Article

Exploratory simulations of experimental burns for instrumentation deployment.

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Abstract: Experimental burns are expensive and require extensive planning and coordination. Logistical challenges compounded with unfavourable weather can lead to cancellations and loss of critical data collection. Moreover, experimental burns are "one and done" events, requiring careful instrument placement to observe desired coupled wildfire-atmosphere characteristics. In this study, we examine the feasibility of using a coupled wildfire-atmosphere model at high spatiotemporal resolution to inform instrument placement for a small-scale prescribe burn. Using black spruce forest burn from [put in date/month here] 2020 as a case study, we demonstrate that the model can reasonably predict the fire behavior, smoke emissions, dispersion and the associated feedbacks. The paper offers details of the numerical experiment design as well as our proposed approach for using such simulations to help inform future experimental burns.

Keywords: experimental burn; fire modeling; observational data; WRF-SFIRE; pelican mountain; fire behavior; smoke emission and dispersion; coupled feedbacks

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1. Introduction

~~Collecting detailed observational data of wildfire activities is extremely difficult. As a result of highly dynamic behavior, the~~ Due to the highly dynamic nature of wildfires, observational studies of their behavior are often challenging. The wildfire's size, shape, and direction(s) can change rapidly ~~. The reasons for these behavioral changes are numerous in addition to the coupled fire-atmospheric processes,~~ in response to fuel type, moisture content, terrain ~~, and even the~~ and ambient weather. The behavior is further complicated by numerous fire-atmosphere feedback processes as well as potential mitigation measures employed by fire response teams~~all impact wildfire behavior~~. As a result~~of these and other factors~~, wildfire observational datasets are ~~nearly nonexistent~~extremely scarce [need reference]. Thus, the fire science community typically relies on experiential burns to collect critical data, which is then used to develop, improve and/or verify ~~numerical wildfire-atmosphere~~ wildfire models.

Advancements in computational power and efficiency have ~~enabled more physical processes to be implemented~~ allowed to include many physical processes within numerical wildfire-atmosphere ~~modeling~~ models [1]. These models, however, still rely on underlining semi-empirical ~~models and parametrization, each of which contains inherent errors. Over the years, data collected at serval experimental burns have improved the underlying parameters subsequently improving the~~ parameterizations that often require many simplifying assumptions, which can lead to prediction errors. Experimental burn data collected in recent years [reference here] has been critical for estimating key parameters within these simplified parameterizations and for improving the overall accuracy of the numerical wildfire-atmosphere model(s). [1–4].

These experimental burns have also led to process enhancements such as better instrument placement [1], and the development of lower-cost (disposable) instrumentation. For process improvements to continue, more experimental burns, using novel experimental designs and conducted in varied forest ecosystems are required ~~. These experiments~~

~~will deepen~~ [reference]. Such experiments may help improve our understanding of the complex coupled wildfire-atmospheric processes which in turn will improve our ability to mitigate the destruction caused by wildfires.

The Pelican Mountain experimental fire research site in central Alberta, Canada was ~~created~~ designed to examine fire behavior in a boreal black spruce forest [5]. The research site ~~provides a unique opportunity for wildfire-atmosphere research and model development. Since~~ is unique for several reasons. Firstly, well-observed experimental burns in black spruce forests are uncommon ~~, the ability to monitor the behavior of this fuel type provides an opportunity to improve our understanding and modeling of wildfires in this forest ecosystem. An additional benefit of the site is its size and layout . It~~ [reference] . Hence, the opportunity to examine fire behavior in this particular fuel type is extremely valuable for improving fire growth models. Secondly, the design and layout of the site allows for comparative experiments. The lot consists of 22 individual blocks that ~~will~~ provide researchers the opportunity to conduct experimental burns over ~~the next~~ several years. Since the fuel characteristics of a block can be modified (i.e., by thinning underbrush) a variety of situations can be studied ~~more easily~~and compared. Most importantly, ~~studying the results of~~ careful examination of data collected from a burn of a ~~burn within a~~ particular block allows researchers to ~~continually address lessons learned, and apply them moving forward~~adjust and improve their methods for subsequent experiments.

~~Even considering the advantages Pelican Mountain provides, experimental burns are expensive and~~ While the multi-lot design of Pelican Mountain site is helpful for prescribed burn planning, individual blocks still require very site-specific weather conditions ~~. The natural question becomes can modeled simulations improve~~ to carry out an experiment. This uncertainty can often be costly. Hence, the main goal of this paper is to examine whether numerical simulations can be used to inform the design and layout of the ~~instrumentation used in the experimental burn~~experiment, thereby reducing costs~~?~~

~~In this paper, we will investigate this question by using~~ . We use the 2019 Pelican Mountain Unit 5 burn as a case study to:(1) verify the forecast accuracy of the WRF-SFIRE model; (2) review learned lessons on the model configuration and the observed data; and (3) discuss the potential use of model forecasts to optimize instrumentation placement at the future burns.

