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Predictive model comparison on a well-documented wildfire event in New Zealand

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Report information sheet

Report title	Predictive model comparison on a well-documented wildfire event in New Zealand
Authors	Wayne Schou, Ilze Pretorius, Samuel Aguilar-Arguello Scion
Client	Resilience to Nature's Challenges
Client contract number	QT-7986
PAD output number	64414936
ISBN Number	978-0-473-67580-6
Signed off by	Katerina Pihera-Ridge
Date	March, 2023
Confidentiality requirement	Confidential (for client use only)
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Published by: Scion, Private Bag 3020, Rotorua 3046, New Zealand. www.scionresearch.com

FRONT IMAGE: DURING THE INITIAL RESPONSE, SUPPLIED BY GRANT HAYWOODS, FIRE AND EMERGENCY NZ.

Executive summary

Introduction

We modelled five scenarios to test the effect of different weather, ignition, grass curing and fuels inputs on the Prometheus fire growth model's performance. The well-documented Pigeon Valley Forest fire of February 2019 was used as a case study.

Methods

The scenarios tested were as follows:

Run 1: Represents a real-time/automated operational run, making use of the first available data right at the start of the fire event. Because this is an automated operational run, all data is either obtained automatically or is set to predefined values.

- Ignitions: Obtained from the near-real-time (NRT) fire detection data products from three satellite systems (MODIS – Aqua and Terra, SUOMI VIIRS, NOAA-20 VIIRS). These satellites traverse New Zealand (NZ) twice a day. MODIS hotspot locations are accurate to 1km, and SUOMI and NOAA 20 are accurate to 375m. Nineteen hotspots were captured by the satellites between the times of 14:18 and 15:00 NZDT on the 5th February 2019.
- Meteorology: Dovedale Remote Automatic Weather Stations (RAWS) hourly observed weather. The Dovedale station was situated 4 km away from the area of origin, and 2 km away from the fire's final extent.
- Grass Curing: A value of 70% was used, retrieved from the Dovedale RAWS met station.
- Fuel types: Default fuel types from the NZ Land Cover Database version 5 (LCDB5) produced for the year 2018/2019.

Run 2: Modified version of Run 1 replacing ignitions with the single actual point of ignition [-41.366190°, 173.019064°]

Run 3: Modified version of Run 2 replacing the weather source with 49 virtual weather stations from NIWA's New Zealand Convective Scale Model (NZCSM) with a 1.5 km horizontal grid resolution

Run 4: Modified version of Run 3 replacing the grass curing value with 90%, believed to be a more accurate representation of conditions during the fire.

Run 5: Modified version of Run 4 adding fuel type patches representative of actual fuel types observed during the fire not accurately represented in the LCDB5.

Results

As expected, scenarios making use of ignition, grass curing and fuels data based on actual fire conditions produced more accurate results than scenarios making use of satellite detects for ignition points, a grass curing value recorded for the closest RAWS (these values are infrequently updated and often out of date) and fuels data from the NZ LCDB version 5.

Scenarios making use of NIWA NZCSM gridded meteorological data at a 1.5 km horizontal spacing produced more accurate spread rates, compared to scenarios making use of meteorological data from the closest RAWS to the fire (approximately 4 km from the area of origin). The reason for this is that the gridded data likely captures the effect of the complex topography on weather inputs more accurately than a single station situated a distance away.

Predictive model comparison on a well-documented wildfire event in New Zealand

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Glossary

Aspect – The direction a slope is facing; its exposure in relation to the sun (e.g. north, east, south, west) (CIFFC, 2003)

Canadian Forest Fire Danger Rating System – (CFFDRS) - The national system of rating fire danger in Canada; referred to as the Canadian Forest Fire Behaviour or Behaviour Rating System before 1976. The CFFDRS includes all guides to the evaluation of fire danger and the prediction of fire behaviour such as the Canadian Forest Fire weather Index System and Canadian Forest Fire Behaviour Prediction System (CIFFC, 2003).

Crown fire - A fire that advances through the crown fuel layer, usually in conjunction with the surface fire (CIFFC, 2003).

Cutover – forested land that has been completely harvested. Debris: the accumulation of remains, including vegetation and soil, from forestry operations (environment.govt.nz 2023)

Extreme Fire Behaviour - A level of fire behaviour that often precludes any fire suppression action. It usually involves one or more of the following characteristics: high rate of spread and frontal fire intensity, crowning, prolific spotting, presence of large fire whirls, and a well-established convection column. Fires exhibiting such phenomena often behave in an erratic, sometimes dangerous, manner (CIFFC, 2003).

Fire Behaviour Prediction – or Canadian Forest Fire Behaviour Prediction (FBP) System - A subsystem of the Canadian Forest Fire Danger Rating System. The FBP System provides quantitative outputs of selected fire behaviour characteristics for certain major Canadian fuel types and topographic situations. For example, head fire rate of spread, which can be adjusted for the mechanical effects of slope, is expressed in metres per minute (m/min). The system depends partly on the Canadian Forest Fire Weather Index System components as inputs (CIFFC, 2003).

Fire intensity - The rate at which a fire releases energy in the form of heat at a given location and at a specific point in time, expressed as kilowatts per metre (kW/m) or kilojoules per meter per second (kJ) (The Scottish Government 2013).

Fire perimeter - The entire outer edge boundary of a fire. Recommended SI units are metres (m) or kilometres (km) (1000 m is equivalent to 1.0 km) (CIFFC, 2003).

Fire suppression - All activities concerned with controlling and extinguishing a fire following its detection (CIFFC, 2003).

Fire Weather Index - The FWI System consists of six components. The first three are fuel moisture codes that follow daily changes in the moisture contents of three classes of forest fuel; higher values represent lower moisture contents and hence greater flammability. The final three components are fire behaviour indexes (CIFFC, 2003).

Grass curing - “the proportion of cured and/or dead material in a grassland fuel complex expressed as a percentage (%) of the total” (Alexander 1994), and is used in recognition of the significant effect grass curing has on fire behaviour and, in particular, potential fire spread (Pearce et al. 2003).

Hotspot - A small area of smouldering or glowing combustion, which may be exhibiting smoke, located on or within the fire perimeter; a term commonly used during the mop-up stage of a fire. Synonym (CIFFC, 2003).

Ignition - The beginning of flame production or smouldering combustion; the starting of a fire (CIFFC, 2003).

Ladder Fuels - Fuels that provide vertical continuity between the surface fuels and crown fuels in a forest stand, thus contributing to the ease of torching and crowning (e.g. tall shrubs, small-sized trees, bark flakes, tree lichens) (CIFFC, 2003).

Mop-up - The act of extinguishing a fire after it has been brought under control (CIFFC, 2003).

Native forest - Forest that is made up of native tree species, and is either primary (have never been clear-cut) or secondary (regenerating naturally) (ipbes.net 2023).

NZ Fire Registry - an online public information and planning resource that supports operational decision-making for wildfires and prescribed burning. Available at (https://www.ruralfireresearch.co.nz/tools/fire-registry)

Rate of Spread - (ROS) - The speed at which a fire extends its horizontal dimensions, expressed in terms of distance per unit of time. Generally thought of in
terms of a fire's forward movement or head fire rate of spread, but also applicable to backfire and flank fire ROS. Recommended SI units are metres per minute (m/min) and kilometres per hour (km/h) (1.0 m/min is equivalent to 0.06 km/h)) (CIFFC, 2003).

Skid site - an area of land in the forest, often specially prepared and surfaced, where logs or tree lengths extracted from the forest are accumulated, processed and loaded onto trucks for removals. Also referred to as a landing (environment.govt.nz 2023).

Spot fires – Fires ignited by firebrands that are carried outside the main fire perimeter by air currents, gravity, and/or fire whirls (CIFFC, 2003).

Wildfire - “Any uncontrolled vegetation fire which requires a decision, or action, regarding suppression.” (The Scottish Government 2013).

Introduction

The aim of this study is to test the effect of different weather, ignition, grass curing and fuels inputs on the Prometheus fire growth model’s (Tymstra et al. 2010) performance. The well-documented Pigeon Valley Forest fire of February 2019 was used as a case study.

