Response to Referee #2

This is a well-written paper presenting an approach to map the hourly progression of the growth of 28 large fires that burned in California during 2019–2021 using the GOES-West and GOES-east satellites. Although the GOPHER fire perimeters are generally less accurate than those detected with higher-resolution imagery, the advance here is the high hourly time resolution. Some of the implications and potential uses for the current dataset may be a bit over-sold, but the dataset will certainly increase in value presuming that it grows in the coming years, and additional value will come when lessons learned with this approach are someday applied to new satellite products with higher spatial resolution and/or other improvements on GOES.

We thank the reviewer for their helpful and constructive comments that have helped us improve our paper. Our point-by-point responses to these comments are listed below, and additional technical changes are listed at the end of our response. Our major changes include (1) restructuring the text in the methods and discussion sections for clarity, (2) adding an analysis of the spatial errors in GOFER perimeters relative to FRAP, and (3) adding a validation of intermediate GOFER perimeters with reference perimeters derived from aerial infrared imagery.

Specific comments:

L22: I realize that Intersection-over-Union (IoU) variable is a common metric in work related to image detection, but as a climate and fire scientist I was not aware of this metric until reading this paper and I suspect that many of the intended readers of this paper are similarly ignorant. For the Abstract, if a concise definition is not feasible, I think the main point that the fire perimeters detected in this study agree well with those from FRAP can be made without the use of the IoU variable, or the meaning of the numbers could be made more intuitive. Then, in the main text I suggest explaining the IoU and any other metrics used in this study that may not be intuitive to fire scientists who lack expertise with remote sensing and/or image detection.

Thank you for this suggestion.

In the abstract, L23-24, we add the following description of IoU: "the IoU indicates the area of overlap over the area of the union relative to the reference perimeters, in which 0 is no agreement and 1 is perfect agreement."

In methods (Section 2.3.3.3), L298-301, we revise the description of IoU to: "The IoU, or Jaccard index, is a common metric for evaluating spatial accuracy against ground truth data in object detection. Here the IoU is calculated as the area of overlap over the area of union using the fire perimeters, in which IoU = 0 indicates no agreement and IoU = 1 indicates perfect agreement."

Section 3.4 (Future work and applications): While I do see value in this work, some of the suggested applications seem unlikely. For example, with only 28 fires, low spatial resolution, and uncertainty in the specific locations of burning and fire-line position, it seems doubtful that this specific dataset will open the possibilities for new insights regarding questions about the vegetation characteristics that promote explosive or quiescent fire activity. I think some of the caveats to this section, and any impression the reader may have that GOPHER is being oversold in this section, could be addressed if the section was preceded by a section that is specifically dedicated to the inherent limitations of GOPHER.

Thank you for this feedback. We have revised Section 3.4 to first highlight the limitations of GOFER before discussing its potential applications, in response to your comments and those of reviewer 1. Section 3.4 is now divided into three subsections: 3.4.1 Limitations, 3.4.2 Future work and development, and 3.4.3 Potential applications. Sections 3.4.1 and 3.4.3, L657-673, 875-901, are revised as follows:

"**3.4.1 Limitations**

Here we use 28 large fires in California from 2019-2021 to test the potential of the GOFER algorithm to track the hourly progression of large wildfires using 2-km GOES active fire detections. While GOFER fills in temporal gaps in tracking fire progression, there are inherent limitations arising from the low spatial resolution of GOES observations, missed active fire detections, and potential geolocation errors in the perimeters and the active fire lines. In particular, GOFER is less reliable around water bodies and mountainous terrain. While GOES-East and GOES-West observations can be combined to increase the overall spatial accuracy of GOES-derived perimeters, we find that in California, GOFER-West is comparable to GOFER-Combined, and the use of GOES-East observations can detract from the spatial and temporal accuracy of GOFER-Combined. We expect that the suitability of the GOFER product for scientific applications, such as improving the fire diurnal cycle in emissions estimates or understanding the controls on extreme fire behavior, will grow as the algorithm is refined and additional fires are processed. However, GOFER cannot be used to understand fine-scale physical fire behavior, such as spotting or convection along the fire line, due to unnatural textures resulting from spatial limitations of GOES. Importantly, lessons learned in developing the GOFER algorithm may be applied to observations from future geostationary satellites over North and South America, such as NOAA's planned GeoXO (Geostationary Extended Observations) satellite system in the 2030s to replace the current GOES-R series with higher spatial resolution and additional bands (Adkins, 2022), and existing geostationary satellites over other regions, such as Himawari over East Asia, Equatorial Asia, and Australia and Meteosat over Europe and Africa (Hally et al., 2016; Roberts and Wooster, 2008).