2. Methods

2.1. Prescribed Burn Design

The Unit 5 burn was conducted in the late afternoon on May 11, 2019, and consumed a 3.6 ha block of black spruce forest peatland. Researchers from diverse scientific backgrounds collected data on fuel moisture, fuel loading, fire behavior, smoke emission, smoke dispersion, and meteorology. The data collected was evaluated against the results of the WRF-SFIRE model simulations which is a coupled wildfire-atmosphere model that combines the Weather Research Forecast Model (WRF), with the Rothermel semi-empirical fire-spread algorithm [6,7].

~~Observational data of fire behavior were captured by~~ Fire spread and intensity were measured using 29 K-type thermocouples and ~~five~~ 5 radiometers. Instruments were placed approximately 30 cm above the surface ~~and placed~~ in roughly a 20x20 meter array within the burn block. Sampling time was once a second (Figure 1). Fire behavior was also monitored by ~~ten~~ 10 in-fire video cameras ~~, Aerial footage captured~~ as well as via visible and infrared ~~spectrums~~aerial footage. The timing and location of ignition were ~~captured by~~ tracked with a GPS logger attached to a large drip-torched tethered underneath a helicopter.

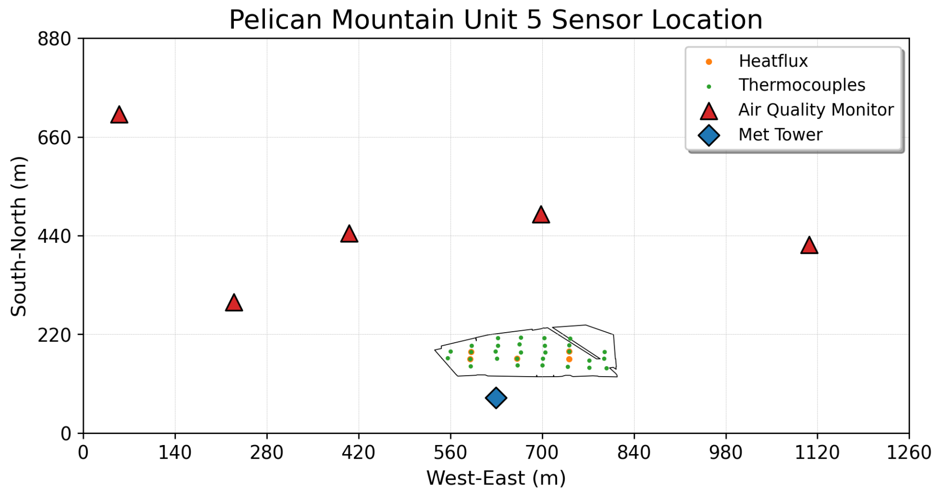

Figure 1. Site ~~Map~~ map showing ~~instrumentation~~ instrument placement during the Unit 5 experimental burn on May 11, 2019 at the Pelican Mountain research site in central Alberta, Canada.

Emissions and ~~dispersions~~ dispersion data were measured using five micro air quality sensors ~~scattered~~ place downwind of the burn at distances ranging from 300-1000 m (Figure 1). Meteorologic data was captured by an ATMOS-41 2D sonic anemometer, measuring every 10 seconds at 6.15 m above ground level (just above tree canopy height) and 40 m south of the ignition line. A detailed description of the research site, the Unit 5 experimental burn, and data collected can be found in [5,8,9].

2.2. Model Overview

The atmosphere and fire models that make up the WRF-SFIRE operate on two distinct spatial gridded meshes within the same geographic model domain. The 3-D ~~atmosphere~~ atmospheric grid used in this study was configured in Large Eddy Simulation (LES) mode, which simulates turbulent flows by numerically solving the Navier–Stokes equations [6,7]. On the refined fire mesh, the Rothermel semi-empirical fire spread model tracks surface-fire propagation using the level set method based on the fuels, terrain, and interpolated wind speeds and ~~direction~~ directions from the atmospheric grid [6,7,10]. The type~~and amount~~, amount and moisture of fuel consumed ~~releases heat and moisture fluxes into the atmosphere gird, altering the fluid dynamic~~determine sensible and latent heat flux forcing back into the atmospheric grid. This process ~~plays out for~~ is repeated at each computational time step of the simulation~~and creates the wildfire and atmosphere coupling~~, thereby allowing coupling between the fire and the atmosphere.

The model ~~domain was established at~~ was configured with a 4 km x 10 km domain with 25 m and 5m horizontal grid spacing for the ~~atmosphere and 5 m horizontal refined fire mesh~~atmospheric and fire meshes, respectively. The 5 m fire grid resolution was intentionally chosen to be finer than the planned 20x20 m array of thermocouples within the burn block. ~~Model top was set at 4000 m divided into~~ We used 51 hyperbolically stretched vertical levels with a 4000 m model top. The lowest five model levels were 4 m, 12 m, 20 m, 29 m, and 40 m. The lowest model level (4 m) ~~was chosen since it is the closest to the~~ roughly matches the mid-flame height defined by Anderson Fuel Category ~~6. This category was chosen since it represents a~~ 6, which most closely represents black spruce forest ~~, which~~ and is the dominant vegetation type at the Pelican Mountain research site [11].

