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WIND-TERRAIN FILTERS FOR VLS PRONE LANDSCAPES

Utilisation Training Manual

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Cover: VLS event underway during the Yankees Gap Fire, September 15th, 2018. Source: Youtube, Helmreich Joinery

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ABSTRACT

Vorticity-driven Lateral Spread, or VLS, is a form of dynamic bushfire propagation that involves rapid fire spread across steep, lee-facing slopes in a direction roughly perpendicular to the prevailing winds.

It is often accompanied by dense spotting downwind of the affected slope. These spot fires interact and coalesce, resulting in active flaming over large areas – a phenomenon known as 'deep flaming'.

As such, VLS is a potent and dangerous pattern of bushfire propagation, which can quickly turn a small fire into a catastrophic large-scale event. The rapid rates of spread associated with VLS are a threat to firefighter safety and the deep flaming associated with VLS increases the likelihood of extreme bushfire development, including fire-generated thunderstorms, which are known in the scientific literature as pyrocumulonimbus.

This document describes an operational mapping overlay for identifying regions prone to VLS. This is prefaced with some discussion on VLS and dynamic fire behaviour more generally. The mapping overlay essentially filters wind and terrain information to identify parts of the landscape that satisfy the necessary conditions for VLS occurrence. They are intended to provide fire managers and fire behaviour analysts with an additional layer of information that can help them anticipate VLS occurrence and subsequent development of extreme bushfires. The use of the mapping overlay is demonstrated using a number of example cases studies.

INTRODUCTION

TRAINING MANUAL LAYOUT

This manual is designed to facilitate a self-led discovery of how to understand and implement the wind-terrain filters for identifying VLS prone landscapes. It is broken down into two parts. The first part covers background information on dynamic fire behaviours, and VLS in particular, before discussing how the wind-terrain filters are derived. The second part guides the learner through a number of practical examples, which will have them implementing the wind-terrain filters as mapping overlays in a Geographical Information System of their choice. The examples cover real case studies where VLS has resulted in extreme bushfire development.

Extreme bushfires manifest as a dangerous escalation of wildfire and exhibit several unique hazards that can pose significant threats to firefighter safety and containment success. Extreme bushfires can be defined as fires that exhibit deep or widespread flaming in an atmospheric environment conducive to the development of violent pyroconvection, which can manifest as towering pyrocumulus (pyroCu) or pyrocumulonimbus (pyroCb) storms (Sharples et al. 2016). Extreme bushfires are increasing in frequency and intensity due to changes in global/regional climate and land management.

All fires start small, but some escalate rapidly due to a variety of factors, which increases their rate of spread and intensity. Extreme fires are characterized by regions of expansive active flaming known as 'deep flaming' (McRae et al. 2015), also referred to as 'areal' or 'mass fires'. Triggers for deep flaming include changes in wind direction, very strong winds, eruptive fire behaviour, mass-spotting and fire coalescence, and VLS (Badlan et al. 2021a; 2021b). The last three of these involve dynamic fire spread, whereby a fire spreads in a non-quasi-steady manner and is driven by interactions between the fire and the surrounding environment. Dynamic fire behaviours are problematic not only because they can result in the abrupt escalation of bushfires, but may also catch people in the vicinity off-guard, leading to loss of life and property. VLS has been identified as a driver of extreme fire development in numerous events, such as the 2013 Aberfeldy fire, the 2013 Wambelong fire and the 2019 Green Valley fire.

PURPOSE OF THIS MANUAL

This manual will:

- Briefly explain dynamic fire behaviour, how it can lead to extreme bushfire development and provide examples of dynamic fire behaviour.
- Describe VLS in further detail and provide insights into the conditions conducive for mass spotting. This will provide a deeper understanding of the principes underlying the VLS mapping overlay.
- Describe how extreme fires are produced by the coalescence of spot fires, which then leads to expansive fires encompassing a large spatial area. Early identification of the likelihood of enhanced spot fire

development better enables early identification, and possibly prevention, of fires that are likely to transition to large, more problematic fires.

- Provide an overview of how the wind-terrain filter (mapping overlay) works.
- Provide the learner with more familiarity into how a change in wind direction may dramatically alter areas at risk from VLS and mass-spotting, and how this can result in an abrupt deterioration in firefighter safety.

Early detection of fires that are likely to blow-up will save lives and prevent entrapment of firefighters, provide an opportunity for early evacuation, and in the best case, may also help to stop any fires escalating further.

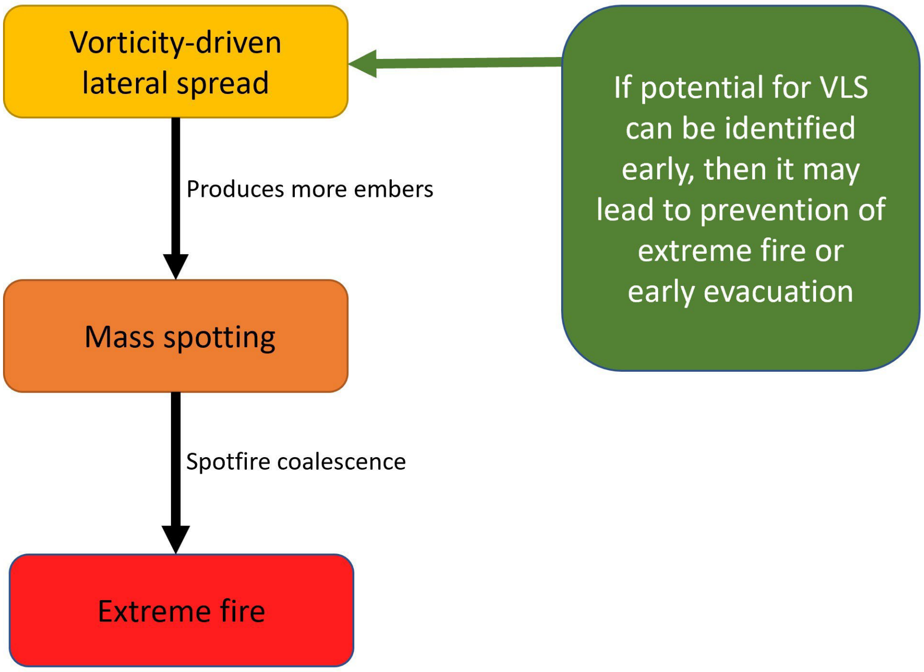


FIGURE 1: SCHEMATIC SHOWING THE LINK BETWEEN VLS OCCURRENCE AND EXTREME BUSHFIRE DEVELOPMENT

ACCOMPANYING TRAINING VIDEO

The authors have also produced a short instructional video to provide further explanation of VLS and how the mapping overlays (wind-terrain filters, or VLS filters) are used to predict and diagnose VLS occurrence.

