help improve the document. We hope to hear back from you regarding some of our points.

Kind Regards,
Conor.

Author Comment 2:
Hi Carolina Leal,

We made a mistake in our previous comment, and I would just like to rectify that now. We stated that we removed lines 99 – 120 from the paper. This is not correct as we were looking at the line numbers in our updated paper. The line numbers that we removed from the uploaded paper were lines 102 – 123. Apologies for the confusion.

Kind Regards,
Conor Hackett.

Author Comment 3:
Hi Referee #1,

Thank you for reading our paper. Your detailed feedback is invaluable. I apologies for the delay in getting back to you, we wanted to make sure that we applied all your changes appropriately to the paper. All changes mentioned below have been implemented in the document and will appear when the next version of the document has been uploaded.

I'll just go over the points that you mentioned and our accompanying changes.

General Comments:

- We have added this line to the abstract to state more clearly what the goal of this paper was: *"The objective of this paper was to compare the various grid types on the metrics of similarity with ForeFire and computational time, while also comparing the FRG to ForeFire on the same metrics with multiple sample wildfires."*

- We have also added a discussion section to the paper which expands further on the effects and expected implications of the different grid types, while focusing on software performance and computational demand: *"Comparing the five different grid types produced a table of computationally efficient and the similarity of their outputs with ForeFire (Table 1). Overall, the regular grids produced the same output every time the program ran making them deterministic. They also took the same time to run the simulation each time as shown by the small standard deviation in their computational times. The small standard deviation can be accounted for with other uncontrollable minor factors effecting the computer such as background tasks. Both irregular grids have a much higher standard deviation in their computational times. This is because* *the process of seeding these grids is non-deterministic, so a different grid is produced each time a simulation is run. Some of the irregular grids have overall regions of higher resolutions than others, which can lead to varying computational times. The number of neighbours each grid has is also correlated to the computational time, as the program has the calculate the propagation ratio between each ignited polygon that can spread fire to its neighbour at every iteration. The square and triangular grids have the fastest computational times while having four and three neighbours respectively. The hexagonal grid has the next fastest computational time with six neighbours. The random grid has a computational time very similar to that of the hexagonal grid even though there is no set number of neighbours per polygon. This is most likely due to each polygon having approximately six neighbours. The FRG has the slowest computational time even though most polygons also have approximately six neighbours. This is due to the increased density of polygons close to the fire source, as propagation ratios need to be calculated for all these ignited polygons and their neighbours that fire can spread to. In terms of similarity of output to ForeFire, the FRG performs the best followed by the random, hexagonal, triangular, and square grids. This is correlated to the numbers of polygons in each grid for the simulations. As previously mentioned, the FRG has a high density of polygons near the fire source, allowing the simulation to nearly follow the continuous movement of the wildfire simulated in ForeFire. For the regular grids to be comprised of regular shapes (and equilateral triangles in the case of the triangular grid) it was only possible to have a set number of polygons in the simulation area. In the table, the number of sites for the regular grids was set as close to 2,000 as possible while still retaining a regular grid. The disparity in the number of polygons between the grids can explain some of the differences in similarities with ForeFire. The irregular random grid tends to produce outputs with a closer similarity to ForeFire's than any of the regular grids. This is most likely due to the irregular shapes produced by the random grid allowing spread in other directions that cannot be computed by the regular grids. It also allows the simulation to follow natural irregular patterns in the Earth's terrain. The regular grids have a set number of directions fire can spread in to reach neighbouring polygons; they also struggle with following the irregular patterns in the Earth's terrain as seen by the lake (Figure 12). Overall, there is no definitive best grid type. It really depends on what the user is trying to simulate and how detailed they are willing to have the simulation in exchange for more computational time. In this paper the FRG was chosen as it produced the results most like ForeFire's.*

Comparing the IGS and ForeFire produced a table showing the computational efficiency of the two software and how similar their outputs were (Table 2). ForeFire is deterministic and therefore produces the same results ever time it is run. In this comparison the IGS was using the FRG grid which is non-deterministic. The IGS wildfires that ran for shorter durations tended to be computationally faster than the wildfires that ran for longer durations, relative to ForeFire. This is caused by the increasing size of the simulated wildfire as it burns, resulting in more ignited polygons that can spread fire to their neighbours therefore creating additional computational burden per iteration. The IGS *produces a larger area of false positives than that of false negatives when compared to ForeFire, this is due to the fire line selection process. As the IGS selects the fire line from the outer edges of the polygon if fire has reached that polygon's site, regardless of how far the fire has spread within that polygon to its surrounding edges; it sometimes overestimates the distance the fire has spread. This is the reason for larger area of false positive than false negatives when compared to ForeFire. The threat score for similarity between the IGS and ForeFire increases with length of simulation. This is due to the overall area of the wildfire which tends to be mostly true positives, growing at a faster rate than the boundary of the wildfire where false positives and false negatives tend to occur."*

- We have added a summary of different fire models categories to section 2 as follows: *"There are three main branches of wildfire modelling, which include statistical, empirical, and physical models (Weber, 1991). Statistical models are built on a statistical description of wildfires found by observing sample fires and are less focused in the thermodynamics of fire. The McArthur Forest Fire Danger Index is a statistical wildfire model (McArthur, 1966; Noble et al., 1980). The statical model was developed by only sampling fires burning dry grassland and forest litter which means it needs to be used with caution on other fuel types. The model takes as input variables such temperature of curing for the fuel, air temperature, relative humidity, and wind velocity to produce a value representing the fire danger index. This value can then be converted into an estimated rate of spread for a wildfire.*

  Empirical models for wildfire spread are built upon the principles of conservation of energy but do not differentiate between the various modes of head transfer. An empirical model was used to calculate fire spread through porous fuels in a fuel bed (Frandsen, 1971). This model calculates the rate of spread by finding the heat generated from combustion of existing fuel and spreading this heat using the principles of the conservation of energy into the surrounding fuel, until that fuel reaches its flashpoint and ignites.

