ADVANCES IN FOREST FIRE RESEARCH 2022

Edited by
DOMINGOS XAVIER VIEGAS
LUÍS MÁRIO RIBEIRO

Observed Wind Vector Change Across New Zealand's National Network of Fire-Weather Stations in Predicting Fire Risk

Siena Brody-Heine*; Marwan Katurji; Jiawei Zhang

[1]*University of Canterbury. 20 Kirkwood Avenue, Upper Riccarton, Christchurch 8041, New Zealand. {sbr153@uclive.ac.nz}, {marwan.katurji, jiawei.zhang}@canterbury.ac.nz*

**Corresponding author*

Keywords

Extreme fire behaviour, vector wind change, complex terrain, fire weather index

Abstract

Wildfire spread is influenced significantly by weather fluctuations. Specifically, wind speed and direction change can drastically alter fire intensity and spread. Vector wind change can result from synoptic or mesoscale weather systems and small-scale meteorological processes, such as thermal circulations and low-level wind shear in complex terrain. These small-scale processes are usually underrepresented in numerical weather forecasting models, usually needing to be resolved by more expensive sub-kilometre grid resolution simulations. Recent New Zealand wildfires, such as 2017 Port Hills and 2019 Pigeon Valley wildfires, experienced wind change due to local sea breezes and strong nocturnal downslopes flows, exacerbating fire behaviour.

The aim of this research is to investigate if vector wind change (VWC) can be a metric to better represent the effect of mesoscale and microscale weather and the subsequent impact in extreme fire behavior. This was achieved utilizing hourly VWC, or the difference in magnitude of the hourly wind vectors, from the Fire and Emergency New Zealand (FENZ) national network of more than 200 weather monitoring stations. An additional variable, wind direction change (WDC), was also calculated to include the degree change of wind direction.

To identify high-risk stations, the top 20% of stations for VWC and WDC were calculated and investigated spatially across the New Zealand landscape. The high-risk stations are located primarily on the South Island, inland and in areas of complex terrain. There is little to no variation of these stations when mapped in each synoptic type, suggesting that the main factor in determining high VWC and WDC is meso and microscale terrain driven meteorology as opposed to larger synoptic regimes. Critically, the current fire risk metric, the Fire Weather Index, does not include wind direction changes at high windspeeds. Therefore, the inclusion of VWC and WDC as additional metrics in fire risk calculations could increase operational understanding of high-risk locations and terrain impacts on extreme and unpredictable fire behavior.

1. Introduction

1.1. Critical Fire Weather

Wildfire behavior is highly dependent on near-surface meteorological conditions such as …"the atmospheric conditions that encourage extreme fire behavior resulting in large and destructive wildland fires." (Werth et al., 2016). Wildfire danger increases with low atmospheric humidity, strong winds, drought, and unstable air conditions (Mills et al., 2020) (Harris et al., 2017). These elements are not simply a sum—they are intertwined and dependent on the other and have a significant impact on extreme and unpredictable fire behavior.

In complex terrain, wildfire behavior can be influenced by dynamically and thermally driven wind systems (Werth et al., 2016). A dynamically driven wind is channeled, directed and amplified by the topography, while thermally driven wind systems are driven by differences in heat flux. New Zealand's complex terrain, including mountain ranges, valley systems and the complex coastal topography, means that near-surface wind systems are a critical variable to understand to better predict wildfire danger (Hilton et al., 2015; Dong et al., 2021).

1.2. Wildfire in New Zealand

Until the last 5 years, large scale wildfires were an infrequent occurrence in New Zealand. However, like many countries around the world, wildfires are increasing in size and frequency with warmer and drier weather

(Langer & Wegner, 2018). These fires are also increasingly encroaching on urban spaces. This trend is illustrated in the recent 2017 Port Hills fire, 2019 Pigeon Valley and the 2020 Ohau fire in New Zealand. All three fires prompted evacuations of residents for multiple days and destroyed residential structures (AFAC, 2017, 2019; Foley, 2020)

To predict fire risk around New Zealand, Fire and Emergency New Zealand (FENZ) and the National Institute of Water and Atmospheric Research (NIWA) collect hourly weather data from over 250 stations. From this weather station data, the Fire Weather Index (FWI) is calculated based on fuel type, temperature, relative humidity, windspeed and precipitation (Mandal et al., 2021; Van Wagner, 1987). The FWI combines individual markers of fire risk, including the Initial Index Spread and Buildup Index, which are combined to give a more comprehensive evaluation of fire risk (Van Wagner, 1987).