The video can be found at: https://www.naturalhazards.com.au/vorticity-driven-lateral-spread

DYNAMIC FIRE BEHAVIOUR

Werth et al. (2011) defined extreme fire behaviour as: Fire spread other than steady surface spread, especially when it involves rapid increases. In these instances, the fire does not attain quasi-equilibrium, and the associated spread cannot be accounted for by simple correlations with environmental conditions. In many cases, dynamic fire behaviour is driven by complex interactions between the fire and the surrounding environment. These include interactions between the fire and the terrain, the fire and the winds, or between different parts of the fire itself. Examples of dynamic fire spread are eruptive fire behaviour, driven by an interaction between the fire and steep slopes, and fire coalescence, which is driven by interactions between different fires or different parts of the same fire. VLS is a form of dynamic fire behaviour driven by the interaction of a fire's plume and terrain-modified winds.

VORTICITY-DRIVEN LATERAL SPREAD (VLS)

Background

VLS occurs when winds flowing over topography separate from the surface over a steep, leeward-facing slope. This separated flow forms a lee-slope eddy as the winds recurve back under themselves. This results in the formation of horizontal vorticity over the lee slope, with the greatest vorticity near the ridge at the top of the slope.

When the plume of a fire interacts with this horizontal vorticity, it is tilted upwards. The plume also causes the vorticity to intensify (vortex stretching). Ultimately, this leads to the formation of two counter-rotating vertical vortices on the flanks of the fire – essentially, these are like two intense fire whirls. The whirl-like vortices then move across the top of the slope, carrying the fire with them and forming fingers of flame that move in a direction perpendicular to the prevailing winds.

Research has shown that for VLS to occur, certain environmental conditions need to be met. The winds have to be sufficiently strong – over about 15-20 kilometres per hour, and they have to align with the topography to a sufficient degree: only leeward slopes with aspects that align to within about 40 degrees of the wind direction will be prone to VLS occurrence. Furthermore, the leeward slope has to be steep enough for the winds to separate from the surface. For this to occur, the lee-facing slope typically needs to steeper than about 20 degrees, although flow separation can also occur due to the presence of topographic prominences (e.g., knolls, cliffs or bluffs) that may not be associated with a lee slope greater than 20 degrees – these instances will be discussed in a later section.

Hence, in most circumstances, if the following conditions are met, then VLS is likely to occur:

- Wind speed > 15-20 km/h
- Topographic aspect within 40° of the wind direction
- Slopes steeper than 20°

VLS and mass spotting events

The strong pyrogenic winds associated with the whirl-like vortices that drive VLS enhance the generation of embers. These embers are carried laterally by the whirls or are caught up in the plume or ambient winds and blown downwind. This results in mass-spotting downwind of the VLS event, as depicted in Figure 2.

The figure shows a schematic of a fire which has ignited on a windward facing slope. This fire initially spreads up the slope in the direction of the prevailing wind. When the fire encounters the ridge line (indicated by the white dashed line), dynamic fire interactions then drive the fire laterally (VLS) along the ridge line. These regions of lateral spread act as an enhanced source of embers, which are consequently deposited downwind on the lee-facing slope, as a dense ember attack. The resulting dense spot fires then interact, coalesce and form deep flaming zones.

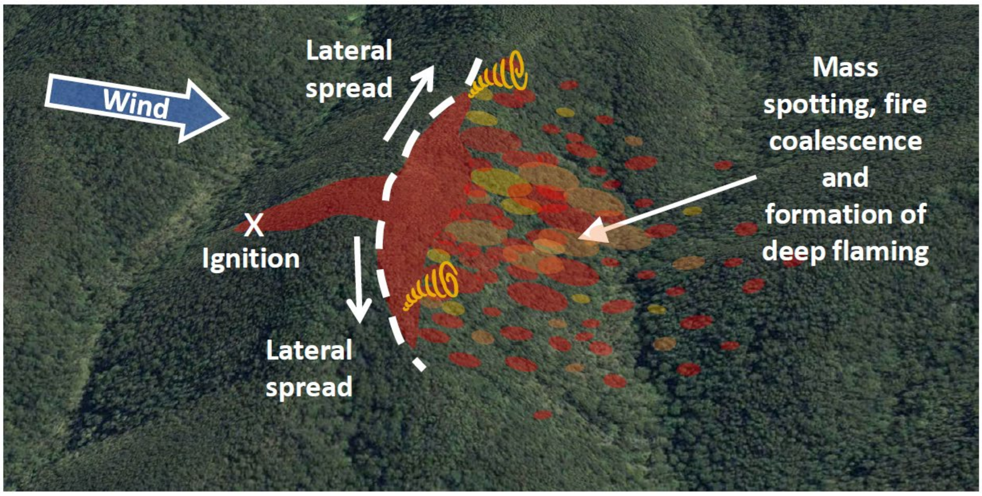


FIGURE 2: SCHEMATIC DIAGRAM ILLUSTRATING A TYPICAL SCENARIO INVOLVING VLS AND ASSOCIATED DOWNWIND SPOTTING, SPOT-FIRE COALESCENCE AND FORMATION OF DEEP FLAMING.

In addition, for deep flaming to occur in association with VLS, other factors like fuel moisture content will need to be sufficiently low to ensure profuse spotting and ember viability. However, it should be noted that the full set of necessary and sufficient conditions required for VLS and mass spotting to occur are currently unknown.

TABLE 1: NOTABLE DOCUMENTED CASES OF VLS OCCURRENCE

Fire Name	Location	Date
Bendora Fire	Bendora Dam, ACT	18 Jan 2003
McIntyres Hut Fire	Goodradigbee, ACT	18 Jan 2003
Wambelong Fire	Warrumbungles, NSW	12 Jan 2013
Aberfeldy Fire	Tomson's Dam, VIC	17 Jan 2013
Green Valley Fire	Jingellic, NSW	30 Dec 2019

THE VLS FILTERS – MAPPING OVERLAYS

This section introduces the wind-terrain filters (VLS filters) designed to be used as operational overlays that highlight areas of high VLS risk. Two separately derived filters are combined to identify high risk locations – a first-order filter, which is defined in terms of terrain slope (the first-order differential of elevation), and a second-order filter defined in terms of the second-order differential of elevation, which can be used to better identify terrain prominences such as knolls, cliffs and bluffs that may not be identified by the first-order filter but which can still cause flow-separation. Figure 3 provides a schematic of how the first-order and second-order filters apply to different terrain profiles.