  Physical models do differentiate between the various modes of heat transfer and are deep-rooted in fundamental physics and mathematics of combustion. A physical model was developed to find the rate of spread between two particles in a fuel bed (Fons, 1946). To calculate the rate of spread for the fire this model found the time it took for fire to spread the distance from one particle to another also using the principles of the conservation of energy but this time incorporating all three forms of heat transfer: conduction, convection, and approximating radiation."

- We have contextualised the results from Table 2 discussing performance and accuracy *"From the sample fires simulated, the IGS runs on average 34 times faster than ForeFire with an average fire line similarity of 0.8 to ForeFire. The use of IGS instead ForeFire allows multiple wildfires to be simulated (restricted to one area) in the same amount of time it would take ForeFire to run one of these fires. From (Table 2) it is evident that the fire line produced by the IGS mostly* *contain simulated wildfire areas of true positives when compared to ForeFire, followed by areas of false positives then false negatives. There is also a trend where IGS simulated wildfires that are ran for longer durations tend to not perform as well as those ran for shorter durations relative to ForeFire. Adding wind or additional fire sources in the comparison does not impact the relative computing time or similarity to ForeFire. There are some issues with the IGS, however. The FRG can have problems with larger fires as the frequency of polygons decreases the further a wildfire spreads from its source. This is evident in Fire 18 (Figure 14) where there is a large drop in site resolution at distances far away from the fire-starting location. The large distance between the IGS and ForeFire's northern and western fire lines highlights this issue. The cubic spline used, forces the curve to intersect the points on the edges of polygons. Due to the resolution of sites within the IGS, this makes the cubic spline produce small modulations on the fire line while ForeFire has more straight edges."*

- We have added this paragraph to the end of the conclusions to highlight the contributions made in this paper: "*This paper compared different grid types. It was shown that the FRG is the best option for greater resolution near the fire source. The regular grids are a better choice for more efficient computation. The decision on which grid type to choose should be selected on a case-by-case basis by the user. The paper also showed that the IGS can run on average 24 times faster than ForeFire with a similarity of 0.8. While ForeFire will always produce wildfire simulations at a greater resolution than the IGS, if computational efficiency is a concern where multiple wildfires may need to be simulated in the one location, then the IGS may end up being an alternative option."*

Specific Comments:
Lines 12-14: The figures are based off RCP, we have added this sentence to the text for extra clarification: *"These values were forecasted by a Representative Concentration Pathway with a radiative forcing value of six (W/m^2), representing the energy imbalance in the Earth's energy system caused by greenhouse gases and other factors, in the year 2100."*
Lines 50-52: We have made the discussion here more nuanced and acknowledged that trends in the frequency of wildfires change regionally: *"The frequency of wildfires has generally increased in recent years, this is most likely due to climate change creating drier terrain, allowing fires to burn more easily (Halofsky et al., 2020). This however varies regionally where factors such as wildland-urban interface, land use changes and fire exclusion policies can have an impact on the number of wildfires (Beltrán-Marcos et al., 2023;Piñol et al., 2005)"*
Lines 51-52: We have removed the following sentence as suggested: *"Wildfires have begun to have more devastating effects due to their increased intensity (Keeley and Syphard, 2021)."*
Lines 52-54: We were unable to find another study which supported this, therefore we edited the sentence as to not overstate the claim: *"Countries that normally have a wet climate such as Ireland, may also start to have an increased number of wildfires due to*

warmer temperatures, likely caused by climate change (McElwain and Sweeney, 2003;Boegelsack et al., 2018)."

Lines 56-58: We have changed the sentence to reflect your comment and more accurately portray the literature: *"In California, USA and Australia a small subset of wildfires that burn in terrain satisfying the correct conditions can potentially grow to be very large fast burning fires which can present an increased risk to life (Keeley and Syphard, 2021;Blanchi et al., 2014)"*

Lines 60-61: We have removed the term hotspot and rephrased the sentence as follows for increased clarity: *"The high abundance of gorse (Ulex europaeus) in bogs makes them a common place for wildfires to occur as the plant is easily ignitable."*

Lines 61-63: We have removed the confusing term from the sentence and reworded it to clarify what we intended to say more clearly: *"Even though wildfires that burn in the USA, Australia, and Ireland tend to have differing burning behaviours, it is still possible to model them all as the underlying physics involved remain consistent. However, the parameters characterising fuel properties, terrain and weather conditions need to be changed to represent the surrounding environment."*

Lines 78-79: We have changed the sentence to reflect the fact that the Rothermel model is just one approach. We have added a brief introduction of different approaches to wildfire modelling in section 2 (which is mentioned in the general comments section).
"The Rothermel model represents one approach to wildfire modelling as a physics-based semi-empirical model based on the conservation of energy that underpins many operational fire modelling tools."