1.3. Vector Wind Change

Wind change is an important variable in fire behavior and can drastically alter the fire direction and intensity (Mills et al., 2020). Wind change can occur at time scales of minutes to hours. Many firefighter entrapments are caused by sudden wind changes, happening within a few minutes, and is defined by the metric Vector Wind Change (VWC), or the difference in magnitude of the hourly wind vectors. Two recent wildfires in New Zealand illustrate the significance of understanding VWC for fire behavior; the 2017 Port Hills and 2019 Pigeon Valley experienced a wind direction change due to local sea breezes and strong nocturnal downslopes flows that exacerbated unpredictable fire behavior (Pretorius et al., 2020). Critically, the current fire risk prediction tool the FWI, does not account for wind direction changes and therefore misses critical meteorological and climatological information for predicting and understanding wildfire danger across complex terrain. This research presents an investigation into VWC in New Zealand, and how VWC can be utilized as an additional metric for predicting wildfire risk.

2. Methods

Observations from the Fire Emergency New Zealand (FENZ) weather stations were gathered using the open access data from the Envlib Modeling Consortium using the Tethysis API in Python (Kitteridge, 2021; New Zealand Modeling Consortium Open Environmental Digital Library, 2021). Stations with a complete time series between November 28th 2020 - November 28th 2021 (130 stations) were included. Meteorological data was logged as sub-hourly intervals, between 10 and 50 minutes, but are presented as hourly averages in the database. Vector Wind Change (VWC) was calculated using the hourly wind vector observations. While VWC does account for impact from both windspeed and wind direction changes, it does not clarify the change in wind direction measured in degrees. Therefore, an additional metric, hourly Wind Direction Change (WDC), was compiled for each station to give a more complete understanding of the wind changes at each of the 130 stations. WDC was calculated hourly using the modified degree range of -180 to 180 degrees. VWC is then averaged for each station over the yearlong period. For wind direction change, the kurtosis of the distribution is calculated to quantify the differences between the tails of distribution amongst stations the data. A high kurtosis value corresponds to light tails, indicating small hourly wind direction change.

To determine the highest risk stations, the top 20% of stations for VWC and WDC were identified, and stations present in both the top VWC and WDC were labeled as “high risk”. Stations were also analyzed with Kidson synoptic regime classifications, are based on the original 12 Kidson regimes, which are further split into three main groups based on overall pressure systems: Trough, Zonal, and Blocking. and are labeled with letters describing the pressure system and location (Kidson, 1999). VWC and WDC are further investigated within each synoptic regime in the year of data (Renwick, 2021). The Fire Weather Index (FWI) is calculated daily using the wind speed, temperature, relative humidity and precipitation at each of the 130 stations with a complete year of data. The FWI value was then averaged for each station over the same yearlong period as the VWC.

3. Results and Discussion

3.1. VWC and WDC for a Canterbury Case Study

In the Canterbury region, and out of the 130 stations, the Hakatere station had the highest values for both VWC and WDC indicating that there are both high windspeeds as well as significant wind direction change at high windspeed (Figure 1A). Given that critical fire weather conditions become more important for both high windspeeds as well as frequent wind direction changes, this suggests that the region around the Hakatere station is likely to experience more wildfire behavior unpredictability in the event of wildfire than the other station locations in Canterbury. In comparison, Godley Head has a low WDC at high windspeed, and therefore experiences more consistent winds, with low hourly changes and a predictable direction. This is likely due to the graduation change of the sea breeze cycle at the coastal location, as compared with the complex topographic influenced meteorology at the Hakatere location (Figure 1B).