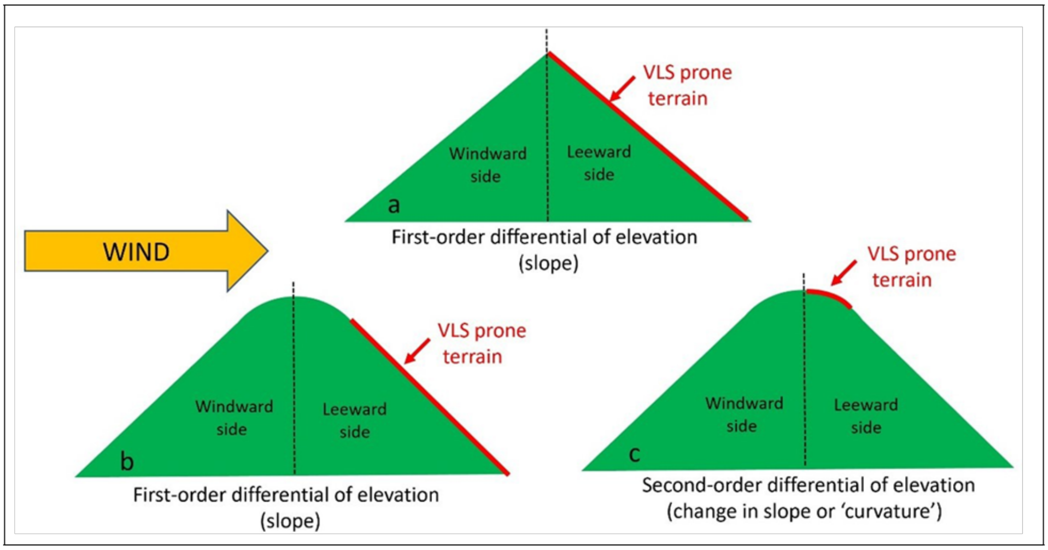


FIGURE 3: FIRST-ORDER VLS FILTERS FOR A) A TRIANGULAR HILL PROFILE, AND B) A SIMPLE RIDGE PROFILE WITH A FIRST-ORDER FILTER AND C) A SIMPLE RIDGE PROFILE WITH A SECOND-ORDER FILTER.

A first-order filter on its own would be sufficient if real topography reflected a hill such as that in Fig. 2a. However, is not sufficient in real terrain with broken topography and topographic prominences of various shapes and kinds. These may not be identified by a first-order filter as this filter only captures slope greater than a certain threshold but not the top of the ridge, which may have a gentler slope (Fig. 2b). The second-order is needed to identify these regions in the immediate lee of the ridgeline (Fig. 2c).

FIRST-ORDER FILTER

As described previously, VLS occurrence typically requires a sufficiently steep lee-facing slope with an aspect that aligns with the prevailing wind to within a certain degree. These conditions can be expressed as a binary variable, defined as:

$$\chi_1(\sigma, \delta) = 1 \text{ if } S \geq \sigma \text{ and } |\theta - \alpha| \leq \delta, \text{ and } \chi_1(\sigma, \delta) = 0 \text{ otherwise.}$$

Here S is the topographic slope, α is the topographic aspect and θ is the direction the wind is blowing towards. This is the opposite of the standard wind direction and is calculated by subtraction or addition of 180° from the standard wind direction; so, for a westerly wind $\theta = 90°$. The parameters σ and δ are the *slope threshold* and *aspect discrepancy* respectively.

In summary, the first-order filter identifies areas of the landscape with lee-facing slopes steeper than the slope threshold σ and with a topographic aspect that aligns to within the aspect discrepancy δ either side of the wind direction.

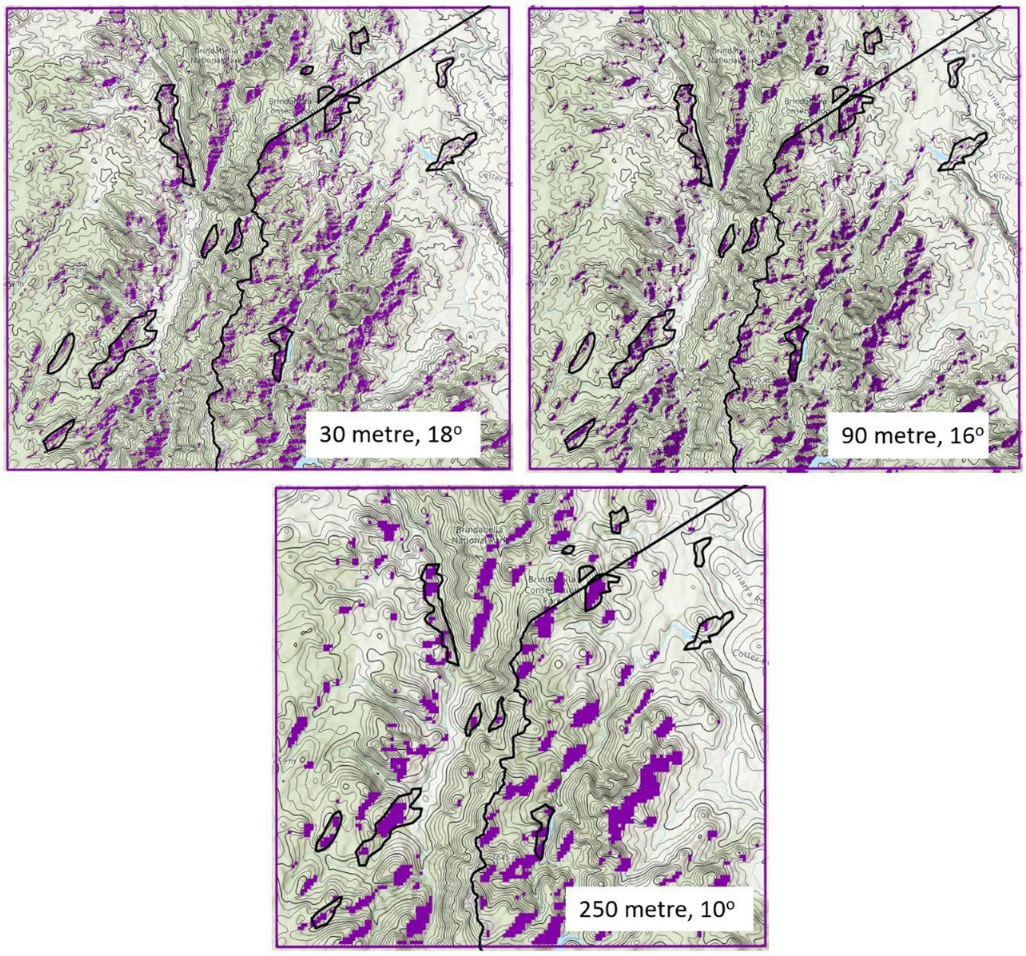


FIGURE 4: FIRST-ORDER VLS FILTERS (PURPLE SHADING) FOR 30, 90, AND 250 METRE DEMS WITH SLOPE THRESHOLDS OF 18, 16, AND 10 DEGREES RESPECTIVELY, APPLIED TO THE AREA WEST OF CANBERRA WEHERE VLS WAS OBSERVED IN JANUARY 2003. THE BLACK POLYGONS INDICATE LOCATIONS WHERE VLS WAS OBSERVED IN LINESCAN IMAGERY.