Line 81: We have removed the following sentence to avoid confusion: *"The Rothermel model is a physics-based model built around the Rothermel equation".*

Lines 81-82: We have changed the following sentence to show that the Rothermel model requires more than just environmental factors: *"The Rothermel model takes as input multiple environmental, fuel and fuel bed factors to produce an estimated rate of spread as an output Eq. (1)."*

Lines 82-83 and Lines 83-84: We have changed the sentence as suggested: *"In the Rothermel model the numerator measures total heat transferred to neighbouring fuel while the denominator measures energy required to ignite neighbouring fuel and R is the spread rate of the fire."*

We have also changed lines 85-87 to reflect this change as follows: *"An easy way to interpret this is with a section of burning terrain acting as a heat source, while the fuel and fuel bed of the neighbouring terrain acts as a heat sink. If there is a surplus amount of heat produced to ignite the neighbouring terrain the fire will spread (Figure 2)."*

Lines 88-89: The Rothermel model in this paper does not use the reformulated values from Wilson, as ForeFire doesn't use them. We decided this was best for a fairer comparison as both programs would be subjected to the same rounding errors. We have made this clearer in the text: *"In this paper these values were converted into SI units within the fire simulations developed, this is the same as in ForeFire to simplify comparison in this paper. Another approach that could be considered would be to use the Rothermel equation reformulated in SI units (Wilson, 1980). The original Rothermel equation that was used in this paper is written as:"*

Lines 122-123: We have already removed these lines from the paper, (in our previous responding comment we accidentally used the updated line numbers). We actually removed lines 102-123 from the paper. We did take note of this suggestion though as these removed lines will be used in a thesis and updated the sentence as follows: *"This method was tested on wildfires in California that were not used as training data, producing realistic results with accuracies ranging from 78% to 98%."*. Apologies for the confusion and thank you for the suggestion.

Lines 169-175: We simplified and condensed the paragraph to make it clearer for the reader: *"The technique of simulating wildfires using the Rothermel model in this paper follows a similar methodology as was used to simulate wildfires using cellular automata (Zhang et al., 2021). In that paper wildfires progressed from a cell's centroid to neighbouring cell centroids at rate determined by the Rothermel model. Once a wildfire had reached a neighbouring cell's centroid that cell would also being spreading the wildfire to its neighbouring cells. Similar techniques will be used in the methods section of this paper."*

Section 3: We have combined sections 3 and sections 4 into a new section 3 called methods. We have also renamed the old section 4 to *"Simulating Wildfire Spead Using the IGS"*.

Lines 208-210: We have added additional context to explain the process of generating a landcover map: *"Areas of known landcover in the Wicklow Mountains were digitized to generate seventy polygons in total, which were further equally split into two sets. The first set was used to train a model and the other was used as an independent validation of the predicted land cover class map, The training and validation datasets had 35 polygons each which totalled to an area of 1.45 km2 and 1.4 km2 respectively. The polygons were selected in a manner to ensure a coverage of the entire study area, separation between the polygons (avoiding extremely close areas for both training and validation) and intra-class variability for avoiding bias in the model. A supervised random forest algorithm was applied on the stack of seven original bands (red, green, blue, near infra-red (NIR), NIR narrow, short wave infra-red (SWIR1 and SWIR2) captured by the Sentinel-2 satellite and the three additional indices to predict the land cover classes."*

Lines 232-233: We have changed the sentence to more clearly explain how the wind conditions were selected. We didn't explicitly state what wind conditions were used in the simulation as we feel they are more appropriately placed in the results Table (Table 2). We would be happy to hear your comments on this. *"For experimental simulation, a set of different wind speeds and directions were selected to allow a comparison between ForeFire and the IGS under the same conditions."*

Lines 290-291: We initially did use the fuel data from the polygons that the fire is spreading from, but we decided to change this so fire could spread unevenly from a polygon to its neighbours. We also considered using a weighted fraction or tracking how far between two polygons a fire has spread and then switching polygon data when the fire has progressed far enough, but we decided not to, so we could keep the program running at its current speed. We have added additional lines of text for clarification: *"Each polygon has fuel data associated with it, during fire spread the fuel data of the polygon that the fire is spreading to is used. If fuel data from the polygon the fire is spreading from is used, then fire would spread from that polygon to all its neighbours at an equal rate in conditions where there is no slope or wind. A weighted fraction between the two polygons also wasn't used as it would create additional computational time for simulating a wildfire."*