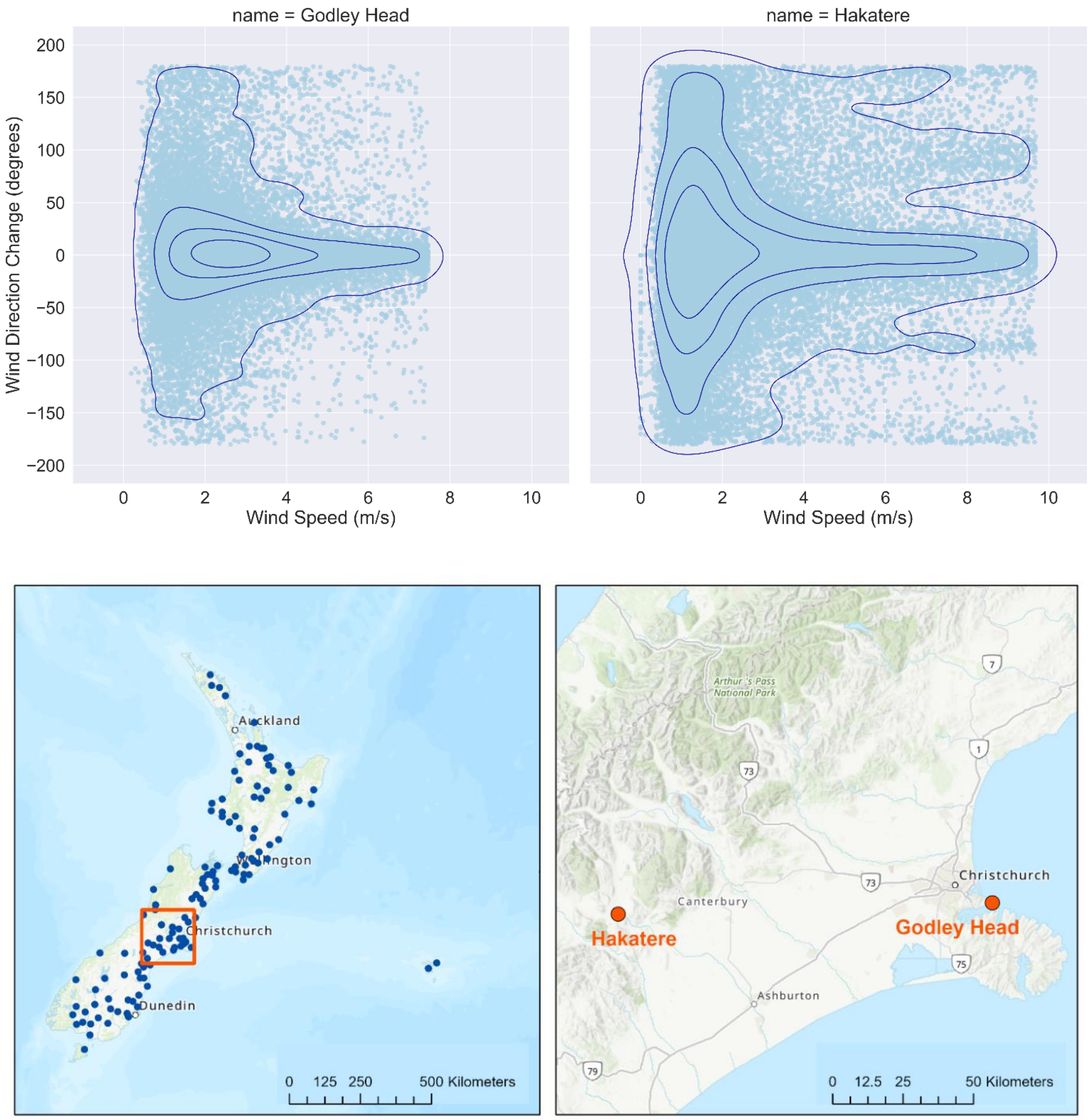

Figure 1- A) Highest and lowest windspeed kurtosis stations in Canterbury, with hourly wind speed plotted against wind direction change. B) Location of national stations, and Hakatere & Godley Head in Canterbury.

3.2. Nationwide wind change distributions

A nationwide analysis of stations shows distinct regional and topographic trends. High-risk stations (Figure 2, red) are located almost exclusively on the South Island, with one exception north of Wellington. Furthermore, all of these stations are located in areas of complex terrain and are not coastal. Similar to the trend in the Canterbury stations, stations in locations of complex terrain, such as the Southern Alps, have high VWC and WDC. This suggests that in New Zealand, there is a correlation between terrain complexity and wind vector and direction change, and therefore a potential trend to better predict fire spread. The locations with high VWC and low WDC (Figure 2, orange) are still a high risk for critical fire weather with high windspeeds, however do not exhibit as significant wind changes at high speeds. The stations with both low VWC and low WDC (Figure 2, green) are located on the North Island and the Chatham Islands. This suggests costal stations and stations on flat terrain exhibit more consistent wind and wind direction leading to lower VWC and WDC. This is likely due to the more predictable sea breeze cycle.