The initial inputs include; a sounding taken from an operation numerical weather ~~predation~~ prediction model (WRF) an hour prior to ignition, a perturbed surface skin temperature (of 290 K) to start of convection, and a surface fuels map of Anderson's Fuel Category 6 with a 10 meter no fuels buffer around each unit at the research site. A one-hour spin-up period was used to develop a well-mixed planetary boundary layer (PBL) prior to the first ignition at 17:49:48 MDT. Refer to Table 1 for basic configuration options and supplementary material for full model setup.

Table 1. Basic Model Configuration

Parameter	Description
Model	WRF-SFIRE V4.2
Domain	160 grids (west-east) X 400 grids (south-north)
Horizontal grid spacing	25 m
Time Step	0.1 s
Model Top	4000 m
Vertical Levels	51
Lateral boundary conditions	periodic
stretch hyp	True
z grd scale	2.2

~~After~~ Following spin-up, ~~a single ignition line was created. The ignition line started~~ the simulated fire was initialized using a single 260 meter ignition line, starting on the southeast corner of Unit 5 at 17:49:48 MDT and ~~was completed 260 meters away~~ ending on the southwest corner 120 seconds later. The locations and timing utilized were an estimated planned aerial ignition pattern.

The simulation continued for 40 minutes past ignition~~, capturing the roughly~~ . Active burn and spread period was approximately 10-minute ~~period of peak burning and spread~~ long. Smoldering did occur after this 10-minute period but was not ~~addressed in this study~~ explicitly modelled by WRF-SFIRE. Fuel mass loading was set to 1.3 kg m^{-2} and dead fuel moister was set to 8% based on the previous day's observations.

~~Lastly, a~~ A passive tracer was used to represent smoke emission. The ~~emissions were proportioned~~ emission rates were proportional to the mass and type of fuel burned and were later adjusted with fuel type-dependent emissions factors to represent particulate matter (PM) 2.5 concentration.

Neither the chemistry nor fuel moisture models were activated within this exploratory WRF-SFIRE ~~configuration. This will be explored in future studies.~~ study.

3. Results

Generally~~speaking~~, the WRF-SFIRE simulations of the experimental burn yielded promising results, particularly when comparing: fire behavior, smoke emission, dispersion, and coupled feedbacks. Of the four parameters, fire behavior was the least successful. There were significant inaccuracies in arrival time in some sections on the burn block. The model's smoke emission and dispersion peak occurrence predictions matched the observational data, although the magnitude did not compare favorably. Coupling feedbacks were evident between the fire and atmosphere with a shift in wind direction and distinctive gusts occurring in both the model and the observed data.

A more quantitative analysis of each component is provided in the following sections.

3.1. Fire Behavior

~~For~~ To assess the modeled fire behavior, we compared the ~~modeled~~ observed temperature values from the 29 in-fire thermocouples (Figure 2(A)) to the simulated heat flux at the nearest model grid cell~~to one of the corresponding 29 in-fire thermocouples. We normalized each variable and plotted a timeseries to capture the arrival time of both the~~ . The arrival time for both observed and modeled fire ~~front.~~ fronts is shown in the normalized timeseries in Figure 2~~A depicts the location of the 29 thermocouples sensors within the burn block. As presented in the figure, the sensors are~~ (B). The sensors were arranged in distinctive columns (~~arranged East-West~~East to West) labeled on the South end of the unit as C2, C3, C4, C5, C6, C7, C8, and C9. Each column is then colored in the North-South direction. Spatially modeled arrival time is color contoured as seconds from ignition where the ignition line is shown as a dashed black line with the ignition start represented by a star and ignition stop as letter X.

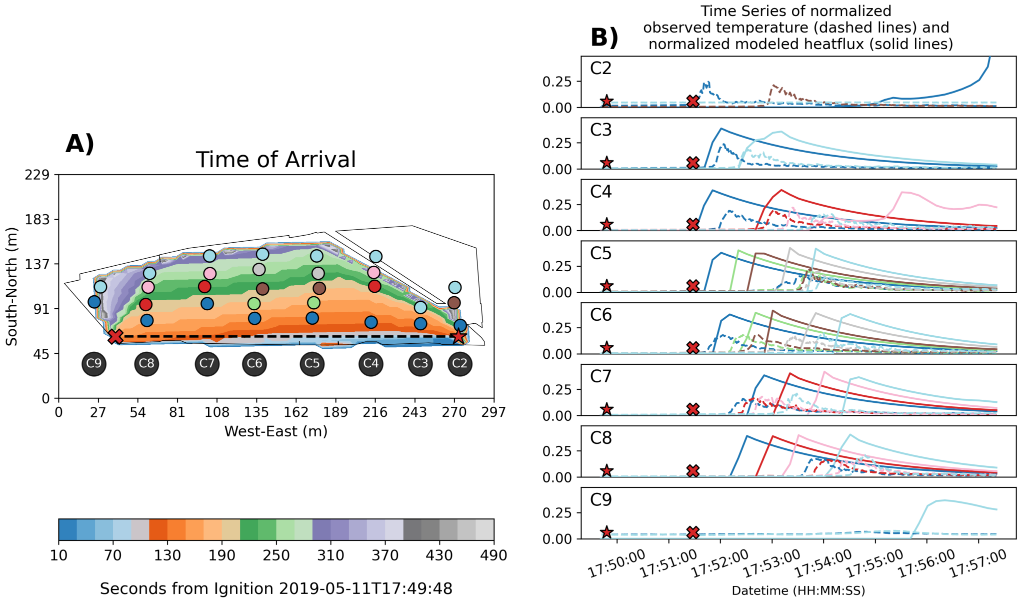

Figure 2. (**A**) ~~Shows model fireline~~ Contours of fire arrival time from seconds past ignition, location of in-fire thermocouples and ignition line with start and ~~stop shown as Star and X respectively~~end. (**B**) ~~hows timeseries~~ Timeseries of normalized modeled heat flux (solid lines) and normalized observed temperature (dashed lines). Start and ~~stop~~ end of ignition symbols are the same as shown in (**A**).