Equation 9: We have added text to discuss the limitations of Eq. 9 as follows: *"Just like the base Rothermel model, (Eq. 9) may have poorer performance in some fuel beds at lower fuel loadings, especially those with high packing ratios. Minor modifications were made to the Rothermel model that helped reduce the over sensitivity to fuel depth (Albini, 1976). This updated form of the Rothermel model was not used by the IGS as ForeFire used the base Rothermel model which would make any comparison unfair."*
Lines 397-398: We have updated the sentence to state what the margin of error was: *"Sometimes the vertices of edges don't line up perfectly, so a 3 m (approximately 0.01 % of the region width) margin of error between vertices of different edges was allowed to ensure a completed shape."*
Lines 420-423: We have updated this sentence to more clearly state that the FRG mesh refinement is dependent on landcover: *"The five grid types consisted of: randomly plotted sites, triangular tessellating grid, square tessellating grid, hexagonal tessellating grid and a grid where more sites would be plotted closer to the fire source and on landcover types defined by the fuel properties table, that are important to monitor; this grid is referred to as the flammable resolution grid (FRG)."*
Lines 486-488: We decided to reword this paragraph to make it clearer that FRG site placement is based on landcover: *"A random grid with increased focus on a region of interest was created. As stated previously this grid was called the flammable resolution grid (FRG). The FRG was designed to have a greater density of sites in regions most likely to be affected by wildfire and regions that are important to monitor. The regions that are most likely to be affected by wildfires tend to be situated closer to the ignition point of the fire or contain landcover types that can sustain large fires (e.g. forested areas). Areas of preselected importance tend to be areas with a higher density of people (e.g., urban areas). To do this the program runs through each pixel of the landcover map within the bounding box where it has a base probability to select the pixel it is currently on (this ensures not too many sites are generated). Once a pixel has been selected a second probability is generated to determine if a site should be placed at this position based on the distance from the ignition point and the landcover type of that pixel Eq. (16):"*
Line 584: The 20 simulated wildfires were not mentioned before this point. We've updated the sentence to reflect this: *"To compare IGS and ForeFire 20 wildfires were simulated."*
Line 584-586: The wildfires were placed randomly in the Wicklow Mountains. We've updated the sentence to reflect this: *"The wildfires were randomly placed in different locations within the Wicklow Mountains, Ireland with varying wind speeds and simulated for different durations so the versatility of the IGS can be tested."*
Table 2: The simulation run time varies across simulations as we wanted to check if IGS and ForeFire were comparable at different simulation durations. We have updated lines 584-586 in the Results to clarify this: *"The wildfires were randomly placed in different locations within the Wicklow Mountains, Ireland with varying wind speeds and simulated for different durations so the versatility of the IGS can be tested."*
Lines 595-596: We have changed a section of the abstract to clearly explain and state the aim of the paper: *"In this paper a novel software platform called the Irregular Grid Software (IGS) was developed which allows the simulation of wildfires on a configurable grid using mathematical models for fire propagation. The aim of IGS was to be more efficient than preexisting software while producing outputs of an acceptable similarity to*

preexisting software. The configurable grid was built using a Voronoi diagram where a fire can spread between polygons propagating throughout the grid. The configurable grid allows cross comparison of both regular grids such as square, hexagonal, triangular, and irregular grids such as a randomly seeded Voronoi diagram and a newly developed flammable resolution grid (FRG)."

Lines 599-600: We've distinguished between ForeFire and IGS more clearly in this sentence: *"Existing software such as ForeFire can produce more precise simulations as it models fires in continuous space by moving markers representing the fire line, instead of simulating the spread of fire on a fixed grid determined before running the simulation."*

Lines 603-605: We have moved this discussion to the results section and expanded upon it as mentioned in the general comments.

Line 608: We have added extra details about the differences between ForeFire and the IGS along with the spatial resolutions in the conclusion: *"Existing software such as ForeFire can produce more precise simulations as it models fires in continuous space by moving markers representing the fire line, instead of simulating the spread of fire on a fixed grid determined before running the simulation. The use of continually moving markers requires additional computational time. The spatial resolutions of both programs must be noted however as ForeFire has a spatial resolution of 30 m^2 throughout, while the FRG has a varying spatial resolution with a maximum resolution of 10 m^2."* We have also added additional details to the ForeFire section of the paper: *"For this paper the spatial resolution of ForeFire was set to the same as its default example's resolution of 30 m^2. On completion the software returns, the final set of coordinates (known as markers) describing the location of the fire front. The use of markers instead of a grid allows for increased resolution as their position is on a continuous plane, limited by the resolution of the input data and their set spatial resolution."*

Technical Comments:

Figure 1: We have reworded to caption to make it clearer: *"Figure 1: A 2D net of the "fire tetrahedron", which shows all four components required to support combustion."*

Line 61: Apologies we noticed this typo shortly after uploading the paper. We have removed this citation, and it will be updated when the next version of the document is uploaded.

Line 348: We have fixed the typo by adding the word *"is"* to the sentence.

Line 349: We have reworded the sentence fixing the issue: *"This is done by removing the net fuel load $(w_n)_j$ from the equation Eq.* ***Error! Reference source not found.*** *to give Eq.* ***Error! Reference source not found.*** *which as previously stated use United States customary units."*

Lines 638-639: We have updated the citation.

Lines 665-666: We have removed this citation from the paper (we made a mistake with the line numbers we removed in Community Comment 1).

Lines 734-735: We have updated the citation.

Thank you again for your time and your detailed suggestions, they were very helpful. We look forward to hearing from you.

Kind Regards,
Conor.