The Prometheus software (Tymstra et al. 2010) can be used to simulate fire growth and behaviour (eg. intensity, rate of spread) over time. The foundations of the Prometheus model are the Fire Weather Index (FWI) and the Fire Behaviour Prediction (FBP) Sub-Systems of the Canadian Forest Fire Danger Rating System (CFFDRS) (Van Wagner 1987, Forestry Canada Fire Danger Group 1992). The Prometheus model is highly sensitive to input data, which is often unavailable or unknown during a fire event. It is therefore important to understand the impact of different input types on simulations, in preparation for operational usage of the model.

The Pigeon Valley Fire

The Pigeon Valley fire occurred within the Tasman District (population ~15,000), which is in the northwestern end of the South Island of NZ (Clifford 2019). Ignition started around 2pm on 5th of February 2019 in Pigeon Valley near Nelson and spread quickly from farmland into forested lands (Dudfield et al. 2020). Communities at threat were Pigeon Valley, Wakefield, Brightwater, Redwood Valley, Golden Hills, Teapot Valley, Eves Valley and Sunshine Valley (Clifford 2019). Despite the fast involvement of firefighters after ignition (~20 mins after ignition) the extreme fire weather conditions favoured the fire progression up to day 3 (Clifford 2019), in which weather conditions finally permitted for significant fire suppression. On the first day alone, the fire burnt 1,600 ha (Figure 1).

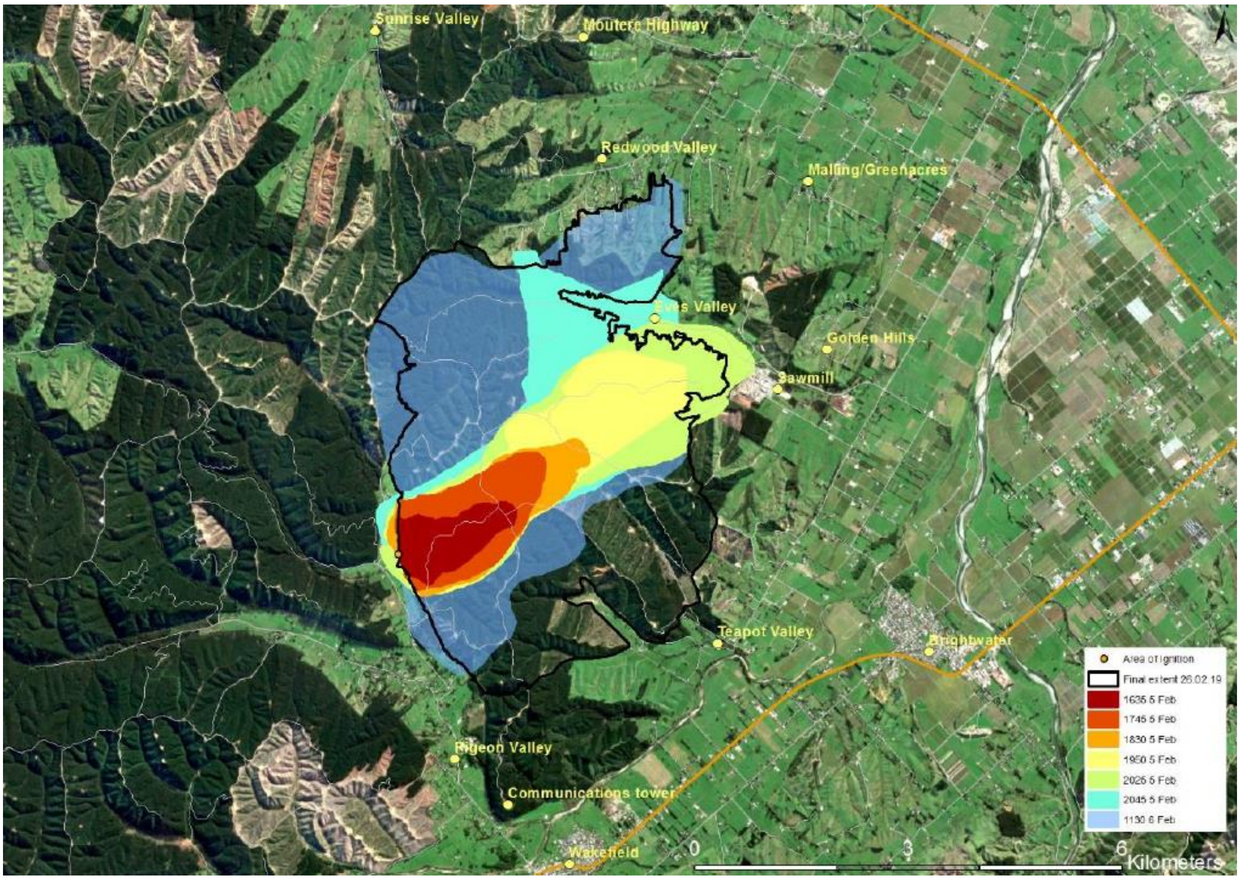

Figure 1: Estimated progression of the Pigeon Valley fire on the first and second days. The final estimated perimeter is outlined in black (retrieved from Clifford 2019).

Observed Fire Environment

Topography

The Tasman District borders the West Coast, Canterbury, Marlborough and Nelson Regions. The landscape is diverse, ranging from mountainous areas to valleys and plains. The terrain is regarded as rolling hill country, where the hills are drained by numerous valleys with flat alluvial floors. Most of this area is used for pastoral farming, forestry, horticulture and residential settlements. The area of origin was located on flat farmland in Pigeon Valley (latitude: -41.365°; longitude: 173.018°) and the bulk of the fire area covered forested hilly terrain (Clifford 2019).

The topography of the fire area can be characterised as undulating, with moderate to steep slopes. Elevation of the forested area ranged from 100 to 280 m above sea level. Elevation ranged from 50 to 140 m in the surrounding open grasslands. Slope steepness for the first day's fire runs within the forested compartments ranged from 2 to 30 degrees (uphill) and -6 to -21 degrees (downhill) (Figure 2) (Clifford 2019).

Figure 2: A photo of the area of origin (red circle) in open grassland, adjacent steep slope, and forestry compartments (retrieved from Clifford 2019).

Fuels

Significant factors that contributed to the fire's propagation were the types of fuel present, and the extreme dryness of these fuels. The vegetation types within the area of the Pigeon Valley fire can be divided into three main fuel types (Figure 3): (1) forestry plantation of various stages (including cutover, skid, and bark sites); (2) native forest; and (3) grassland (Clifford 2019).