Figure 2B shows time series subplots of each column with a matching color sequence to the map in Figure 2A. On all-time series plots, normalized observed temperatures are represented as a dashed line, and normalized modeled heat flux is shown as sold lines. Also shown are the start-stop times of the ignition line.

~~Comparing the data, we find that the peak occurrence is off by an average of 13.6 secs for sensors in~~ We found that on average for columns C3, C4, C6 ~~,~~ and C7 the modeled peak heat occurred 13.6 sec later than observed. This represents an error of 2.7% when considering the full duration of the burn. ~~In~~ For columns C5 and C8, the ~~model's peak occurrence timing was much too earlywhen~~ modeled peak was early, compared to the observed~~data~~. This was due to the actual ignition line pattern. The planned aerial ignition pattern was to occur over a 120 second period and intended to be on a 260 m straight-line, terminating at the southwest corner of the block. Unfortunately, the actual ignition pattern and timing did not occur as planned.

Instead of being a single line, four distinct ignition ~~lines~~ segments were created. The first ~~ignition~~ segment started on the southeast corner of Unit 5 at 17:49:48 MDT. The fourth and final ~~ignition was completed~~ segment ended on the southwest corner 163 seconds later~~with an~~. Small un-ignited ~~section between each of the four lines. To address these deviations, we re-ran the simulation using the actual~~ sections between each segment matched the locations and times ~~. This data was obtained from~~ observed from aerial footage and the GPS data logger~~, which was attached to the ignition source, and was cross-verified by aerial videography~~.

~~Re-running the simulation using the actual ignition patterns yielded much higher accuracy in~~ This alternative ignition configurations yielded improved accuracy for columns C5 and C8 as well ~~,~~ as in columns C3, C4, C6, and C7 (Figure 3). Columns C9 and C2 were poorly captured due to odd behaviors of the level set method at the fuel / no fuel boundaries.

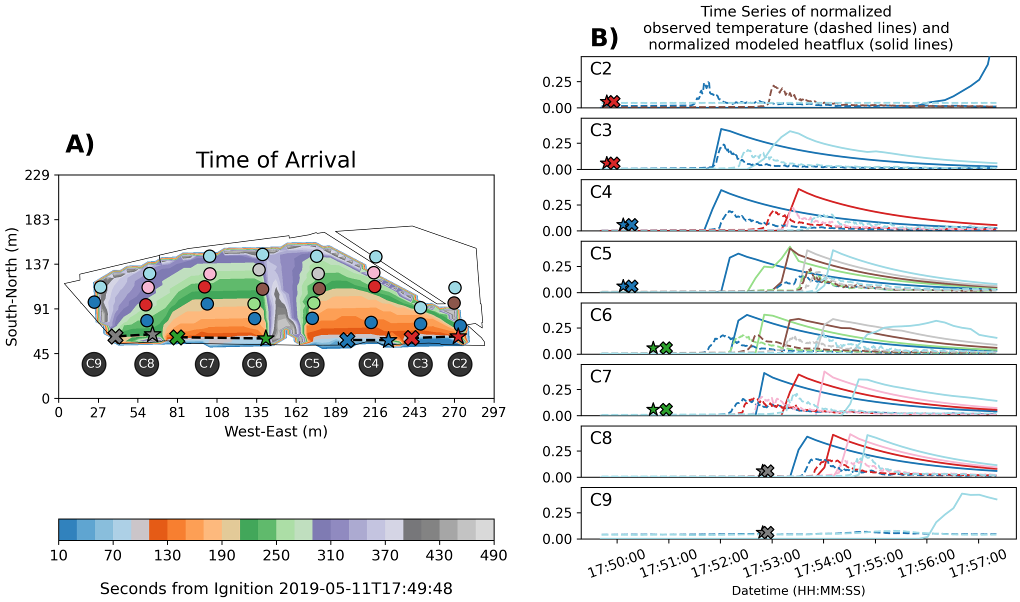

Figure 3. Same information as Figure 2 with a modified four-line ignition pattern. ~~This pattern more accurately represents what occurred in during the Unit 5 experimental burn~~.

3.2. *Smoke Emissions and Dispersion*

~~For smoke emission and dispersion, we~~ We compared PM 2.5 concentrations from the single line simulation to the observed concentration at five air quality monitors downwind of the burn. The five-air quality stations were deployed downwind in a near-field region ~~coving~~ coverng an arc angle of 128 degrees [9]. The model passive tracer concentrations were converted to PM2.5 concentration using the combustion phase emission factor for black spruce flues of 10.4 g kg^{-2} [12].