Author Comment 4:
Hi Jonas Mortelmans (Referee #2),

Thank you for reading our paper. Your detailed feedback is invaluable. All changes mentioned below have been implemented in the document and will appear when the next version of the document has been uploaded.

I'll just go over the points that you mentioned and our accompanying changes.

We have added a discussion section to the paper: "*Comparing the five different grid types produced a table of computationally efficient and the similarity of their outputs when compared to ForeFire (Table 1). Overall, the regular grids produced the same output every time the program ran making them deterministic. They also took approximately the same time to run the simulation as shown by the small standard deviation in their computational times. The small standard deviation can be accounted for with other uncontrollable minor factors effecting the computer such as background tasks. Both irregular grids have a much higher standard deviation in their computational times. This is because the process of seeding these grids is non-deterministic, so a different grid is produced each time a simulation is run. Some of the irregular grids have overall regions of higher resolution than others, which can lead to varying computational times. The number of neighbours each grid has is also correlated to the computational time, as the program has the calculate the propagation ratio between each ignited polygon that can spread fire to its neighbour. The square and triangular grids have the fastest computational times while having four and three neighbours respectively. The hexagonal grid has the next fastest computational time with six neighbours. The random grid has a computational time very similar to that of the hexagonal grid even though there is no set number of neighbours per polygon. This is most likely due to each polygon having approximately six neighbours. The FRG has the slowest computational time even though most polygons also have approximately six neighbours. This is due to the increased density of polygons close to the wildfire source, as propagation ratios need to be calculated for all these ignited polygons and their neighbours that fire can spread to. In terms of similarity of output to ForeFire, the FRG performs the best followed by the square, triangular, hexagonal and random grids. As previously mentioned, the FRG has a high density of polygons near the wildfire source, allowing the simulation to nearly follow the continuous movement of the wildfire simulated in ForeFire. For the regular grids to be comprised of regular shapes (and equilateral triangles in the case of the triangular grid) it was only possible to have a set number of polygons in the simulation area. In the table, the number of sites for the regular grids was set as close to 2,000 as possible while still retaining a regular grid. The disparity in the number of polygons between the grids can explain some of the differences in similarities with ForeFire. The irregular random grid tends to produce outputs with the lowest similarity to ForeFire's than any other grid. This may be due to the minor variations in cell sizes within the random grid. The regular grids have a set number of directions fire can spread in to reach neighbouring polygons; they also struggle with* *following the irregular patterns in the Earth's terrain as seen by the lake (Figure 12). Overall, there is no definitive best grid type. It really depends on what the user is trying to simulate and how detailed they are willing to have the simulation in exchange for more computational time. In this paper the FRG was chosen as it produced the results most like ForeFire's.*

Comparing the IGS and ForeFire produced a table comparing the computational efficiency and similarity of their outputs (Table 2). ForeFire is deterministic and therefore produces the same results ever time it is run. In this comparison the IGS was using the FRG grid which is non-deterministic. The IGS wildfires that ran for shorter durations tended to be computationally faster than the wildfires that ran for longer durations, relative to ForeFire. This is caused by the increasing size of the simulated wildfire as it burns, resulting in more ignited polygons that can spread fire to their neighbours therefore creating additional computational burden per iteration. The IGS produces a larger area of false positives than that of false negatives when compared to ForeFire, this is due to the fire line selection process. As the IGS selects the fire line from the outer edges of the polygon if fire has reached that polygon's site, regardless of how far the fire has spread within that polygon to its surrounding edges; it sometimes overestimates the distance the fire has spread. This is the reason for larger area of false positive than false negatives when compared to ForeFire. The threat score for similarity between the IGS and ForeFire increases with length of simulation. This is due to the overall area of the wildfire which tends to be mostly true positives, growing at a faster rate than the boundary of the wildfire where false positives and false negatives tend to occur."

General Comments:

1. Ireland has sparse data in terms of wildfire impact. In the introduction we wanted to state the possible ramifications of wildfires globally, we do this by examining wildfires outside of Ireland. We also wanted to provide reasoning as to why wildfire modelling is important in Ireland, as it is a traditionally wet country. We understand how this could appear as we are stating some of the global impacts also occur in Ireland regularly, which is not true. We have therefore split the introduction into separate paragraphs where the first two paragraph focus on wildfires outside of Ireland and the third paragraph transitions the discussion to Ireland: "*A wildfire is a destructive fire that quickly burns throughout an area, this includes forest fires and bushfires (Haghani et al., 2022). Usually, they begin in remote areas where there is a higher density of combustible vegetation such as grasslands and peatlands. They can sometimes threaten urban areas (Park et al., 2023). Wildfires can be caused by both natural events such as lighting, and through man-made actions such as arson and farming techniques like slash-and-burn (Jiao et al., 2023; dos Reis et al., 2021). The frequency of wildfires has increased within forested extratropical and boreal regions in recent years, this is most likely due to climate change creating drier terrain, allowing fires to burn more easily (Janssen et al., 2023; Abatzoglou et al., 2018; Halofsky et al., 2020). This however varies regionally where factors such as wildland-urban interface, land use changes and fire exclusion policies can have an impact on the number of wildfires (Beltrán-Marcos et al., 2023; Piñol et al., 2005).*

The devastation of wildfires can be measured in different ways such as fatalities, ecological, environment and economic damage. In California, USA, and Australia a small subset of wildfires that burn in terrain satisfying the correct conditions can potentially grow to be very large fast burning fires which can present an increased risk to life (Keeley and Syphard, 2021;Blanchi et al., 2014). Wildfires result in the destruction of flora with the displacement of fauna, impacting that ecosystem (Kala, 2023).When wildfires burn through terrain, they release Carbon dioxide and other environmentally harmful gasses such a methane, further contributing to an increase in greenhouse gas emissions (Xue et al., 2024; Jones et al., 2019). The economic impact of wildfires includes damage to the agricultural and forestry sectors (Meier et al., 2023). When a wildfire spreads to an urban area it can also cause considerable damage to town infrastructure (Park et al., 2023).