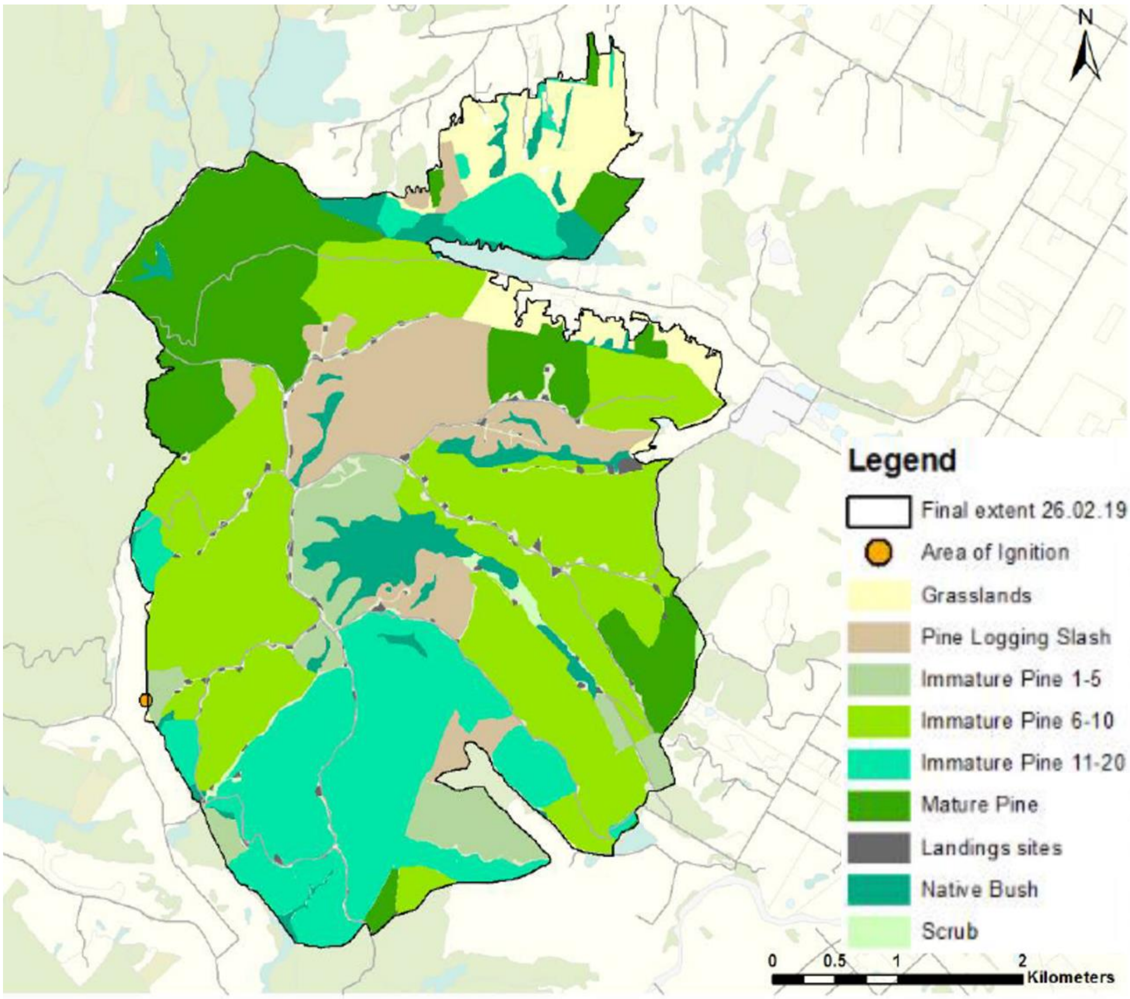

Figure 3: Fuels distribution within the Pigeon Valley fire final perimeter. Data sourced from Tasman Pine Forest Ltd. Image adapted from Clifford 2019.

Pine Logging slash

In the Nelson-Tasman regions the main process for harvesting of radiata forests is the whole-tree harvesting (WTH) process, which extracts trees to a processing area (landing sites) where they are delimbed and cut into logs, resulting in significant amounts of woody material accumulating at landing sites. The slash/cut-over compartments are desiccated before planting to kill off any regenerating weeds and gorse. However, gorse and other weeds begin to reappear in cut-over areas a year or two after planting. Therefore, the forest cut-over areas also contained flammable weeds and high volumes of light, medium and heavy woody materials that were very dry (Clifford 2019).

On the other hand, there were numerous landing sites with high volumes of wood waste discarded and buried off the edge. Over decades, bark waste from the nearby sawmill had been buried in the forest. These areas consisted of 3 m layers capped by a 0.5 m layer of clay between each of the layers. Forest was planted on top of these in some areas and facilitated the fire burning down deep underground and smouldering for more than a month after ignition (Clifford 2019).

Immature pine, age 1-4 (1st, 2nd and 3rd rotation); & Immature pine, age 5 - 10

The young forests were typically second or third rotation commercial forestry. By the age of 3 years, much of the younger stands were overwhelmed by a thick continuous gorse understory. The highly flammable gorse fuel that was present was a main contributor to the severe fire behaviour and spread of the fire (Clifford 2019).

Immature Pine, age 11- 20; & Mature pine, age 20+

After canopy closure, a layer of dead needles is suspended on the lower branches, providing ladder fuels to link the surface and crown fuel layers. The dry, elevated fuel loads contribute to easy fire ignition and spread, and to high fire intensities including crown fires that are very difficult, if not impossible to control, especially in steeper terrain. These stands were typically un-pruned, and thinnings around waist deep on the ground, which increased the fuel loading. These areas also have litter (1 cm deep) and organic duff layers (2-4 cm deep). The canopy closure resulted in the gradual death and decay of the gorse scrub understory. The understory vegetation also varied depending on the silviculture regime (Clifford 2019).

Some areas had trial “millennium stands”, where the trees were not pruned or thinned and had high stocking rates. These were thick stands with the presence of dead fine needles elevated on the branches (Clifford 2019).

Native forest

There were several pockets of native forest involved in the fire. Typically, native forests are found in the gullies or valleys within the forestry blocks as small pockets of remnant forest. These forests are representatives of lowland native forests of mixed beech (silver and black) and podocarps, with matai, rimu, totara, miro and other broadleaf species (fuchsia, five-finger, broadleaf and marble leaf). The understory was more open with small-leaved shrubs (coprosmas), vines, ferns and regenerating seedlings of the forest trees. The ground cover was typically sparse of vegetation and had a continuous cover of litter (Clifford 2019).

These native areas are generally characterised by low flammability fuels that are a mix of tall beech and podocarp trees (averaging 20 m tall) with an understory of litter, moss, bark, punky tree stumps, ferns and small shrubs. Field observations showed that the presence of low flammability vegetation types did slow or halt the head of the fire initially, but continued smouldering. However, these areas were not wide enough to stop the spread from spot fires (Clifford 2019).

Grasslands

Grasslands were typically situated outside of the forest estate on the lower elevations and flatter slopes. These grass fuels were very dry and fully cured (dead), as the region was experiencing drought at the time. As a result, any source of ignition in these grass fuels would result in easy ignition and rapid development of a fire. Embers generated from a burning forest could also easily ignite new spot fires in these fine, flashy grass fuels (Clifford 2019).

The fire was initially ignited in 90-100% cured grass, making it extremely easy to ignite and for a fire to develop quickly. The grass fire travelled 2 m in partially grazed grass and weeds, then 7 m into long rank grass before encountering a 15-degree slope into forestry fuels. The heights of the grass fuels varied, ranging between 2 – 20 cm tall. These areas were typically grazed and kept short (Clifford 2019).

Weather

The 2018/2019 year was not typical for this region. It began with a cool wet winter, followed by below average rainfall for spring, and by early summer conditions continued to dry out rapidly. Monthly rainfalls for December were about average; however, rainfall for January and February were significantly below the average at all stations investigated. As a result, the region was facing its worst drought since 2001, and water restrictions were imposed to conserve water. A short dry spell of around 20 days occurred at most rainfall stations during late January and early February 2019, in which little or no rainfall was recorded (Clifford 2019).

The summer was hot for much of the country, with a warm Tasman Sea transporting warm air over NZ. January was characterised by frequent high pressure. Well above normal temperatures across NZ were a regular occurrence, with a significant 5-day heat wave ending the month. January was also a very sunny month, with Richmond setting a record for monthly sunshine hours in the South Island. The combination of a dry spell and a heat wave resulted in significant soil moisture deficits for the top of the South Island, with the driest soils across the island at the time the fire began present in the Nelson and Tasman districts (Clifford 2019).

The nearest and most representative weather station to the fire site was the Dovedale RAWS (4 km away from the area of origin, and 2 km away from the fire’s final extent). Over the 2018/2019 fire season, few significant rainfall events occurred. The last significant amount of rain that fell was on 26 December (5.4 mm). As a result, fine, medium, and heavy fuels progressively dried out leading up to the fire start. The day the fire broke out, only 0.6 mm of rain were reported in the morning at Dovedale RAWS. The next major rain events occurred on the 24th of February and 8th of March. Further decent amounts of rain fell on the dates 9th, 12th, 13th, 14th, 27th, and 31st of March which aided in the fire's mop-up, significantly reduced any remaining hotspots along with a reduction in the fire weather codes and indices.