The slope threshold is used to identify slopes over which flow separation is expected to occur. As noted, in actual landscapes this is known to occur for slopes over about 20° but when a digital elevation model (DEM) is being used to represent the topography, the value chosen for the slope threshold needs to reflect the resolution of the DEM, as terrain slope will generally have larger values in a finer resolution DEM compared to a coarser DEM. Calibration of the filters using DEMs of different resolutions yielded the slope threshold values listed in Table 2.

Figure 4 shows the first-order filters for the area where the Canberra fires occurred, with the three different resolution DEMs, assuming a north-westerly wind direction for each (i.e., $\theta = 135°$). In each panel, the purple shading indicates parts of the terrain that are prone to VLS occurrence; that is, where $\chi_1 = 1$. Regions not prone to VLS (satisifying $\chi_1 = 0$) have no shading. While the

250-metre resolution filter lacks the detail of the two finer filters, it does capture the general areas at risk of VLS, and where VLS was observed to have occurred.

TABLE 2: SLOPE THRESHOLD VALUES FOR DIGITAL ELEVATION MODELS OF VARIOUS RESOLUTIONS

DEM resolution	Slope Threshold σ
30 metre	18°
90 metre	16°
250 metre	10°

SECOND-ORDER FILTER

The second-order filter is determined by the second-order directional derivative of the surface Digital Elevation Model (DEM) and the aspect. The second-order directional derivative, also known as the *profile curvature*, basically tells us how curved the terrain surface is in a particular direction. In this case the direction of interest is the topographic aspect direction. Parts of the terrain exhibiting high degrees of curvature (e.g., knolls, cliffs and bluffs) will be prone to flow separation and the generation of ambient horizontal vorticity – one of the precursors for VLS occurrence (see Figure 2). The second-order wind terrain filter is defined as:

$$\chi_2(\gamma,\delta) = 1 \text{ if } C < \gamma \text{ and } |\theta - \alpha| \leq \delta\text{, and } \chi_2(\gamma,\delta) = 0 \text{ otherwise.}$$

Here C is the profile curvature, α is the topographic aspect and θ is the direction the wind is blowing towards. In practice, the profile curvature tool in ArcGIS Pro can be used to calculate C. Note that in the current version of the second-order filter, the profile curvature is in the direction of maximum slope, and not necessarily aligned with the wind. This is an aspect of the second-order filter that could be modified in future versions, as more data becomes available.

OPERATIONAL FILTERS

The current suite of VLS filters have been produced for each state, for wind directions corresponding to each of the sixteen cardinal points of the compass. The general idea in implementing the VLS filters is to apply the filter at a certain location of interest, for either the current or predicted wind conditions to determine if a fire burning in that location is likely to be affected by VLS; that is, if a fire is within, or is likely to enter into an area identified as prone to VLS occurrence.

The filters have been created based on DEMs with resolutions of 90 and 250 metres. The 250-metre product is useful to identify broad areas of interest, while the 90-metre product may then be utilized for more detailed analyses.

APPLICATION OF THE VLS FILTERS - CASE STUDIES

This section discusses three case studies involving fire propagation affected by VLS and how the mapping overlays described in the preceding sections can be used to predict the potential for VLS or diagnose its occurrence.

CASE STUDY 1: BRIDGER HILLS FIRE, MONTANA, USA

Details:	Date: 5th September 2020 Custer-Gallatin National Forest, near Bozemann, Montana
Timeline:	4th September 2020. 1500 fire ignited by lightning. 5th September 2020. 1030 Fire activity increases Helispot chosen as safety zone. 1300 Helitack team retreated upcanyon to helispot. 1343 Emergency fire shelters deployed.
Weather:	Forecast for Saturday 5/9/2020, Temperature: 33 – 36°C, Relative Humidity: 6-11%, Winds: S 8-16 km h^{-1}, shifting to 16-30 km h^{-1} out of the W, with gusts of up to 50 km h^{-1} in the afternoon, Gusts across the ridgetop of 40-55 km h^{-1} out of the W. Haines index of 6

At approximately 1500 on Friday 4th September 2020, lightning ignited a fire along the west side of Bridger Ridge, NE of Bozeman, Montana (Fig. 5). Attempts at suppression of the fire from fire departments, US Forest Service and other responders were immediate, however they were unsuccessful in halting the fire due to the extremely dry conditions. By nighttime, approximately 100 homes were at risk, within Bridger Canyon.

The forecast for Saturday was for hot, dry, and windy conditions. The fire danger index was also at Severe - the highest rating in the United States. Temperature was forecast to be 92-97°F (33-36°C), and relative humidity forecast to be 6-11%. Southerly winds were forecast for 5-10 mph (8-18 km h^{-1}), shifting to westerly 10-20 mph (18-36 km h^{-1}) with gusts up to 30 mph (approx. 50 km h^{-1}).

For further information, see the 'Bridger Foothills Fire Entrapment and Shelter Deployment' Report from the Montana Department of Natural Resources and Conservation[1].

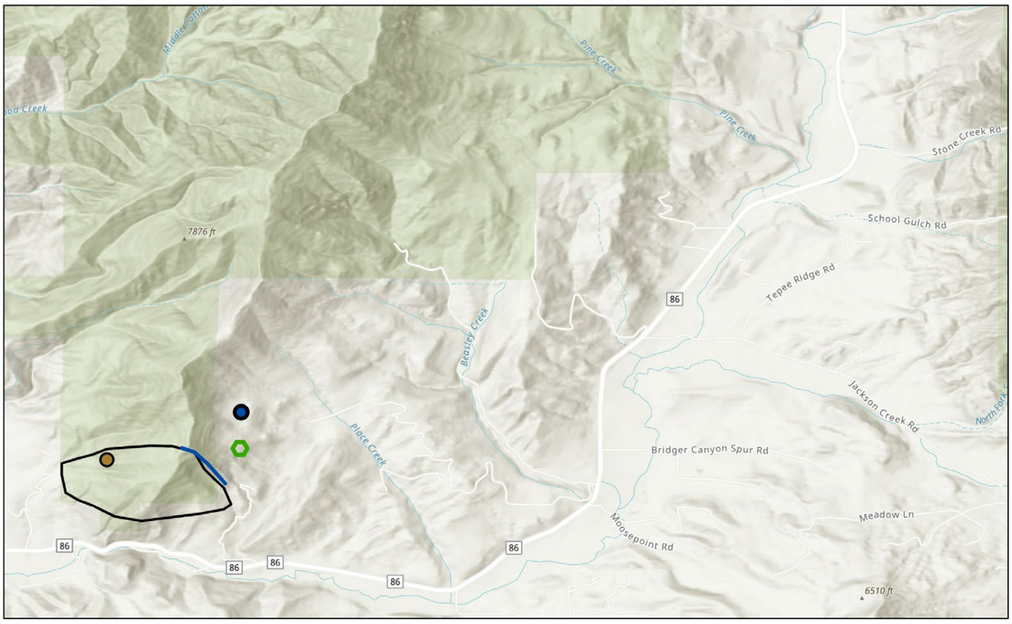


FIGURE 5: IGNITION POINT (BROWN CIRCLE) AND FIRE PERIMETER SATURDAY MORNING 5/9/2020. THE BLUE LINE IS THE HANDLINE ESTABLISHED BY FIREFIGHTERS THAT MORNING. THE BLUE CIRCLE MARKS THE HELISPOT AND THE GREEN HEXAGON THE CAMPSITE.