~~To conceptualize the dispersion, we vertically~~ Vertically and horizontally (i.e., cross-wind) integrated ~~the~~ PM 2.5 concentration at the ~~timing of peak modeled values at~~ time of peak heat for each air quality station 303-100 is shown in (Figure 4A, 4B, and 4C). ~~Peak~~ Maximum concentrations of the modeled PM 2.5 occurred 40 seconds earlier than observed and at roughly half the order of magnitude at station 303-100 (Figure 4C).

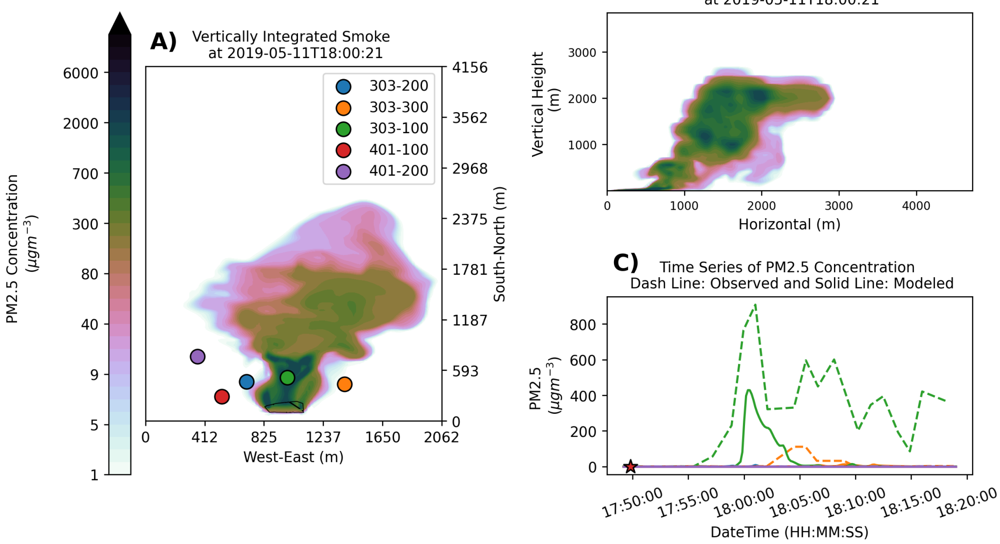

Figure 4. (**A**) Vertically integrated smoke at 18:00:21 (HH:MM:SS) and position of air quality sensors. (**B**) Crosswind integrated smoke at 18:00:21 (HH:MM:SS). (**C**) Time series of observed ~~to nearest model grid cell~~and modeled concentrations at the air quality sensors in (A). Peak emission occurred for station 303-001 at 18:00:21 (HH:MM:SS).

~~The timing of peak~~ Maximum concentration for both modeled and observed PM2.3 concentrations occurred after peak heat flux. ~~In supplementary material, S1 is a model animation of a crosssection of smoke dispersion along the exact longitude as sensor~~ Animation of a smoke cross-section at location of sensor (303-100~~which, is represented as a~~ ; green dot in Figure 4C~~. We see from the video that after the extinction of the heat flux, the~~) is provided as Supplementary Material S1. As seen in the animation, once the active burning stage is complete the vertical motion of the plume ~~column stops, and ambient horizontal winds force dispersion downwind. As expected,~~ slows and transitions to dispersion by ambient horizontal flow. Note, that the magnitude difference is negligible since emission factors for black spruce have not been fully studied [12].

The results from the four-line ignition simulation were comparable to the single-line ignition simulation (Figure 5). Sensor 303-300 was the only other instrument to detect smoke from the burn. This observed increase in smoke was caused by smoldering combustion, which is not addressed in the WRF-SFIRE model. [2,6,7].

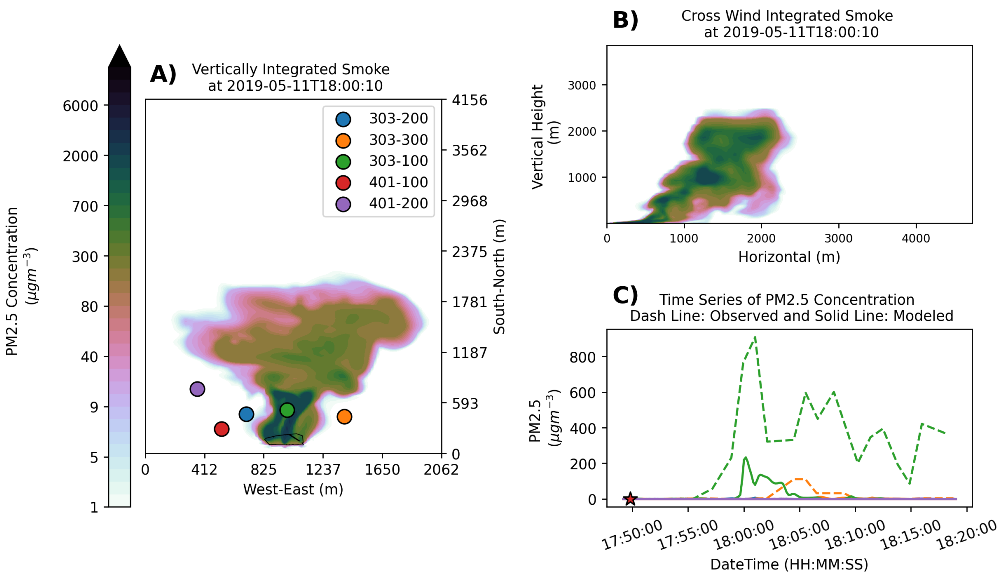

Figure 5. Same as Figure 4 with a modified four-line ignition pattern. ~~This pattern more actually represents what occurred in during the Unit 5 experimental burn.~~ Note timing of peak emission occurred for station 303-001 at 18:00:10 (HH:MM:SS) or 10 seconds earlier than the single line ignition pattern.