Countries that normally have a wet climate such as Ireland, may also start to have an increased number of wildfires due to warmer temperatures, likely caused by climate change (McElwain and Sweeney, 2003; Boegelsack et al., 2018); (Benyon et al., 2023). Wildfires have had an ecological impact; in Ireland, wildfires tend to be smaller slower burning fires occurring mainly in bogs (peatlands), which are home to many rare species of both flora and fauna (Prat-Guitart et al., 2019). The high abundance of gorse (Ulex europaeus) in bogs makes them a common place for wildfires to occur as the plant is easily ignitable.

Even though wildfires that burn in Ireland, Australia and the USA tend to have differing burning behaviours, it is still possible to model them all as the underlying physics involved remain consistent. However, the parameters characterising fuel properties, terrain and weather conditions need to be changed to represent the surrounding environment."

2. We have streamlined increased the clarity of sections 3 and 4. Please let us know if these changes are what you had in mind. We are happy to make additional alterations to the sections if necessary. The changes we have made are as follows:
Lines 178-180: "*To compare the platform ForeFire with this paper's novel approach the Irregular Grid Software (IGS), the IGS was purposely designed to use the same input parametrisation as ForeFire. This allowed a fair comparison between both platforms as the same input data was used.*"
Lines 182-185: "*A satellite image of the region around Lough Dan, County Wicklow, Ireland, was used as input data for both ForeFire and the IGS. A random forest machine learning model was applied to the satellite data to produce a land cover map. Each pixel on the landcover map referenced an associated land cover type including pastures, sparsely vegetated areas, mixed forests, moors and heathland, urban fabric, water bodies, clouds, and cloud shadows.*"
Lines 187-200: We have moved these lines to an appendix at the bottom of the document.
Lines 216-225: "*Each type of land cover was mapped to a set of physical attributes that were contained in a lookup table used by both programs. ForeFire contains one of these files called a fuel file, by default and which was also used by the IGS (Fuels.ff Fuel Attribute Table, 2024). ForeFire's fuel file was indexed based on Corine Land Cover*

classes (Home :: Corine Land Cover classes, 2024). The fuels file contained values for fuel particle density (kg/m3), fuel particle moisture content, fuel particle surface area to volume ratio (m-1), fuel height (m), the oven-dry fuel load (kg/m2) and fuel particle low heat content (J/kg) for the different land cover types. Each of the listed fuel properties were required to run the Rothermel model. The land cover map had two additional fuel types for when it was not possible to identify the land type due to clouds or shadows. These fuel types were not present in the simulation area, as it was cloud free, so they did not affect either program."

Lines 243-245: "*The IGS was a Python program with the aim of generating a grid-based fire spread model that could be compared to ForeFire. The use of a grid with static points allows a model to compute fire spread without having to continually move and add markers during the simulation as found in ForeFire.*"

Lines 247-255: "*A Voronoi diagram was used to create an irregular grid. They have been used to simulate the geographic spread of disease in the past (Hackett et al., 2021). A Voronoi diagram takes in a set of points called sites. From these sites it generates edges (lines) located equidistant between itself and other sites, perpendicular to the direction between both sites. For the length of a particular edge the two sites that separate it are the two sites that are closest to it, therefore once the distance between the edge is closer to a third different site that edge stops. This creates tessellating polygons where every point within a polygon's perimeter is closer to that polygon's site than any other polygon's site (Figure 5). This means that each edge separating polygons is equidistant to both polygons' sites. The Voronoi diagram was generated using the efficient Fortune's algorithm implemented in the Foronoi (not spelled Voronoi) Python library (foronoi, 2024;Fortune, 1987). One of the biggest advantages of using a Voronoi diagram is the ability to create irregular simple tessellating shapes which allows for efficient computation of fire spread between polygons.*"

Lines 260-266: "*The NetCDF file containing input data, created using ForeFire, is imported into the IGS using the Snappy Python library (How to use the SNAP API from Python, 2024). Snappy allowed the NetCDF data to be read into Python arrays used for computation. The Voronoi diagram generated was overlayed on top of the NetCDF data. The elevation, wind, and fuel values (per fuel index) were recorded for every pixel in all polygons of the Voronoi diagram. This was done using the scan-line polygon fill algorithm to extract environmental data from the pixels contained within the polygon (Al-Rawi, 2014). The mean elevation, wind and fuel values of each polygon were then saved.*"