Instructions

Download and unzip the 'Supplementary_training' folder and open the 'Bridger' folder. Within that folder, unzip the 'Bridger_shapefiles' and 'Bridger_VLS_tifs' folders. In the 'Bridger_shapefiles' folder you will see a number of shapefiles. These are as follows:

- 'Area' - a polygon showing the area covered by the VLS filters.
- 'BForigin' - the point of ignition of the fire.
- 'Bridger_Foothills_Early_Perimeter' - the fire perimeter in the early stages before blow-up
- 'BridgerFoothills_Perimeter' - the final burn perimeter.
- 'Handline' - Location of the handline made by the three firefighters.
- 'Helispot' – Location of the crew's helispot.
- 'HelitackCampsite' – Location of the campsite

[1] Available from: https://lessons.wildfire.gov/incident/bridger-foothills-fire-entrapment-and-shelter-deployment-2020
A copy of this report has been included in the Bridger Foothills Fire Directory.

In the 'Bridger_VLS_tifs' folder you will see a number of .tif files. These are as follows:

- 'VLSFinal_S_' – a raster showing the areas of VLS risk (based on a 90m DEM) under a southerly wind, which was blowing *before* the blow-up.
- 'VLSFinal_W_' – a raster showing the areas of VLS risk (based on a 90m DEM) under a westerly wind, which was blowing *during* and *after* the blow-up.

Step 1: Within a Geographical Information System, open all the shapefiles in 'Bridger_shapefiles' to obtain a display similar to Figure 6.

Step 2: Add the layer 'VLSFinal_S_' to the display to see which parts of the terrain were prone to VLS under a southerly wind. It is recommended that you set the '0' values to be transparent. You should see a picture to that in Figure 6. Note that the VLS filter for a southerly wind indicates that there was no risk of VLS in the area where the fire crew was working.

FIGURE 6: FIRE PERIMETER ON SATURDAY MORNING 5/9/2020. THE BLUE LINE IS THE HANDLINE ESTABLISHED BY FIREFIGHTERS THAT MORNING. THE BLUE CIRCLE MARKS THE HELISPOT AND THE GREEN HEXAGON THE CAMPSITE. PURPLE AREAS INDICATE REGIONS OF THE LANDSCAPE WHERE VLS IS LIKELY TO OCCUR UNDER A SOUTHERLY WIND DIRECTION.

Step 3: Add the layer 'VLSFinal_W_' to the display to see which parts of the terrain are prone to VLS under the forecast westerly wind. Again, it is recommended that you set the '0' values to be transparent. In your GIS platform, you can select/unselect the layers corresponding to the VLS filters for southerly and westerly winds to see how the regions prone to VLS change under southerly and westerly winds.

Step 4: Unselect the VLS filter for southerly winds and select the VLS filter for the forecast westerly winds. You should see a picture similar to that in Figure 7.

Key Question: Is the fire crew working in a safe zone given the forecast westerly wind direction? Do the helispot and campsite offer safe egress?

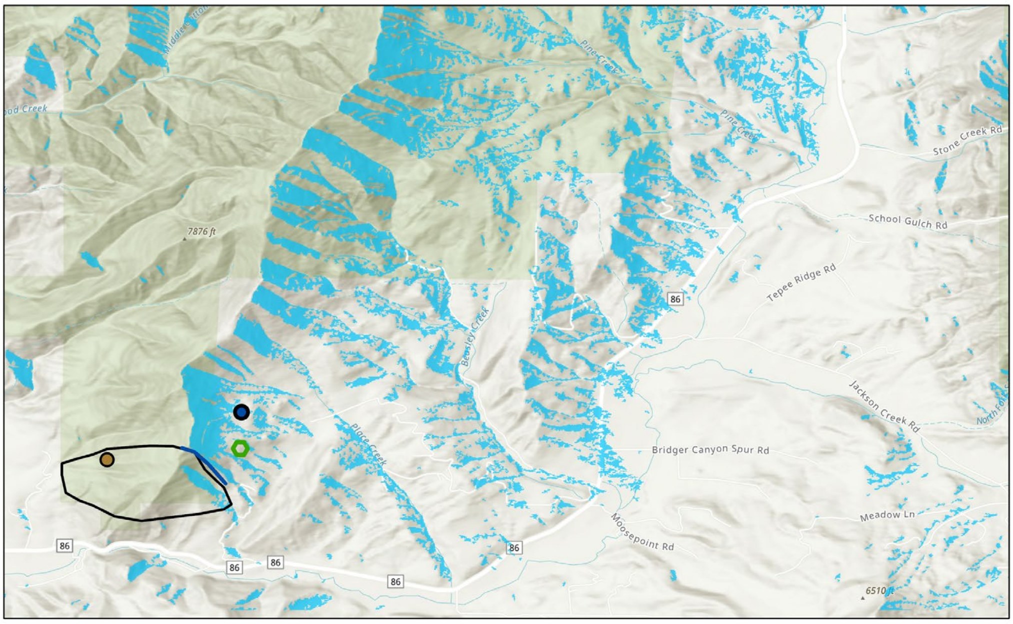


FIGURE 7: FIRE PERIMETER ON SATURDAY MORNING 5/9/2020. THE BLUE LINE IS THE HANDLINE ESTABLISHED BY FIREFIGHTERS THAT MORNING. THE BLUE CIRCLE MARKS THE HELISPOT AND THE GREEN HEXAGON THE CAMPSITE. PURPLE AREAS INDICATE REGIONS OF THE LANDSCAPE WHERE VLS IS LIKELY TO OCCUR UNDER A WESTERLY WIND DIRECTION.

Step 5: Add the final perimeter layer 'BridgerFoothills_Perimeter' to see the extent of the final area burnt. You should see an image similar to Figure 8.

Summary

The southerly VLS filter indicates that the fire crew was initially working in an area that was not prone to VLS. It is interesting to note that the method of indirect attack being employed by the fire crew is fairly standard practice. They were working on a sheltered slope along a flanking part of the fire. They had well defined safety zones and escape routes. Even under the forecast westerly wind change, they would still have been working on the fire's flank on a down-slope run, for which fire behaviour would be expected to be more benign. However, the change in wind direction out of the west and the increase in wind speeds above 20 km h^{-1}, meant that the lee-facing slopes became prone to VLS, as indicated by the westerly VLS filter. The fire subsequently burnt rapidly to the north across the lee-facing slope. The fire crew were burnt over and were forced to deploy their shelters. Fortunately, all survived the incident.