3.3. Coupled Feedback

To analyze the fire and atmospheric coupled feedbacks we first compared the measured in-fire heat flux values to the modeled heat flux values (Figure 6). The peak heat at each of the fire sensors to the nearest model grid showed strong agreements of heat introduced to the atmosphere from the fire.

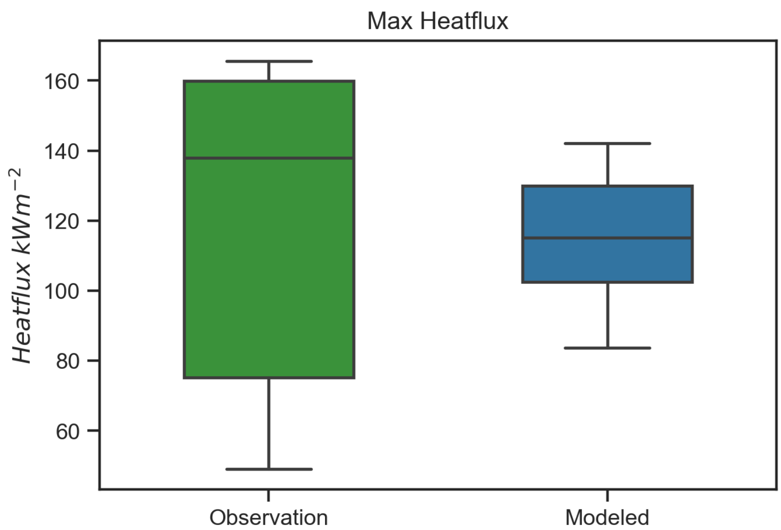

Figure 6. Distribution of ~~Max heat flux~~ maximum values for for observed ~~to nearest model grid cell to~~ vs modelled heat flux at the five in fire heat flux sensors.

Next, we analyzed the fire thermodynamic effects on the atmosphere by comparing observed wind speed and direction to those of the model at 6.15 meters above ground level (AGL) from a tower 40 m south of the burn (Figure 7A). Also ~~, shown in Figure 7A~~ shown are color contoured wind speeds and directional streamlines at 6.15 m AGL during peak modeled wind gust at the nearest modeled grid to the met tower.

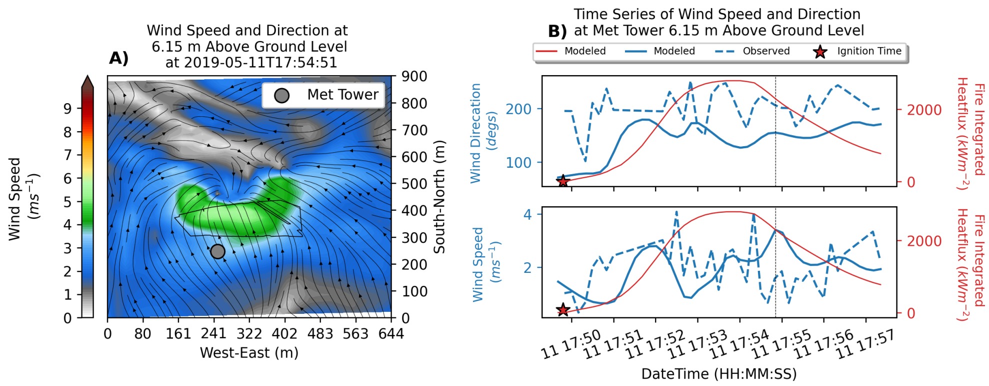

Figure 7. (**A**) Modeled ~~Wind Speed~~ wind speed and ~~Direction)~~ direction at 6.15 m AGL at 17:54:51 (HH:MM:SS) and location met tower~~sampling at 6.15 m AGL~~. (**B**) Timeseries of ~~Wind Speed~~ wind speed and ~~Direction~~ direction at met tower ~~showing~~ shown in solid and dashed blue ~~model (sold line)~~ for modelled and observed ~~(dashed line)~~values, respectively. Also shown is modeled max heat flux ~~values as a red~~ (solid ~~line~~red). The vertical dashed line is at at 17:54:51 (HH:MM:SS)

Figure 7B shows a time series comparison of wind speed and direction during the burn period. We found that after ignition wind direction observed and molded showed less random variation maintaining southerly wind flow that helped propagate the east-west orientated fireline north. Also, after ignition, wind speeds exhibited an increasing trend that peaks roughly 30 seconds after maximum accumulated heat flux in the atmosphere. Figure 7B shows the temporal relationship of the model, using the maximum modeled heat flux, and observed wind direction and speed.