Based solely on weather observations, the Fire Weather Index System (FWI System) provides numerical ratings of relative ignition and fire behaviour potential which are used to guide fire management activities (Stocks *et al.* 1989). The FWI System's components individually and collectively account for the effects of fuel moisture and wind on ignition potential. The three fuel moisture codes represent a value of moisture content in surface litter (Fine Fuel Moisture Code), loosely compacted duff of moderate depth (Duff Moisture Code) and deep compact organic matter (Drought Code). On the other hand, the Initial Spread Index (ISI) and Buildup Index (BUI) components of the FWI System are used to determine Forest fire danger (Anderson 2005). Based on these Indices, Fire Danger Class criteria are determined for Forest, Scrubland and Grassland vegetation.

Table 2. Recorded variables from Dovedale RAWS weather station. RH = Relative Humidity, FFMC = Fine Fuel Moisture Code, DMC = Duff Moisture Code, DC = Drought Code, ISI = Initial Spread Index, BUI = Buildup Index, FWI = Fire Weather Index, FDC = Fire Danger Class (from Clifford 2019).

	Daily values for 5th Feb	**Hourly values for 2pm, 5th Feb**
Temp	15.2 - 26.4ºC	25.8 ºC
RH	33 – 72%	34%
Wind Speed	4.7 - 24.1 km/h	16.9 km/h
Wind Direction	S - W - S	250 (WSW)
FFMC	90.7	88.0
DMC	95	
DC	451	
ISI	11.4	7.5
BUI	125	
FWI	37.8	28.6
Forest FDC	Extreme	
Grass FDC	Very High	
Scrub FDC	Extreme	

Materials and methods

Fire Growth Model

We use the Canadian operational wildland fire growth model Prometheus (Tymstra et al. 2010) to test different models for simulations of the Pigeon Valley Fire. Prometheus was developed to predict fire growth for near real-time operational decision support and to assess the effectiveness of various fuel management strategies (Tymstra et al. 2010). It computes spatially explicit, deterministic fire spread and behaviour using topography (slope, aspect, and elevation), fuel, and weather data as inputs. Fire perimeters are produced in time and space based on Huygen's principle of wave propagation (Seto et al. 2022).

Prometheus was selected for this study as it is commonly used as a tool to predict fire behaviour in New Zealand by fire authorities. It was used by the Incident Management Team during the Pigeon Valley fire and during the mop-up and re-entry phases. Prometheus, which is underpinned by the Canadian Forest Fire Behaviour Prediction (FBP) System (FCFDG 1992, Wotton et al. 2009), is largely based on field experiments and high-intensity wildfire observations. Prometheus accounts for the effect of short-range spotting and breaching of non-fuel areas (lakes, rivers, roads, and fuel breaks) based on the relationship between fire intensity and flame length (Byram 1959).

The simulations in this study were undertaken for the first 8 hours after ignition (day 1) for which a sequence of observed fire growth perimeters (obtained from helicopter flyovers) were available.

Weather data input

Two sources of weather information were used:

1. Data from the nearest RAWS at Dovedale (obtained from the NIWA Fire weather system). Actual hourly observed meteorology (Temperature, Relative Humidity, Wind Speed, Wind Direction, and Precipitation) was used together with the previous day (4 February 2019) fire weather daily starting codes (also obtained from the NIWA fire weather system) needed for Prometheus to calculate hourly fire weather indices.
   NIWA's New Zealand Convective Scale Model (NZCSM) produced at a 1.5 horizontal grid (Pirooz et al. 2023).
2. To use this data in Prometheus, the values from the 49 cells (in a 7x7 arrangement) closest to the fire location were extracted and introduced to the Prometheus software as 49 distinct weather stations, each with their own location and hourly weather stream. NZCSM weather does not include estimates of the fire weather indices, starting codes were retrieved from the Dovedale weather station and used for all virtual weather stations.

Landscape data input

Prometheus requires gridded elevation and fuel type landscape input data:

Elevation data

Elevation data was obtained from 25-metre resolution digital elevation model data produced by Landcare Research New Zealand (2011) (retrieved from: https://doi.org/10.26060/6AS4-4Z82 and https://doi.org/10.7931/L1R94). The same elevation data was used for all simulations.

Land Cover data

The Landcare New Zealand Land Cover Database version 5.0 (LCDB5) data for 2018/2019 was used as fuel type input (https://doi.org/10.26060/W5B4-WK93). The LCDB5 vector data was converted to a 25-metre resolution grid using the Python computer language and the gdal package (GDAL/OGR contributors 2022). LCDB5 Vegetation classes were mapped to their closest equivalent fuel types.

Manual land cover/fuels data

All but one of the simulations used LCDB5 data as the underlying fuel type layer. The final simulation (Run 5) applied fuel type patches to modify the fuel type in specific areas to more accurate fuel types observed during the fire (see below in Section "Model Evaluation and Experiments" for a description of Runs 1 – 5).

Tasman Pine Forest Ltd, provided accurate land cover data for the time of the fire in their forestry inventory data map (see Figure 3). This differed from the out-dated LCDB5 land cover (see the difference in fuels data used for Runs 1-4 versus Run 5 in Figure 4).

There are several methods available in Prometheus to adjust fuel types. This includes replacing all fuels of a given type with another, identifying areas using polygons that should be replaced with alternative fuel types, and altering the parameters of a fuel type to change its modelled behaviour. In Run 5, the following modifications were applied:

- Relevant areas, as defined in the forestry inventory data map (Figure 2), were manually mapped using ArcGIS.
- These polygons were imported into Run 5 as fuel patches with the following mappings used:
    - Pine Logging Slash > Harvested
    - Immature Pine 1-5 > Mixed Exotic Shrubland (Default settings: 145% foliar moisture, crown base height 4 m, tree height 10 m, fuel load 1.2 kg/m2)
    - Immature Pine 6-10 > Pine Forest – Closed Canopy (Default settings: 145% Foliar moisture, 7 m crown base height, 14 m tree height, 1.8 km/m2 fuel load)
    - Immature Pine 11-20 > Pine Forest – Closed Canopy (Default settings)
    - Mature Pine > Exotic Forest (Default settings: 145% Foliar moisture, 7 m crown base height, 14 m tree height, 1.8 km/m2 fuel load)
    - Native Bush > Indigenous Forest

The decision was made to use Pine Forest – Closed Canopy (which has the same model parameter settings as Exotic Forest) for all forested areas aged 6 years as it was noted by Clifford (2019) that mature forest fuel types were the most appropriate match for the observed fire behaviour. For forested areas less than 6 years an exotic shrub model was selected.

Model Evaluation and Experiments

The model performance was verified by comparing with the observed/actual Pigeon Valley Fire growth perimeters determined from helicopter flyovers for 16:35, 17:45. 18:30, 19:50, 20:25, 20:45, 21:39 NZDT. Model performance was also evaluated against observations of fire Rate of Spread (ROS), intensity and flame length.

Five simulations were conducted, each with different inputs for ignitions, weather, fuels and grass curing. The scenarios run are as follows:

Run 1: Represents a real-time/automated operational run, making use of the first available data right at the start of the fire event. Because this is an automated operational run, all data is either obtained automatically or is set to predefined values.

- Ignitions: Obtained from the near-real-time (NRT) fire detection data products from three satellite systems (MODIS – Aqua and Terra, SUOMI VIIRS, NOAA-20 VIIRS). These satellites traverse New Zealand (NZ) twice a day. MODIS hotspot locations are accurate to 1 km, and SUOMI and NOAA 20 are accurate to 375 m. Nineteen hotspots were captured by the satellites between the times of 14:18 and 15:00 NZDT on the 5th February 2019.
- Meteorology: Dovedale Remote Automatic Weather Stations (RAWS) hourly observed weather. The Dovedale station was situated 4 km away from the area of origin, and 2 km away from the fire's final extent.
- Grass Curing: A value of 70% was used, retrieved from the Dovedale RAWS met station.
- Fuel types: Default fuel types from the New Zealand Land Cover Database version 5 (LCDB5) produced for the year 2018/2019.