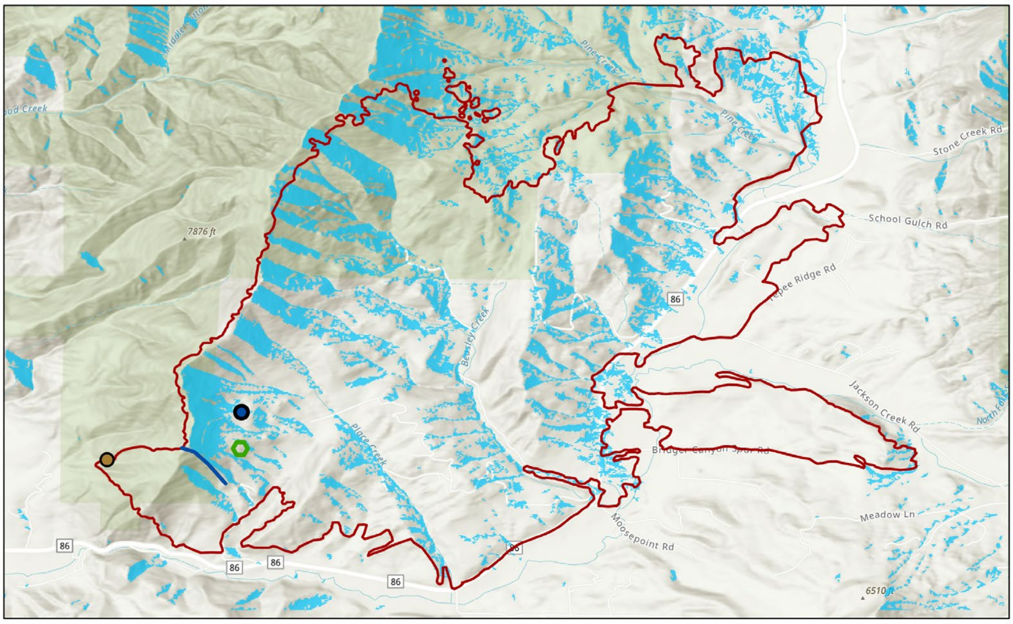
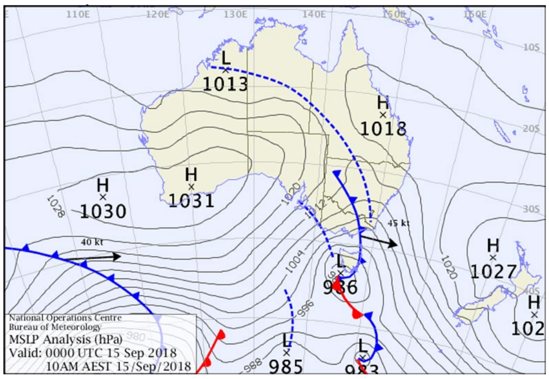


FIGURE 8: FIRE PERIMETER ON SATURDAY MORNING 5/9/2020. THE BLUE LINE IS THE HANDLINE ESTABLISHED BY FIREFIGHTERS THAT MORNING. THE BLUE CIRCLE MARKS THE HELISPOT AND THE GREEN HEXAGON THE CAMPSITE. PURPLE AREAS INDICATE REGIONS OF THE LANDSCAPE WHERE VLS IS LIKELY TO OCCUR UNDER A WESTERLY WIND DIRECTION.

CASE STUDY 2: YANKEES GAP FIRE, NSW

Details: Date: 15th September 2018
Bemboka, NSW

Weather: Temperatures up to 30°C, very strong pre-frontal winds out of the WNW, with reported gusts of up to 100 km h^{-1}. Total Fire Ban.



This event was part of the broader fire complex that had been burning since 15th August 2018 in the Yankees Gap area.

Instructions

Download and unzip the 'Supplementary_training' folder and open the 'Bemboka' folder. Within that folder, unzip the 'Bemboka_shapefiles' and 'Bemboka_VLS_tifs' folders. In the 'Bemboka_shapefiles' folder you will see the following shapefiles:

- 'Bemboka_domain' - a polygon showing the area covered by the corresponding VLS filters.
- 'Bemboka_DEM' - a digital elevation model of the area.

In the 'Bemboka_VLS_tifs' folder you will see a number of .tif files. These are as follows:

- 'YANKEES GAP_1320' – a linescan of the fire ***before*** the blow-up
- 'YANKEES GAP_1417' – a linescan of the fire ***after*** the blow-up
- 'VLS_WNW' – a raster showing the areas of VLS risk (based on a 90m DEM) under a WNW wind, which was blowing *during* and *after* the blow-up.

Step 1: Within a Geographical Information System, open all the shapefiles in 'Bemboka_shapefiles' and the 'YANKEES GAP_1320' file to obtain a display similar to Figure 9.

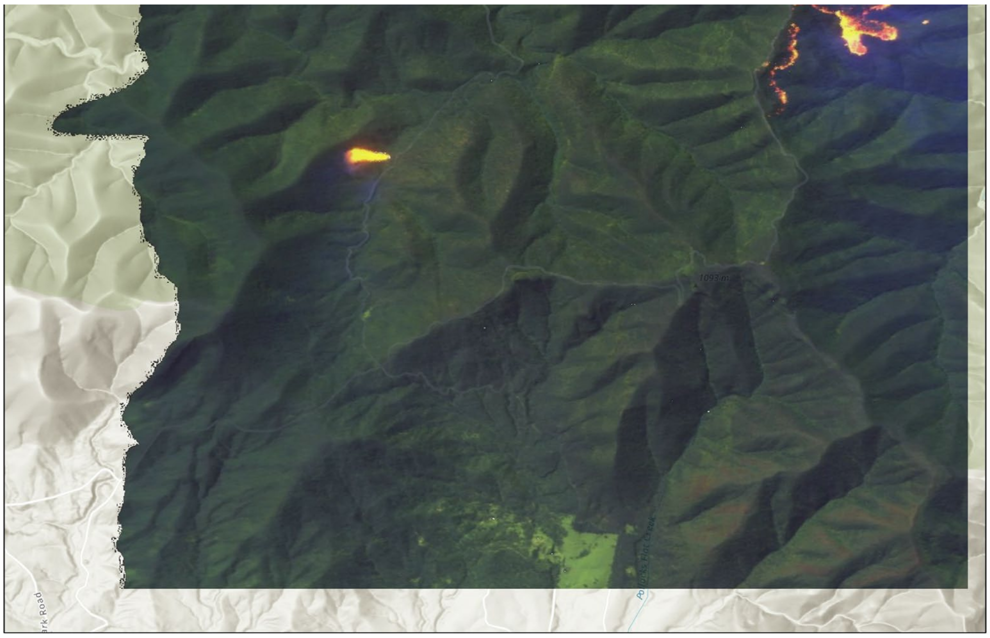


FIGURE 9: LINESCAN TAKEN AROUND 1320 HOURS ON 15TH SEPTMEBRE 2018. AN IGNITION CAN BE SEEN NEAR THE MIDDLE OF THE IMAGE – THE FIRE CAN BE SEEN TO BE BURNING BACK UP A LEEWARD SLOPE IN A DIRECTION ROUGHLY OPPOSED THE WNW WINDS.