4. Discussion

Our objective was to determine the WRF-SFIRE model's ability to forecast ~~an experimental burn using the~~ fire and smoke dispersion conditions at 2019 Unit 5 experimental burn at Pelican ~~Mountains as the comparison event. We initialized WRF-SFIRE, configured in LES mode, with a numerical weather prediction model.~~ Mountain. The following sections discuss ~~how we determined the model 's configurationand what we'd like to do differently at future experimental burns~~model configuration, it's accuracy and implications for future experimental planning.

4.1. Observation Dataset

~~Data collected at experimental burns has led to the creation of new model parameters and improved model accuracy [1–4,13]. We believe that these efforts should continue and propose new experimental designs based on our Unit 5 cases study and field experience.~~

~~Improving the~~ Our ability to observe ~~actual~~ and quantify fire behavior is critical for model development and hazard mitigation. In particular, our understanding of vertical heat and moisture transfer from the fire into the atmosphere remains limited. Moreover, the associated feedback mechanisms introduce an additional layer of complexity to our modeling efforts. ~~Two of the most important parameters to more fully observe and understand are heat flux and temperature. Expanding observations vertically to include multiple levels with detailed fuel moister sampling will allow us better to assess heat and moisture flux in the atmosphere. This is particularly important since these two parameters directly impact smoke emissions, smoke dispersion, and coupled feedbacks.~~

To gain a better understanding of the coupled feedback(s) we propose building expendable cup anemometers and wind vanes. We have been developing these sensors and plan to have them in use at an experimental burn in May 2022. These sensors will be placed above, below, and most importantly, directly at the projected mid-flame height. The data will be broadcast by long range radio frequencies to a nearby receiver. The data collected will establish the altered flow patterns at and around the fire front. Of particulate interest are the vertical-to-bent-over vortices on the ends of the fireline. These areas rapidly mix environmental air into the smoke plume, and directly impact modulation of fire intensity and fire updrafts [13–15].

The current approach for observing smoke emissions and dispersion can be improved by simply utilizing the forecast simualtion of the conltred burn. This will allow better placement of air quality sensors so that a better arch angle can be established. Using more sensors, placed at better locations, will increase both the quantity and quality of the data collected. This enhanced data set will be valuable for improving emissions factors for black spruce forest ecosystems, thereby improving regional smoke forecast models [12].

To collect data on smoke emission and dispersion aloft, we are developing expendable air quality sensors that will vertically profile the smoke plume. The sensors will be treated as radiosondes or dropsonde to make in-situ observations of PM 1.0, 2.5, and 10 concentrations within the smoke plume. The sensor will be attached to a Windsond radiosonde instrument [16] that measures the vertical profile of temperature, dew point, wind speed, and direction. Coupling the two instruments will hopefully provide a much-needed dataset to aid in evaluating smoke plume rise modeling.

Sampling locations will be determined by the WRF-SFIRE forecast simulations. Our goal is to profile the smoke plume once its vertical motion has stabilized and is at a safe downwind distance so that the aircraft supporting the experiment are not threatened. Figure 8 shows a modeled profile of the atmosphere and smoke plume for what would have been our target launch location if the equipment was available at the May 2019 experimental burn.

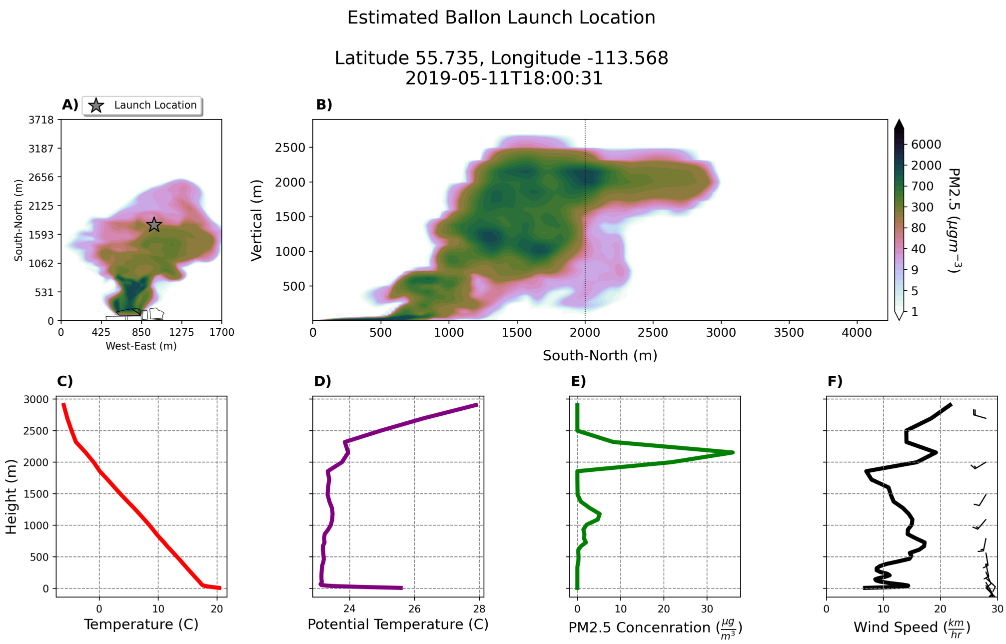

Figure 8. The preferred launch location for radiosonde or dropsonde with combined air quality sensor to make in-situ observations of the smoke plume. (**A**) Show the location of the proposed launch along with vertically integrated smoke at 18:00:31 (HH:MM:SS). (**B**) Crosswind integrated smoke plume at the same time as A with launch location marked as a dashed vertical line. Associated profile at launch location of (**C**) temperature, (**D**) Potential Temperature (**E**) PM2.5 Concentration Speed and Direction (**F**) Wind Speed and Direction.