Run 2: Modified version of Run 1 replacing ignitions with the single actual point of ignition [-41.366190°, 173.019064°]

Run 3: Modified version of Run 2 replacing the weather source with 49 virtual weather stations from NIWA's NZ Regional Climate Model (NZRCM) with a 1.5 km horizontal grid resolution.

Run 4: Modified version of Run 3 replacing the grass curing value with 90%, believed to be a more accurate representation of conditions during the fire.

Run 5: Modified version of Run 4 adding fuel type patches representative of actual fuel types observed during the fire not accurately represented in the LCDB5.

All scenarios were started at an assumed ignition time of 14:00 New Zealand Daylight Time (NZDT) on 5th of February 2019 and were allowed to run for 8 hours until 22:00 NZDT. Table 3 Summary of simulations conducted in this study.

Simulation ID	Ignition	Weather	Grass Curing	Fuel Type
Run 1	NRT	Dovedale RAWS	70%	Default
Run 2	**Single Point**	Dovedale RAWS	70%	Default
Run 3	**Single Point**	**NZCSM**	70%	Default
Run 4	**Single Point**	**NZCSM**	**90%**	Default
Run 5	**Single Point**	**NZCSM**	**90%**	**Patches**

Results and discussion

Scenario comparison

For each simulation (Run 1 – Run 5) hourly modelled perimeters for the first 8 hours (14:00 to 22:00 NZDT time) of fire growth was plotted and compared to the observed 21:39 NZDT perimeter (Figure 4). A summary of model results is given below:

Run 1: This run's results are strongly influenced by the locations of ignition points obtained from NRT satellite fire detections. Nineteen fire detections, or 'hotspots' were captured by the various satellites between 14:18 and 15:00 NZDT on 5th February 2019, all depicted as magenta dots in Figure 4. Three fire detections were outside of the actual fire perimeter, an indication of the spatial inaccuracy that is possible with this source of input data. These detections caused the fire growth model to result in fire growth extending south of the actual fire.

Overall, modelled fire growth rates were slower than the actual growth rates. This was most probably a result of the input meteorological data from the Dovedale RAWS hourly observed weather, situated 4 km away from the area of origin, and 2 km away from the fire's final extent (depicted as a yellow triangle - Figure 4).

This run is representative of the current input data used by the automated New Zealand Fire Registry system (https://www.ruralfireresearch.co.nz/tools/fire-registry). The aim of the system is to provide a first guess of fire growth conditions, before detailed information on the fire (such as the true ignition point(s)) can be obtained. This run illustrates that while using satellite detects as a proxy for ignition points is probably sufficient as a first guess, the fire growth modelling can be significantly improved by including more accurate input data (see Runs 3-5).

Run 2: This run made use of the actual point of ignition of the fire, and meteorological input from the Dovedale RAWS hourly observed weather (like the meteorological input used for Run 1). Modelled fire growth rates were slower than the actual growth rates, most probably due to inaccuracies in the input meteorological data, similar to Run 1.

Run 3: This run illustrates the improvement in fire growth modelling when meteorological input data more representative of actual conditions is used. This run made use of gridded meteorological data from the NZRCM model, 49 input points, spaced 1.5 km apart (depicted as blue squares in Figure 4). The gridded meteorological data likely captured the variable meteorological (especially wind speed and directions) conditions in the complex topography of the fire area (Figure 2) more accurately than the single Dovedale RAWS situated 4 km to the northwest of the area of origin. The fire growth rates from this run are closer to actual rates, however, modelled fire growth is to the south of the actual fire growth.

Run 4: This run is similar to Run 3, but with a grass curing value of 90%, believed to be a better representation of actual conditions, instead of 70% obtained from the Dovedale RAWS and used in Runs 1-3 (this is the grass curing value that is representative of the broader area that station covers, often these values are not frequently updates and they may be out of date). Overall growth rates do not differ significantly from Run 3, since the increased grass curing value only influences fire growth in grass fuels located in small patches at the point of ignition and at the northern edge of the fire growth (light green colouring - Figure 4).

Run 5: Represents the increased in modelled fire growth accuracy obtained by making use of meteorological and fuels input data that are representative of actual conditions during the fire. This run is like Run 4 but makes use of fuel type patches representative of actual fuel types present during the fire not accurately represented in the LCDB5. The combination of improved meteorological input data (making use of the NIWA NZRCM model data), and representative fuels (provided by Tasman Pine Forest Ltd - Figure 3) led to an improvement in accuracy of the fire growth modelling compared to actual perimeters. It is important to note that fire growth modelling did not take account of any fire suppression activities and therefore the modelled perimeters extending beyond the actual perimeter (red versus blue lines - Run 5, Figure 4) is expected. Between 3 and 5 helicopters were conducting an aerial attack (water dumped by monsoon buckets) between approximately 15:33 and 19:00 NZDT on 5 February 2019.

Fire modelling also doesn’t take account of fire spotting, which can cause the fire growth to spread/enlarge quicker or have a different shape to a modelled fire. Spotting was anecdotally observed during the fire.

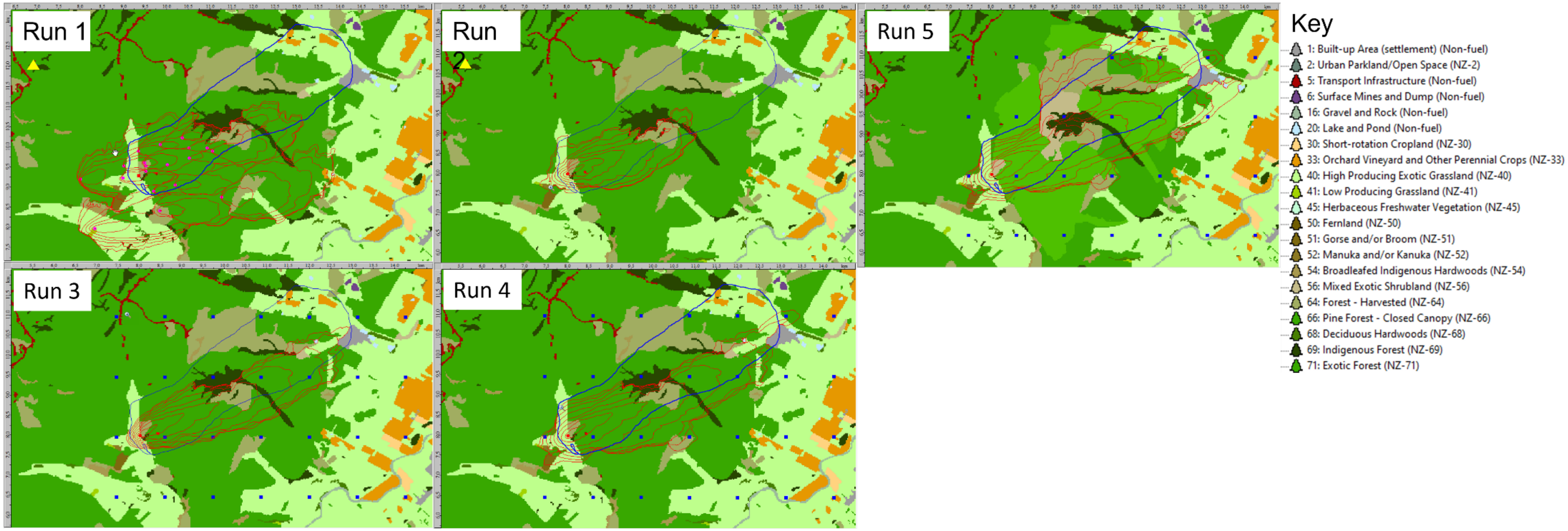

Figure 4: Fire growth simulations, Runs 1 to 5. Actual Fire Perimeter Estimate as at 21:39 NZDT indicated in blue, Prometheus hourly perimeters (5/2/2019 14:00 –22:00 NZDT) indicated in red, Satellite hotspots are depicted as magenta dots, the Dovedale weather station is indicated as a yellow triangle, the true point of ignition shown as a red square, the virtual weather stations from the NZCSM gridded meteorological data is depicted as blue squares. Modelled fuel types are shown in the background and were obtained from the LCDB5 for Runs 1-4 and from data provided by Tasman Pine Forest Ltd for Run 5.