Lines 383-399: "*The boundary of ignited and burnt polygons can then be converted into a fire line, representing the outer perimeter of the fire. This allows the IGS to be compared to other continuous programs such as ForeFire. The boundary polygons need to be found to produce a fire line. A straightforward algorithm was used to find the boundary polygons where each polygon was checked to see if it can spread the fire (a polygon is only able to spread fire if the fire spread model has reached that polygon's site). Once a set of polygons capable of spreading fire is found, it can be shortened by checking if these polygons have one or more neighbours that cannot spread fire. This gives an updated set of boundary polygons that are on the fire line perimeter of the fire spread model. This was then converted to a list containing boundary edges by checking the edges of each boundary polygon and recording any edges between a boundary polygon and a polygon that cannot spread fire. Getting the boundary edges of the* *boundary polygons helps reduce underpredicting of how far the fire has spread within a given boundary polygon. Polygons that can spread fire while also touching the outer perimeter of the NetCDF file are checked and any edges of that polygon on the permitter are added to the list of boundary edges. Edges each consist of two vertices. To begin a random edge is selected from the list of boundary edges and a recursive algorithm finds the next edge to share vertices with the randomly selected edge, removing it from the list and storing it in a stack. This process is repeated until no more shared vertices can be found and the stack then becomes an ordered boundary. The process of selecting a random edge continues until all edges have been removed from the list (Figure 10). Sometimes the vertices of edges don't line up perfectly, so a 3 m (approximately 0.01 % of the region width) margin of error between vertices of different edges was allowed to ensure a completed shape. All edges shorter than the margin of error were removed to prevent other problems generating the completed boundary."*

3. We had previously used other metrics such as the permitter length and area of the burn scar for the comparison of wildfires, but we felt as though they did not provide a satisfactory comparison. We also investigated using root means square to compare fire lines, but this method had issues when comparing wildfires with more than one fire line. In the end, after a review of the literature we decided to develop the method present in the paper to find the threat score. We felt as though this metric was the fairest method we could find and if we were to add other forms of analysis we may be sending the same message twice. We have added the threat score as a metric of similarity for comparing the different grid types in the paper.

4. We have limited access to data on wildfires in Ireland. We are not aware of any open-source wildfire databases in Ireland that records the wildfire ignition point, starting time, finishing time and burn scar. Without this additional data it would be difficult to make the comparison. We have however, got wildfire burn scar data in Ireland, and openly available data from the Global Wildfire Information System. Unfortunately, neither of these sources provide the ignition point that started the wildfire or starting/finishing times at a high enough resolution. This would make it difficult to correctly input a wildfire duration or historic wind conditions. ForeFire is the industry standard in terms of wildfire modelling software. Both the IGS and ForeFire use the Rothermel model which has been validated against sample fires in fuel arrays, these commissioning experiments are referenced in the paper.

We have also added the following paragraph to the conclusion: "*For the results ForeFire was treated as the ground truth as its continuous nature can be made to produce results of a higher resolution than that set in the IGS experiments. Both approaches use the same fire progression model. ForeFire could be considered an industry standard as it is commonly referenced in relevant literature (Kaur et al., 2016; Farguell et al., 2019; Trucchia et al., 2019).*"

Your response has identified a need within the community to have more extensive data in open-source databases. Currently we are completing lab based burning experiments to validate the IGS but due to the nature of this research it would be a different publication.

The focus on this paper is the comparison to existing software and the choice of grid as the underlying wildfire model is the same in our comparison.

5. We fixed the six incorrectly spelled ‘girds’ to “*grids*”.

Specific and Technical Comments:
Line 46: We have removed the term uncontrolled: “*A wildfire is a destructive fire that quickly burns throughout an area, this includes forest fires and bushfires (Haghani et al., 2022). Usually, they begin in remote areas where there is a higher density of combustible vegetation such as grasslands and peatlands.*”
Line 47: We have updated this line to say remote instead of rural: “*Usually, they begin in remote areas where there is a higher density of combustible vegetation.*”
Line 49: We have updated this line to remove any mention of deforestation: “*Wildfires can be caused by both natural events such as lighting, and through man-made actions such as arson and farming techniques like slash-and-burn (Jiao et al., 2023; dos Reis et al., 2021).*”
Line 50: We have updated this line to reflect the suggested literature: “*The frequency of wildfires has increased within forested extratropical and boreal regions in recent years, this is most likely due to climate change creating drier terrain, allowing fires to burn more easily (Janssen et al., 2023; Abatzoglou et al., 2018; Halofsky et al., 2020).*”
Line 61: Apologies we noticed this typo shortly after uploading the paper. We have removed this citation, and it will be updated when the next version of the document is uploaded.
Line 65: We have added a space: “*(Xue et al., 2024; Jones et al., 2019)*” We believe this problem may be caused by our referencing software and is present in all other cases of double references. We will manually override this prior to re-submission.
Line 70: We have updated this line to reflect the literature suggested: “With the increasing severity and frequency of wildfires in forested extratropical and boreal regions, the ability to model and predict wildfire propagation has become an invaluable asset to planners and firefighters (Penney et al., 2019).”
Line 89: We have updated this line to make it read more clearly: “*In the Rothermel model the numerator measures total heat transferred to neighbouring fuel while the denominator measures energy required to ignite neighbouring fuel and R is the spread rate of the fire.*”
Section 3: We have shortened section 3 and made the text more concise with the changes mentioned in the response to general comment 2. However, we believed it was best not to remove too much of the information regarding the main process used, as it may impact the ability to replicate the study.
Line 193: We have updated this line and added the missing space “*This is due to Level 1-C products originally containing information regarding both the Earth’s surface and atmosphere which may not accurately depict the actual conditions on the surface of Earth.*”
Line 194: We have updated this line by removing the additional ‘the’: “*This is due to Level 1-C products originally containing information regarding both the Earth’s surface*

and atmosphere which may not accurately depict the actual conditions on the surface of Earth."