3.4.3 Potential applications

We foresee several extensions and applications of the GOFER algorithm and product. First, GOFER can be used to improve the fire diurnal cycle for atmospheric modeling of smoke emissions. In current global fire emissions databases, the diurnal cycle is broadly generalized by land cover and generally static from day to day throughout a fire's lifetime; for example, the 3-hourly fire diurnal cycles in the Global Fire Emissions Database (GFED) are derived from historical GOES observations from 2007-2009 and implemented as climatological means based on three land cover types (van der Werf et al., 2017; Mu et al., 2011). As is evident from GOFER, however, large fires may have explosive days of growth where burning extends from the afternoon to evening. In contrast, other days with slower fire spread are generally marked only by growth during the afternoon peak. Recently, GOES observations have been merged with VIIRS observations to estimate hourly fire emissions at 3-km spatial resolution in a top-down, FRP-based approach for the Regional ABI and VIIRS fire Emissions (RAVE) product (Li et al., 2022). Similarly, for a bottom-up, burned area-based approach, the GOFER diurnal cycle of the fire-wide growth in area can be used to downscale the perimeters of select fires in existing fire progression products, such as FEDS, to hourly intervals. Second, the GOFER product can be used to build statistical and machine learning models to understand how temporal variations in weather, topography, fuels, and active fire suppression at the active fire line drive fire spread rate and fire-wide growth in area at an hourly scale. Owing to limitations in spatial resolution in both the input and output data, GOFER is most suitable for 1D time series models. For example, the GOFER product can be used to explore periods of critical stress on firefighting resources, such as in mid-August and early September of 2020 when 8-9 large fires were simultaneously active (Figure A1). Using the set of available fires in GOFER as case studies, we can identify periods when large fires are explosive or quiescent, including extreme cases when nighttime "brakes" on fire spread fail (Balch et al., 2022), causing evacuations and damaging structures. For spatial analyses, GOFER could be used as a secondary product to FEDS and high-resolution perimeters from state and federal agencies. GOFER and FEDS can be used to improve the parameterization of 3D fire spread models, such as ELMFIRE and WRF-Fire, during periods of extreme fire spread and active nighttime burning, which are often poorly estimated compared to satellite and aircraft observations (Stephens et al., 2022; Turney et al., 2023). Potential geolocation errors in GOFER and FEDS active fire lines for initializing 3D fire spread models should be accounted for, such as by perturbing the active fire lines in an ensemble approach according to the distribution of error relative to reference perimeters."

We have revised the conclusion to emphasize that the GOFER dataset can be used as a case study reference in potential applications to identify periods of explosive or quiescent fire activity, rather than open opportunities for providing new insights about vegetation characteristics.

L909-914: "GOFER resolves the time dimension of fire progression mapping to hourly intervals and can identify critical, explosive periods of fire spread… Additionally, our GOFER dataset for the 28 large wildfires in California from 2019-2021 is a useful case study reference for modeling weather-human-fire relationships and improving estimates of fire emissions and smoke pollution."

Technical corrections:

L249: "such as"?

Thank you for pointing out the typo. We have corrected this to "such as."

Other technical corrections:
Changes to specific fires:
For the July Complex Fire, we have expanded the spatial bounds of the search box to include the Dalton and Allen fires, which are smaller fires considered part of the complex. This change is reflected in the GOFER product and Figures 1, 4b, 8, 9, A1, and C4 and Tables 1, and C1.

For the Red Salmon Complex Fire, the GOES_UTC time was incorrectly copied in the metadata csv file in the GOFER product from the Earth Engine metadata dictionary. This change is reflected in the GOFER product and Figure C4 and Table A1.

For the Beckwourth Complex Fire, we have reprocessed the fire and manually adjusted the start time for the GOES time series to reflect the earlier start of the Dotta Fire (part of the complex). The CAL FIRE information shows a later ignition for the Beckwourth Complex Fire.

Table A1. There was a typo in the lat/lon coordinates for CZU Lightning Complex, and the previous coordinates were entered incorrectly. These coordinates were not used in the analysis and were only used in this table to illustrate some metadata for each fire. The coordinates have been corrected from Lon: -120.68 and Lat: 40.06 to Lon: -122.22 and Lat: 37.17.

Table B2: There was a typo in Table B2 on the range of the kernel size of GOFER-West. This has been corrected from 2.5-2.6 km to 2.5-2.7 km.

Figure 5. There was a typo in the top-left panel. We have corrected “exceeds” to “exceeding” and updated the figure.

We have requested a more complete set of the DINS (Damage Inspection Program) dataset of the status of structures (e.g. damaged, destroyed) within fire perimeters from CAL FIRE. The validation DINS dataset to calculate the omission error of GOFER has increased from 12 to 20 fires. There were some inconsistencies with previous data from the CAL FIRE Open Data Portal. The DINS dataset is more complete, and we redid the analysis for the 12 fires using the complete DINS data (Table C3).
In Section 2.2, we change the text accordingly to:
“For select fires (20 of 28 fires), the CAL FIRE Damage Inspection Program (DINS) database also provides the location of permanent structures inside or within 100 m of the perimeter and the level of damage sustained by each structure (accessed from the CAL FIRE Records Center at the GovQA Portal). These data are used to calculate the number of affected and destroyed structures contained by our derived fire perimeters.”

Other minor changes:
Figure 1. We added a thin black outline to the fire detection confidence color bar to make the lighter colors clearer.

Citations have been updated to the ESSD format.