Run 5: Rate of spread, flame length and intensity

Run 5 was the most representative of the modelled scenarios (Figure 4) and comparisons between modelled and observed Rates of Spread (ROS), fire Intensity and flame lengths can be made to further assess the performance of this simulation.

Rate of spread

Observed rates of spread on 5 February 2019, the first day of the Pigeon Valley fire, published by Clifford 2019, were compared to modelled results:

- **Observation:** The maximum ROS occurred in the initial upslope run as the fire entered the forest soon after its ignition. This was estimated at 2443 m/h on the 15-degree slope in young (1-4 y.o.) pines.
  Model: The high ROS soon after ignition is evident in the model results (indicated by a black circle in Figure 5), however, this was not the highest ROS modelled on this day. Higher ROS are indicated by pockets of yellow and red in Figure 5 and the highest modelled value was 4773 m/h.
- **Observation:** Following this, the fire was observed to spread at rates between 474 - 752 m/h in a range of forest fuel types, predominantly in young (1-4 y.o.) and immature (5-10 y.o.) pines.
  Model: The model was able to reproduce this observation (see grey rectangle, Figure 6).

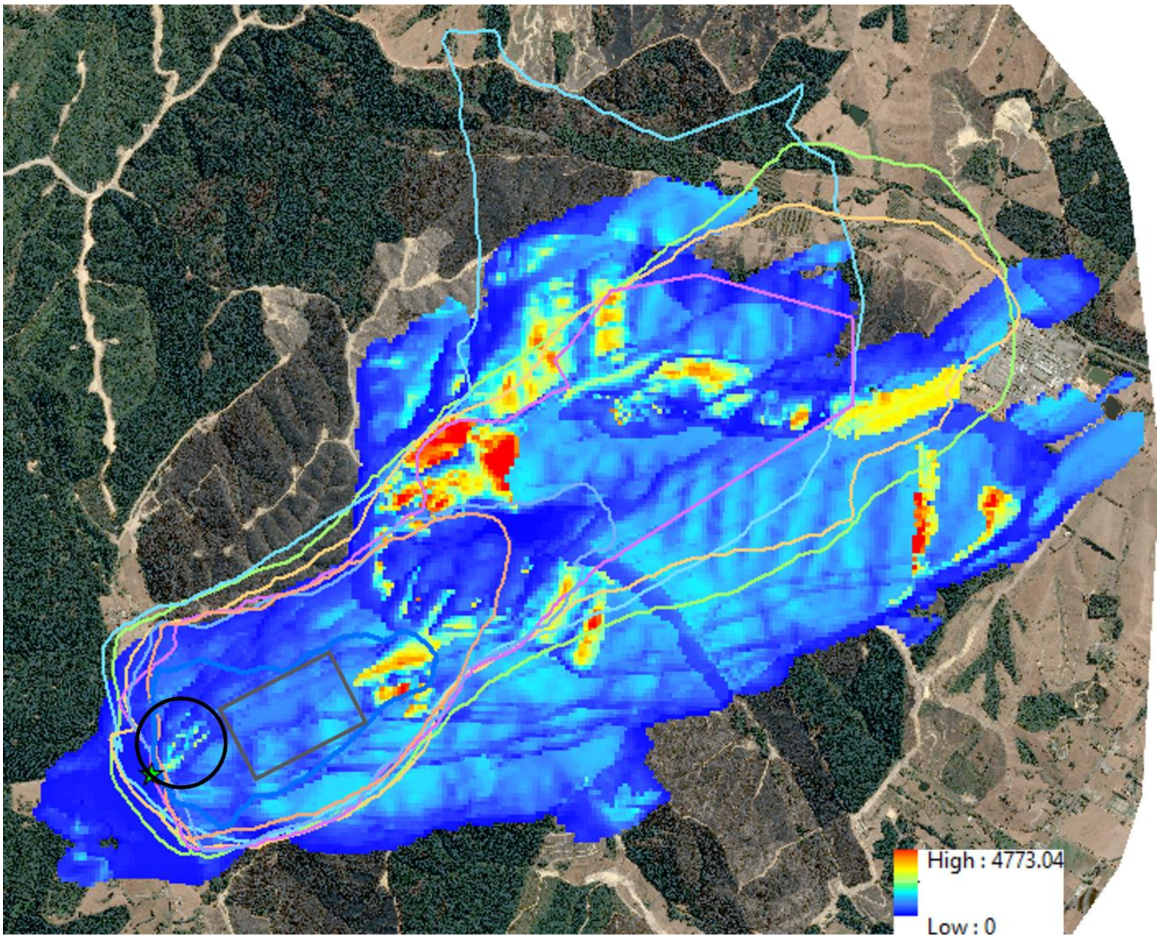

Figure 5: Run 5 modelled Rate of Spread (ROS) (m/h) shown in solid colours ranging from blue (low values) to red (high values). The actual/observed hourly fire perimeters (lines) between 16:30 and 21:40 are shown for spatial context.

Intensity and flame lengths

Observed rates of spread on 5 February 2019, the first day of the Pigeon Valley fire, published by Clifford 2019, were compared to modelled results:

- **Observation:** The initial upslope run through young (1-4 y.o.) pines, with the fastest observed spread rates, also had the highest fire intensities. These were in the order of 44,000–65,000 kW/m, which would readily produce crowning and flame lengths of around 10–13 m.
  Model: Model results are generally within the same ranges except for pockets where flame length as high as 35 m were predicted (grey boxes, Figures 6 and 7).
- **Observation:** With its relatively consistent observed spread rates, the main fire run is estimated to have had an average fire intensity of around 17,700 kW/m (range 8,300–33,000 kW/m, depending predominantly on fuel type), which would result in flame lengths of 7 m (4.9–9.3 m), however, these are lower than those observed on occasions during this period, which were reported to be more like 20–30 m. Such flame lengths would equate to potential head fire intensities more than 150,000 kW/m.
  Model: Modelled results are within the same ranges (black ellipses, Figures 6 and 7). The maximum modelled fire intensity was 553,000 kW/m and maximum modelled flame length was 35 m.