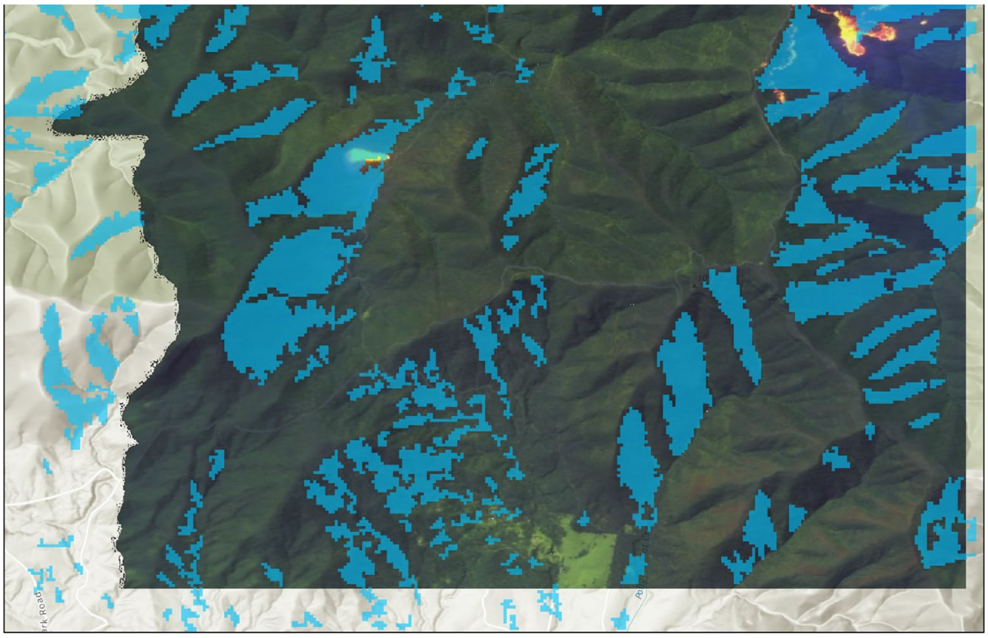


FIGURE 10: LINESCAN TAKEN AROUND 1320 HOURS ON 15TH SEPTMEBRE 2018. AN IGNITION CAN BE SEEN NEAR THE MIDDLE OF THE IMAGE – THE FIRE CAN BE SEEN TO BE BURNING BACK UP A LEEWARD SLOPE IN A DIRECTION ROUGHLY OPPOSED THE WNW WINDS.

Step 2: Add the 'VLS_WNW' layer to identify areas prone to VLS occurrence. You should see a picture similar to that in Figure 10. Note that the fire burning near the centre of the image is burning in a region prone to VLS.

Key Question: What does this suggest about the likely development of the fire? Which way do you think it is likely to spread under a WNW wind?

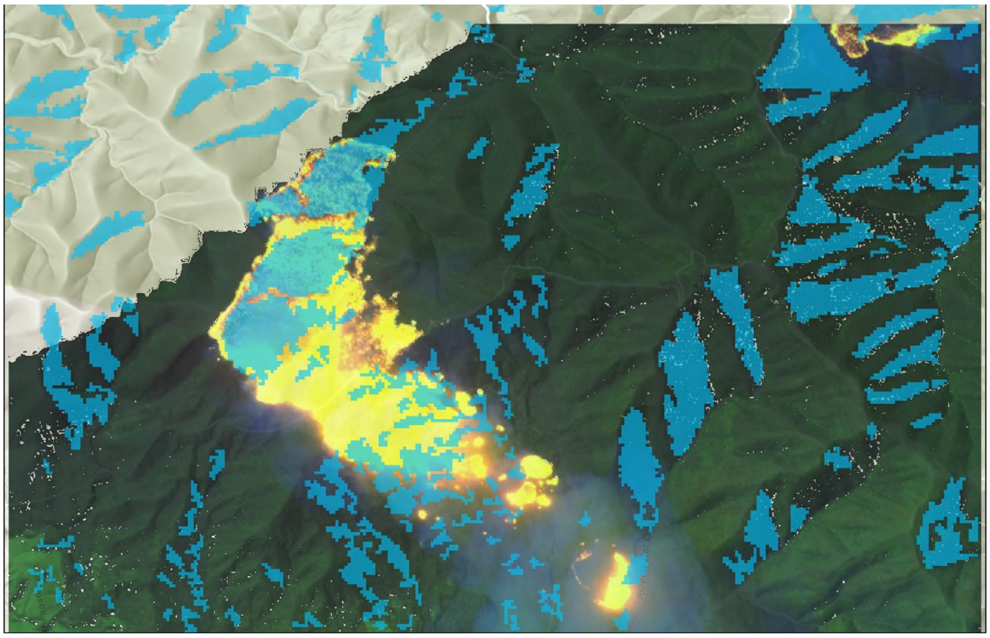


FIGURE 11: LINESCAN TAKEN AROUND 1417 HOURS ON 15TH SEPTMEBRE 2018. THE FIRE HAS DEVELOPED TO THE SOUTHWEST ACROSS THE REGIONS IDENTIFIED AS PRONE TO VLS BEFORE SPILLING OUT DOWNWIND WITH DENSE SPOTTING.

Step 3: Add the 'YANKEES GAP_1417' to see the extent of the fire spread approximately an hour later. Reorder the layers, if necessary, so that the VLS filter is the top layer. You should see an image similar to Figure 11. How does this fire extent compare with your assessment after Step 2?

Summary

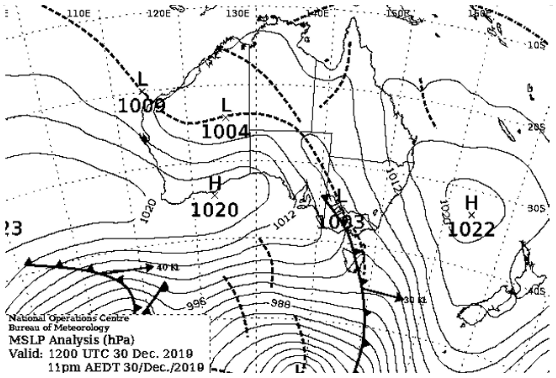
The WNW VLS filter indicated that the fire had entered a region prone to VLS, thus indicating the potential for the fire to propagate laterally across the leeward slope in a south-westerly direction. This is not intuitive – given the WNW winds, the expectation would normally be for the fire to spread to the southeast. The second linescan demonstrates that the fire did indeed travel to the southwest before 'spilling-out' to the southeast. Note that the upwind edge of the fires aligns almost perfectly with the ridge line upwind of the VLS prone regions and that the south-easterly spread is associated with a large number of spot fires and deep flaming.