Line 195: We have replaced 'bands' with "*indices*". We have also added a brief explanation of which spectral bands are utilised here: "*NDVI is a ratio between red and the near infra-red bands whereas NDBI is calculated from the short wave infra-red (SWIR2) and near infra-red bands (Sun et al.2019, Kebede et al. 2022). The tillage index (NDTI) is calculated from both the available SWIR bands (SWIR1 and SWIR2) (Sun et al. 2019).*"

Figures 6 and 8: If possible, we would like to keep these two figures in the body of the manuscript, the figures assist the reader by providing a visual representation of the text. Figure 8 is novel, and its aim is to help those learning about the Rothermel model. That said, we will remove it if the editors still feel that it would produce a better manuscript. The figure captures insights that were not present in other paper describing how to apply Rothermel such as ForeFire.

Lines 313 – 317: Thank you for the observation, we have cited figure 9 at the end of the paragraph: "*A 50% transparency was used to allow the underlying map data to be seen (Figure 9).*"

Line 322: We have removed 'therefore' from the sentence: "*For fire line calculations, the oven dry fuel load per m2 was sourced from the fuel file and used to find the total fuel per polygon (kg)*"

Lines 385-395: We have slightly reworded these lines. We only refer to the list of boundary edges as a list. All other previous lists are now labelled as sets for increased clarity and better readability: "*The boundary of ignited and burnt polygons can then be converted into a fire line, representing the outer perimeter of the fire. This allows the IGS to be compared to other continuous programs such as ForeFire. The boundary polygons need to be found to produce a fire line. A straightforward algorithm was used to find the boundary polygons where each polygon was checked to see if it can spread the fire (a polygon is only able to spread fire if the fire spread model has reached that polygon's site). Once a set of polygons capable of spreading fire is found, it can be shortened by checking if these polygons have one or more neighbours that cannot spread fire. This gives an updated set of boundary polygons that are on the fire line perimeter of the fire spread model. This was then converted to a list containing boundary edges by checking the edges of each boundary polygon and recording any edges between a boundary polygon and a polygon that cannot spread fire. Getting the boundary edges of the boundary polygons helps reduce underpredicting of how far the fire has spread within a given boundary polygon. Polygons that can spread fire while also touching the outer perimeter of the NetCDF file are checked and any edges of that polygon on the permitter are added to the list of boundary edges. Edges each consist of two vertices. To begin a random edge is selected from the list of boundary edges and a recursive algorithm finds the next edge to share vertices with the randomly selected edge, removing it from the list and storing it in a stack. This process is repeated until no more shared vertices can be found and the stack then becomes an ordered boundary. The process of selecting a random edge continues until all edges have been removed from the list (Figure 10). Sometimes the vertices of edges don't line up perfectly, so a 3 m (approximately 0.01 % of the region width) margin of error between vertices of different edges was allowed to ensure a completed shape. All edges shorter than the margin of error were removed to prevent other problems generating the completed boundary.*"

Line 469: We have combined these two sentences into once sentence: "*The floored square root of the number of sites to plot is found and is used to equally space sites within the bounding box into equidistant columns and rows.*"
Line 485: Thank you for the comment, we have removed the second explanation of the acronym.
Section 7: We added a discussion section after the results in the paper. We have also added an additional paragraph to the results section: "*From the sample wildfires simulated, the IGS runs on average 34 times faster than ForeFire with an average fire line similarity of 0.8 to ForeFire. The use of IGS instead ForeFire allows multiple wildfires to be simulated (restricted to one area) in the same amount of time it would take ForeFire to run one of these wildfires. From (Table 2) it is evident that the fire line produced by the IGS mostly contain simulated wildfire areas of true positives when compared to ForeFire, followed by areas of false positives then false negatives. There is also a trend where IGS simulated wildfires that are ran for longer durations tend to not perform as well as those ran for shorter durations relative to ForeFire. Adding wind or additional wildfire sources in the comparison does not impact the relative computing time or similarity to ForeFire. There are some issues with the IGS, however. The FRG can have problems with larger wildfires as the frequency of polygons decreases the further a wildfire spreads from its wildfire source. This is evident in Wildfire 18 (Figure 14) where there is a large drop in site resolution at distances far away from the wildfire-starting location. The large distance between the IGS and ForeFire's northern and western fire lines highlights this issue. The cubic spline used, forces the curve to intersect the points on the edges of polygons. Due to the resolution of sites within the IGS, this makes the cubic spline produce small modulations on the fire line while ForeFire has more straight edges.*"

Thank you again for your time and your detailed suggestions, they were very helpful. We look forward to hearing from you.

Kind Regards,
Conor.