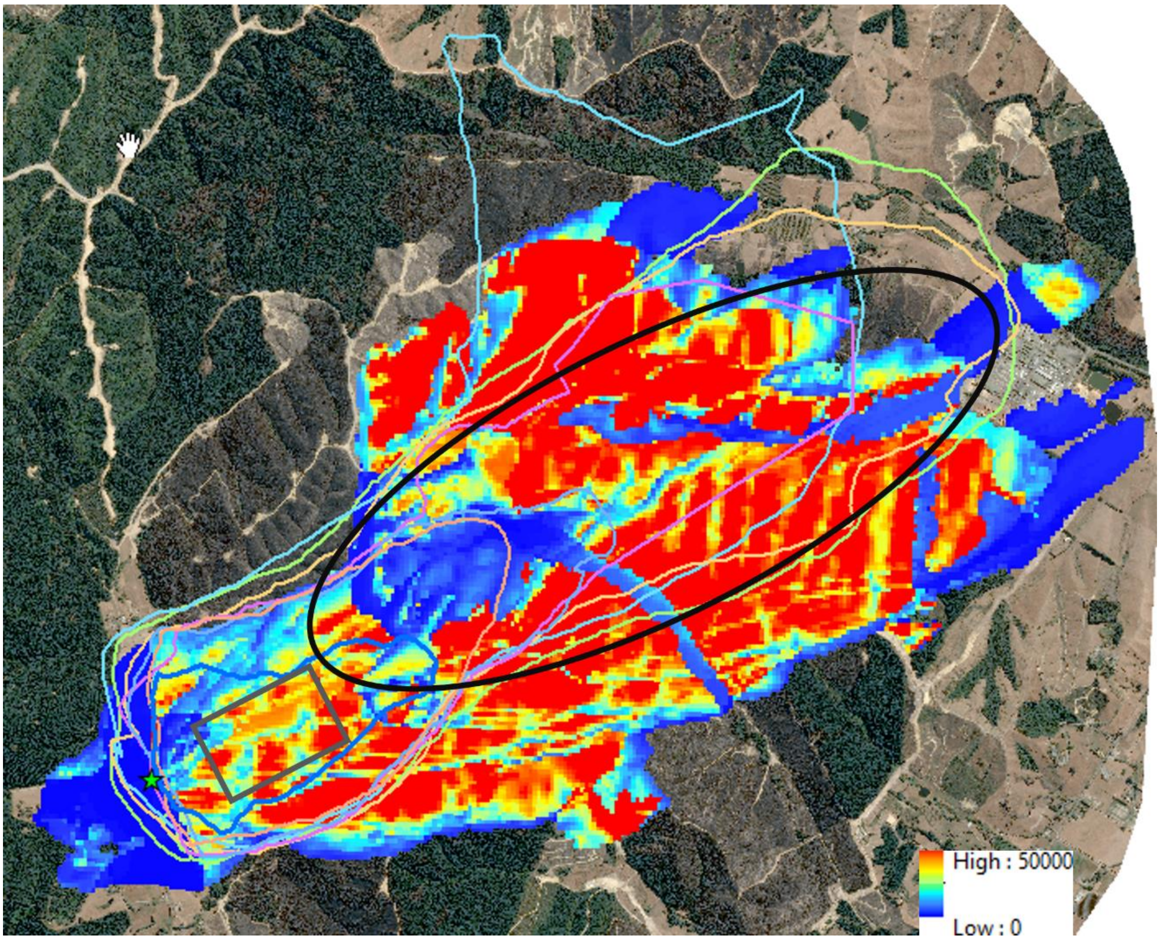

Figure 7: Run 5 modelled fire intensity (kW/m) shown in colours ranging from blue (low values) to red (high values). The actual/observed hourly fire perimeters between 16:30 and 21:40 are shown for spatial context.

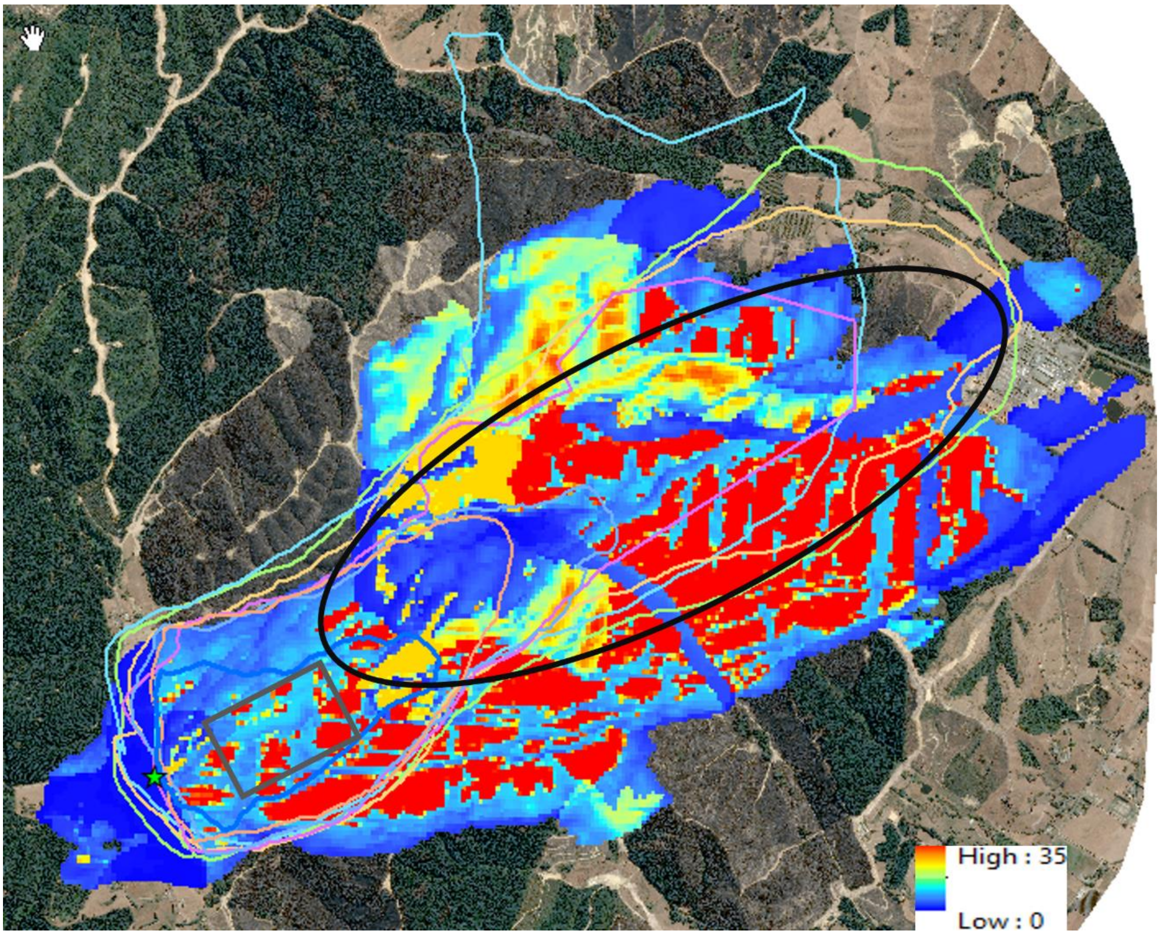

Figure 6: Run 5 modelled flame lengths (m) shown in solid colours ranging from blue (low values) to red (high values). The actual/observed hourly fire perimeters (lines) between 16:30 and 21:40 are shown for spatial context.

Recommendations and conclusions

We modelled five scenarios to test the effect of different weather, ignition, grass curing and fuels inputs on the Prometheus fire growth model's performance. The well-documented Pigeon Valley Forest fire of February 2019 was used as a case study.

As expected, scenarios making use of grass curing and fuels data representative of actual fire conditions produced more accurate results than scenarios making use of a grass curing value recorded for the closest RAWS (a general representation for the weather station zone rather than a specific location) and fuels data from the New Zealand LCDB version 5.

Scenarios making use of NIWA NZCSM gridded meteorological data at a 1.5 km horizontal spacing produced more accurate spread rates, compared to scenarios making use of meteorological data from the closest RAWS to the fire (approximately 4 km from the area of origin). The reason for this is that the gridded data likely captures the effect of the complex topography on weather inputs more accurately than a single station situated a distance away.

A recommendation for future work is to test whether gridded meteorological input data leads to improved fire growth modelling results for a wider case study sample set. If this is the case, it is recommended that automated fire growth modelling, such as the NZ Fire Registry makes use of gridded meteorological input data instead of relying on data from the closest RAWS.

Acknowledgements

The authors thank Stuart Moore and Wolfgang Hayek from NIWA for the provision of gridded NZRCM meteorological data, Veronica Cliiford and Tara Strand from Scion for reviewing this report, and for the National Science Challenges, Resilience to Nature's Challenges for providing funding for this work.

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Appendix A

Run 5 - Hourly comparison to observed conditions

Run 5 provided the closest representation to the actual fire perimeter over the first eight hours of the fire (Figure 4). To understand how the model compared against observations at an hourly interval, a comparison of hourly modelled perimeters for Run 5 and observed perimeters are depicted in Figures A1 and A2 (red lines - modelled perimeter, blue lines - actual perimeter). Because suppression could not be modelled, and between 3 and 5 helicopters were actively pouring water onto the fire with monsoon buckets during this time, it is difficult to definitively determine the true accuracy of the model growth.