CASE STUDY 3: GREEN VALLEY TALMALMO FIRE, NSW

Details: Date: 30th December 2019

Woomargama National Park, near Jingellic, NSW

Weather: Very hot and dry. Strong north-westerly (pre-frontal) winds averaging 30 to 40 km h^{-1}. Temperatures were near 40°C and relative humidity dropped below 10%.



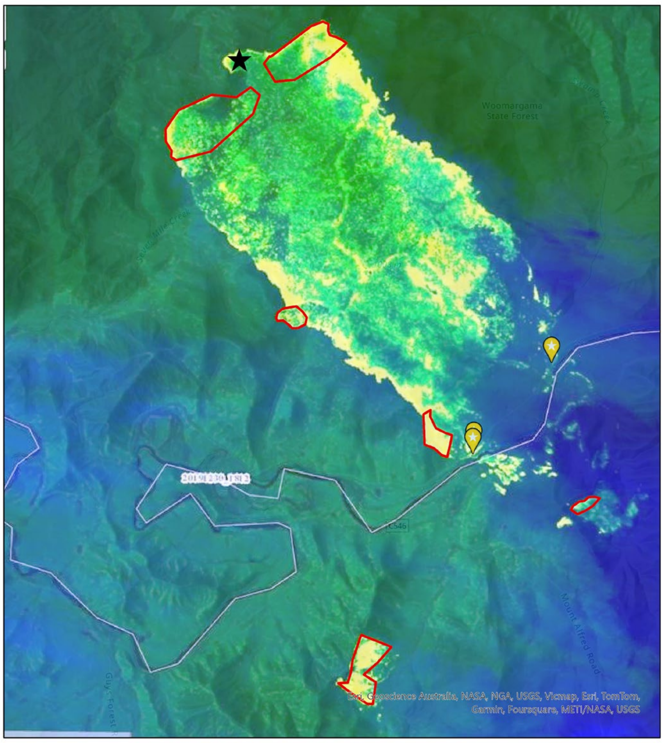


FIGURE 12: LINESCAN SHOWING THE EXTENT OF THE GREEN VALLEY TALMALMO FIRE AFTER THE FIRE HAD MADE ITS MAJOR RUN. THE BLACK STAR INDICATES THE POINT OF IGNITION AND THE WHITE POLYGONS SHOW AREAS WHERE ATYPICAL LATERAL DEVELOPMENT OF THE FIRE IS OBSERVED. THE PIN MARKERS INDICATE LOCATIONS OF CRITICAL FIRE SAFETY INCIDENTS.

The Green Valley Talmalmo fire was ignited by lightning in the Woomargama National Park in NSW on 29 December 2019. Under hot, dry north-westerly winds on 30 December, the fire spread through rugged terrain to the southeast, across Green Valley and across the border (Murray River) into Victoria. The fire exhibited extreme fire behaviour and intense pyrogenic winds, which resulted in the fatality of one firefighter and the injury of three others. Figure 12 shows the extent of the fire after it had made its major run and indicates regions where atypical lateral propagation of the fire was observed.

Instructions

Download and unzip the 'Supplementary_training' folder and open the 'Jingellic' folder. Within that folder, unzip the 'Jingellic_shapefiles' and 'Jingellic_VLS_tifs' folders. In the 'Jingellic_shapefiles' folder you will see the following shapefiles:

- 'Jingellic_Domain' - a polygon showing the area covered by the corresponding VLS filters.
- 'Spread' – polygons indicating regions where atypical lateral spread was observed.

In the 'Jingellic_VLS_tifs' folder you will see a .tif file. This is:

- 'VLS_NW' – a raster showing the areas of VLS risk (based on a 90m DEM) under a NW wind, which was blowing during the main run of the fire on 30 December 2019.

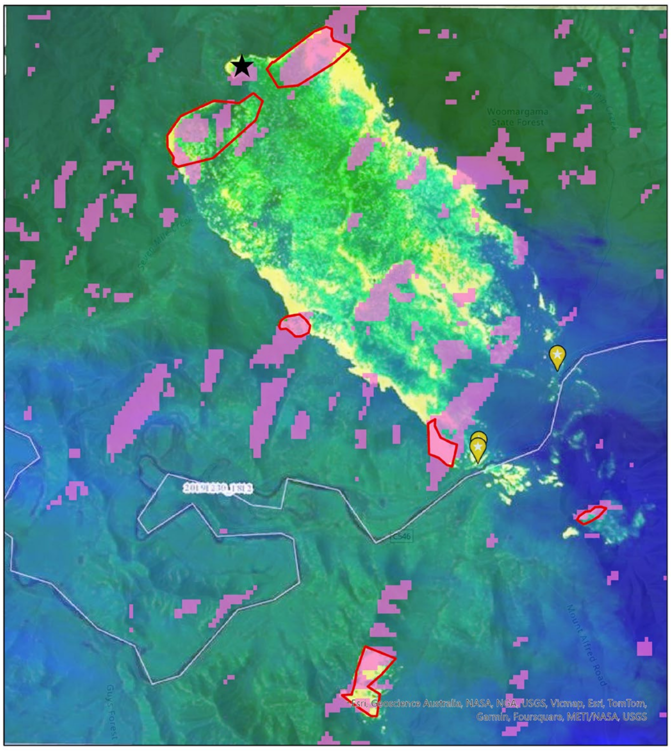


FIGURE 13: REGIONS PRONE TO VLS UNDER A NORTHWESTERLY WIND INDICATED IN PINK SHADING. RED POLYGONS INDICATE REGIONS OF THE LANDSCAPE WHERE ATYPICAL LATERAL PROPAGATION OF THE FIRE WAS OBSERVED. THE BLACK STAR IS THE IGNITION POINT.

Step 1: Within a Geographical Information System, open all the shapefiles in 'Jingellic_shapefiles' to obtain a display similar to Figure 13.

Step 2: Add the 'VLS_NW' layer to identify areas prone to VLS occurrence under the north-westerly winds that were blowing during the fire's main run. You should see a picture similar to that in Figure 14. Note the alignment between the red polygons in Figure 14 and regions identified by the VLS filter.

Key Question: What does the alignment between the regions identified by the VLS filter and the parts of the landscape where atypical lateral propagation of the fire was observed suggest to you. How might this help you diagnose the cause of the atypical lateral spread that was observed in the linescan imagery?

Summary

The NW VLS filter identifies all of the instances of atypical lateral spread that were observed in the Green Valley Talmalmo fire linescan. Given that the wind speeds were sufficiently strong, this is a strong indication that the evolution of the fire was influenced by VLS occurrence on several occasions. Indeed, it is known that this fire was significantly influenced by pyrogenic vorticity, including the formation of at least one large fire generated vortex that upended a tanker and killing one of its crew (Peace et al. 2021).

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