Another important data set to be collected are the vertical profiles of the atmosphere both before, at, and after ignition. Accurate sounding datasets are needed to initialize models during detailed verification research [1,13]. The Windsond radiosonde sensor mentioned previously will also be utilized for this purpose. The sensors have distinct advantages over more conventional equipment since their size, weight, and cost, all are much less making them very useful for deployment in remote locations.

4.2. Model Configuration

As ~~mentioned~~ discussed in section 2.2, the lowest model level of 4 m was chosen ~~since it is was the closest level to the~~ based on the associated fuel (Anderson's category 6) mid-flame ~~height, based upon Anderson's fuel category 6.~~ height. The model's output compared well against the observed parameters (i.e., fire behavior, smoke emission, and dispersion, and coupled feedbacks) and most importantly captured fire behavior accurately ~~since it is very sensitive to small variations in the lower vertical grid~~. In developing our simulations we discovered that modeled fire behavior was particularly sensitive to this choice of near-surface vertical levels.

We conducted a sensitivity analysis by adjusting the ~~`z grd scale` values in the `namelist.input` and evaluated how hyperbolically stretched the vertical levels became. A range~~ hyperbolic vertical stretching factor. We tested the following values of `z grd scale` ~~values~~ parameter while leaving all other configuration settings constant: 1.6, 1.8 2.0, 2.2, 2.4~~were tested while leaving all other model inputs and configuration options constant~~.

Low `z grd scale` values resulted in relatively slow fire spread rates, lower emissions, and weakening coupled feedbacks. High ~~,~~ `z grd scale` values ~~resulted in numerical instabilityand run failure due to~~ generated numerical instability, resulting in violations of Courant–Friedrichs–Lewy (CFL) conditions~~. The vertical motion was too fast particularly in the low to mid levels which became more tightly packed due to excessive vertical stretching.~~

~~To overcome the CFL violation time step for integration was lowered which inevitability~~ and, hence, required reduced timesteps lengths and increased model run time~~As our objective was to run WRF-SFIRE as a forecast product this was not desirable and required further sensitivity testing of model resolution to model accuracy and run time. The resulting~~. Such simulation have limited utility as forecast products. Based on the results of the sensitivity study we determined the optimal configuration to be [ADD DESCRIPTION HERE]. Full details of the configuration can be found in supplementary ~~martial~~materials.

In the WRF-SFIRE model development manuscript, Mandel stresses that "*the fire model should use the wind speed taken from the level as close to the mid-flame height as possible. This requirement translates into a need for very high vertical resolution*" [6]. ~~This statement is incredibly important and something we want to reiterate.~~

Finally, we welcome the developers of WRF-SFIRE to implement crown fire modeling capabilities into the model. The majority of planned experimental burns at Pelican Mountain are intended crown fires. The Unit 5 burn was classified as a high-intensity crown fire, something we could not address in our modeling efforts. The dataset collected at Pelican Mountain could help with this implementation and verification.

5. Conclusions

~~Employing~~ In this work we demonstrate the feasibility of using WRF-SFIRE ~~, configured in LES mode,~~ as a forecasting ~~tool to predict fire behavior, smoke emissions, and dispersions of experimental burnsis achievable. We tested this by initializing the WRF-SFIRE-LES simulation with numerical weather prediction model forecast outputs—verifying the simulation to data observed at the~~ and planning tool for prescribed burns. We provide two case-study numerical simulations for 2019 Unit 5 Pelican Mountain experimental burn in central Alberta, Canada. Our results that [QUICK RECAP HERE.. like can predict peak smoke. Need accurate ignition. Need vertical levels etc]

We illustrated how our approach can be applied to further the knowledge gained at experimental burns and expand the critical dataset of the coupled fire-atmosphere interactions. By ensuring instruments are positioned to capture key parameters of interest, researchers can improve the quality of data collected and importantly lower the costs associated with working at remote experimental burn sites.

Supplementary Materials: The following are available at https://www.mdpi.com/article/10.3390/1010000/s1, Animation S1: South-North cross-section of smoke dispersion along the same longitude as sensor 303-100 with crosswind initgrated heat flux. The supporting animation and inital input condtions for WRF-SFIRE are available at doi: link.

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Data Availability Statement: In this section, please provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. Please refer to suggested Data Availability Statements in section "MDPI Research Data Policies" at https://www.mdpi.com/ethics. You might choose to exclude this statement if the study did not report any data.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

WRF	Weather Research Forecast
SFIRE	Surface Fire
LES	Large Eddy Simulation
AGL	Above Ground Level
PM	Particulate Matter
LD	Linear dichroism

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