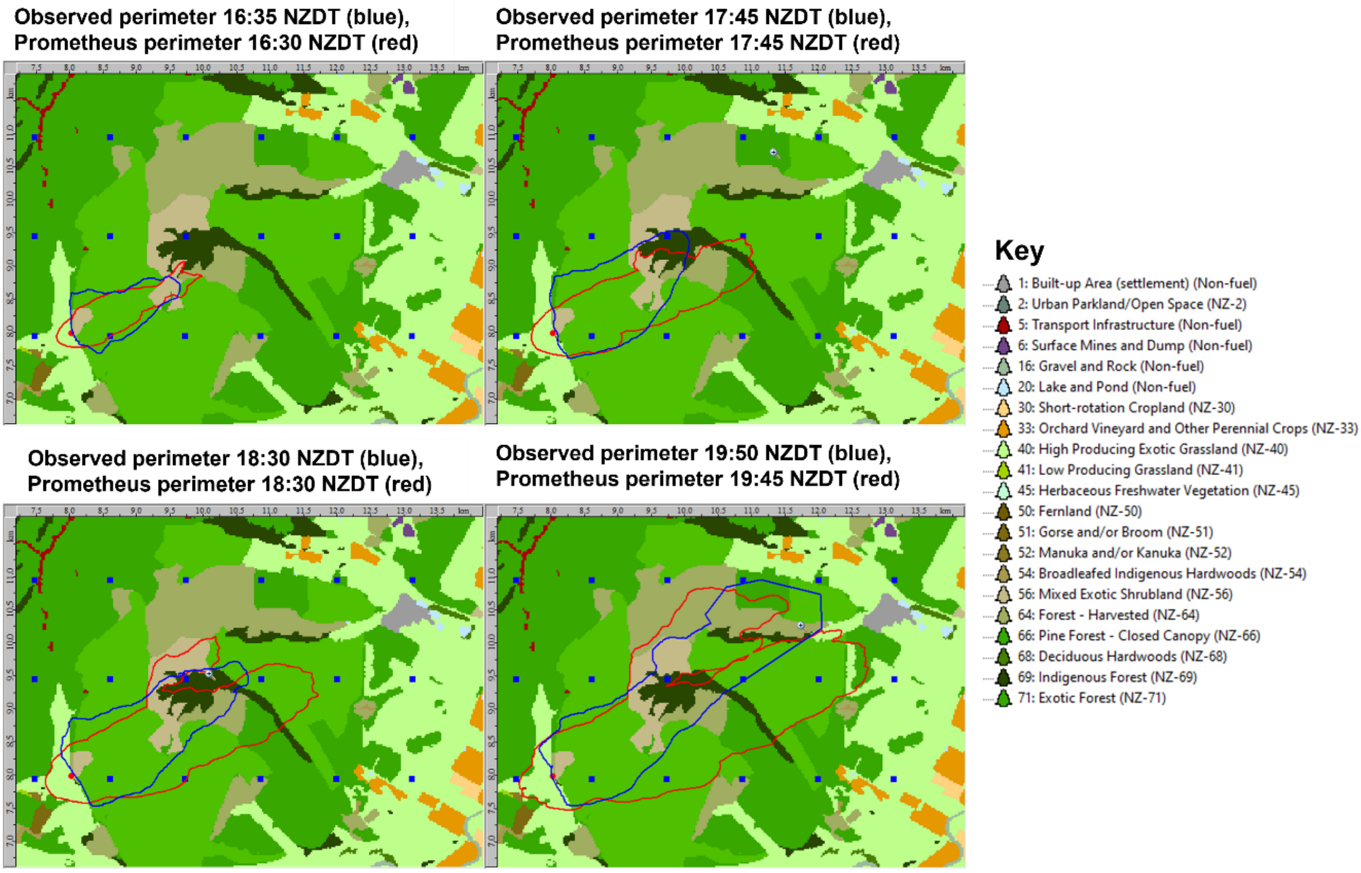

Figure A1:Run 5 modelled (red outline) and actual (blue outline) fire perimeters for 16:30 to 19:50 NZDT on 5 February 2019. The Virtual weather stations from the NZCSM gridded meteorological data is depicted as blue squares. Modelled fuel types are shown in the background and were obtained from data provided by Tasman Pine Forest Ltd.

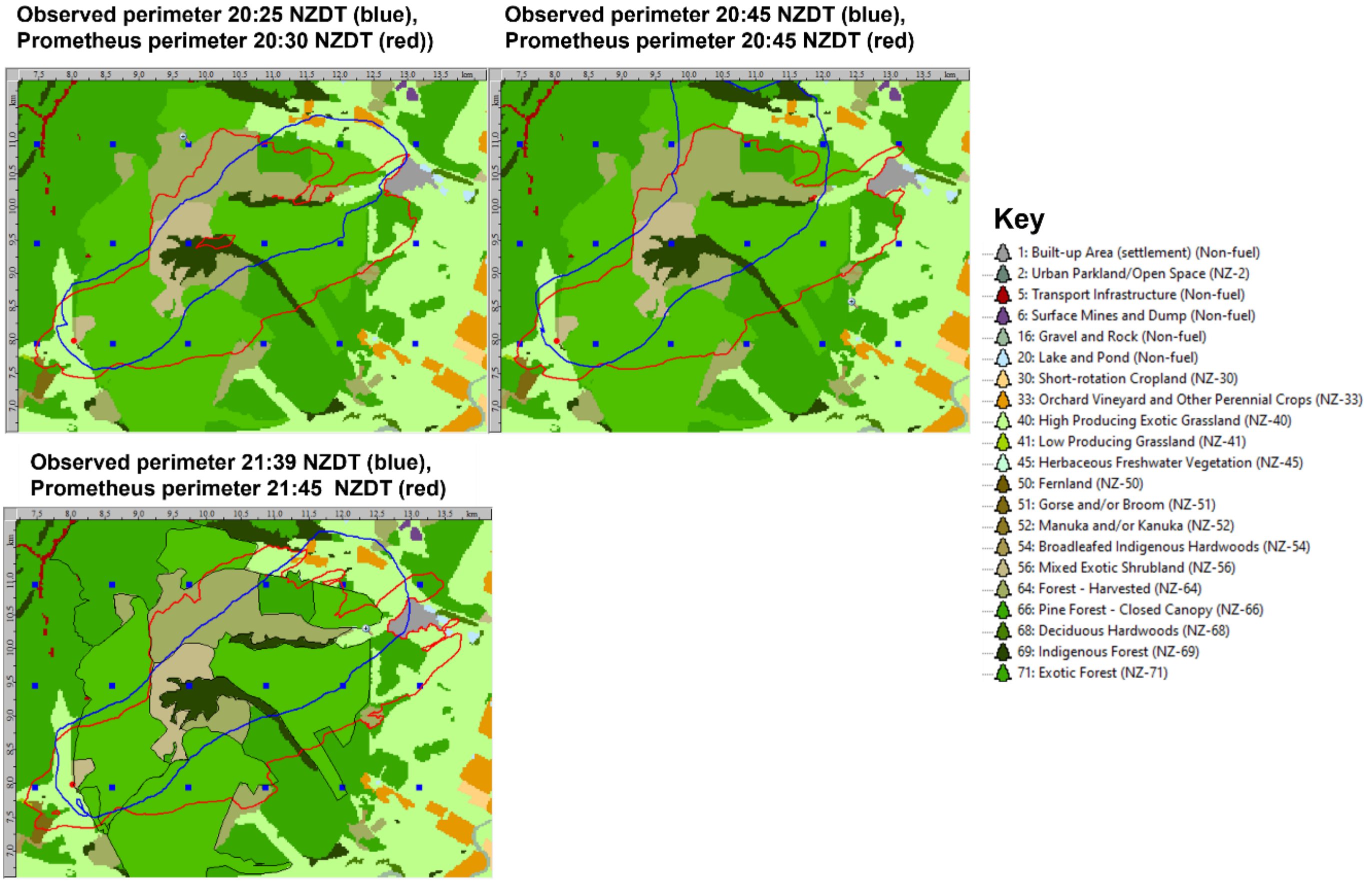

Figure A2: Run 5 modelled (red outline) and actual (blue outline) fire perimeters for 20:30 to 21:45 NZDT on 5 February 2019. The Virtual weather stations from the NZCSM gridded meteorological data is depicted as blue squares. Modelled fuel types are shown in the background and were obtained from data provided by Tasman Pine Forest Ltd.