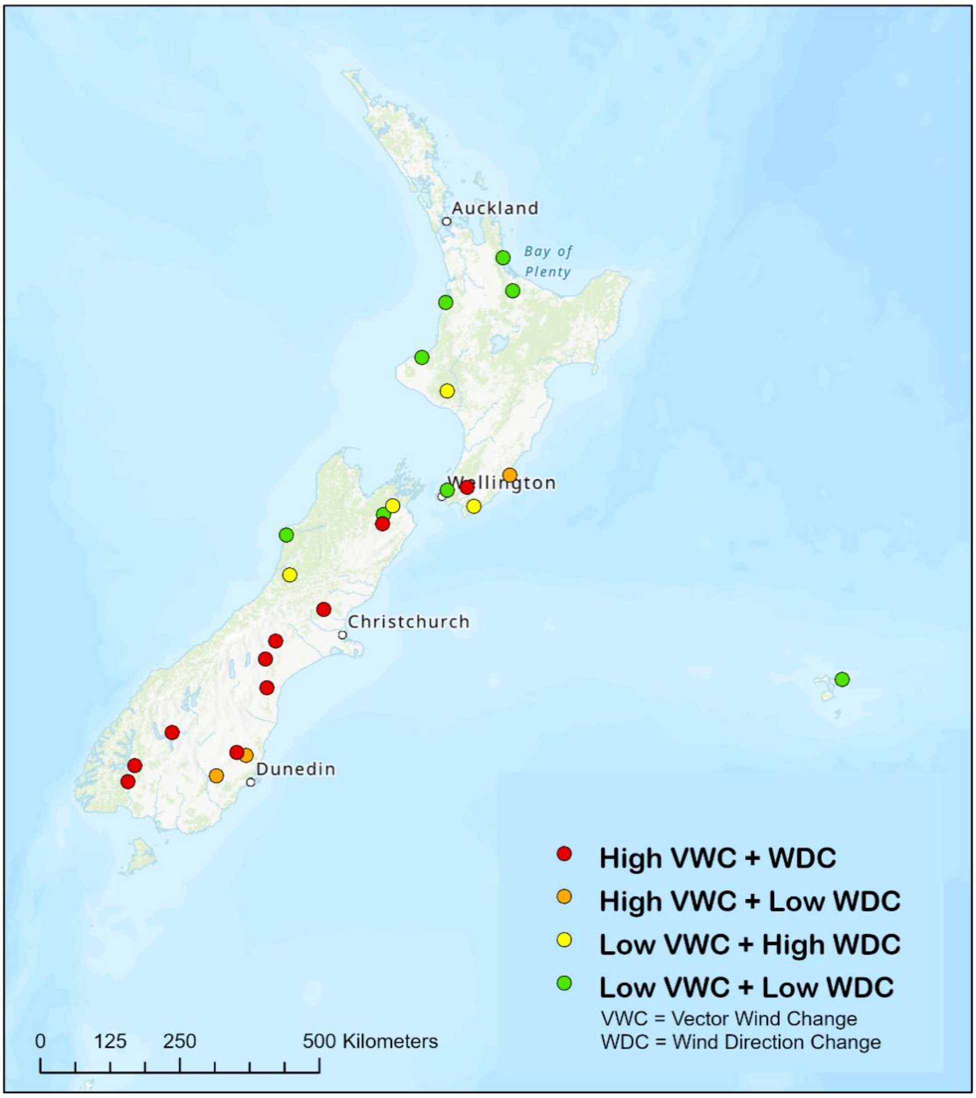

Figure 2- National Stations, highest or lowest 20% of VWC or WDC (based on mean and kurtosis respectively).

3.3. Synoptic Type Impact on Wind Change

In order to better understand the variables affecting VWC and WDC across New Zealand, a synoptic regime analysis was applied to investigate spatial pattern changes of high-risk stations in regard to weather systems. There is some variation between synoptic regimes in the stations identified, however the overall trend is consistent. High-risk stations appear almost exclusively on the South Island, except for a station near Wellington and one in the Central North Island (Figure 3). There are several stations that appear in almost all synoptic types, located in Fiordland, mountainous Canterbury and the top of the South Island. This uniformity in stations with VWC and WDC across synoptic types can suggest that the primary factor in these variables is terrain, not synoptic weather. Therefore, it is likely that some locations in New Zealand are at a higher risk of extreme fire behavior regardless of synoptic type due primarily to location and proximity to complex terrain.

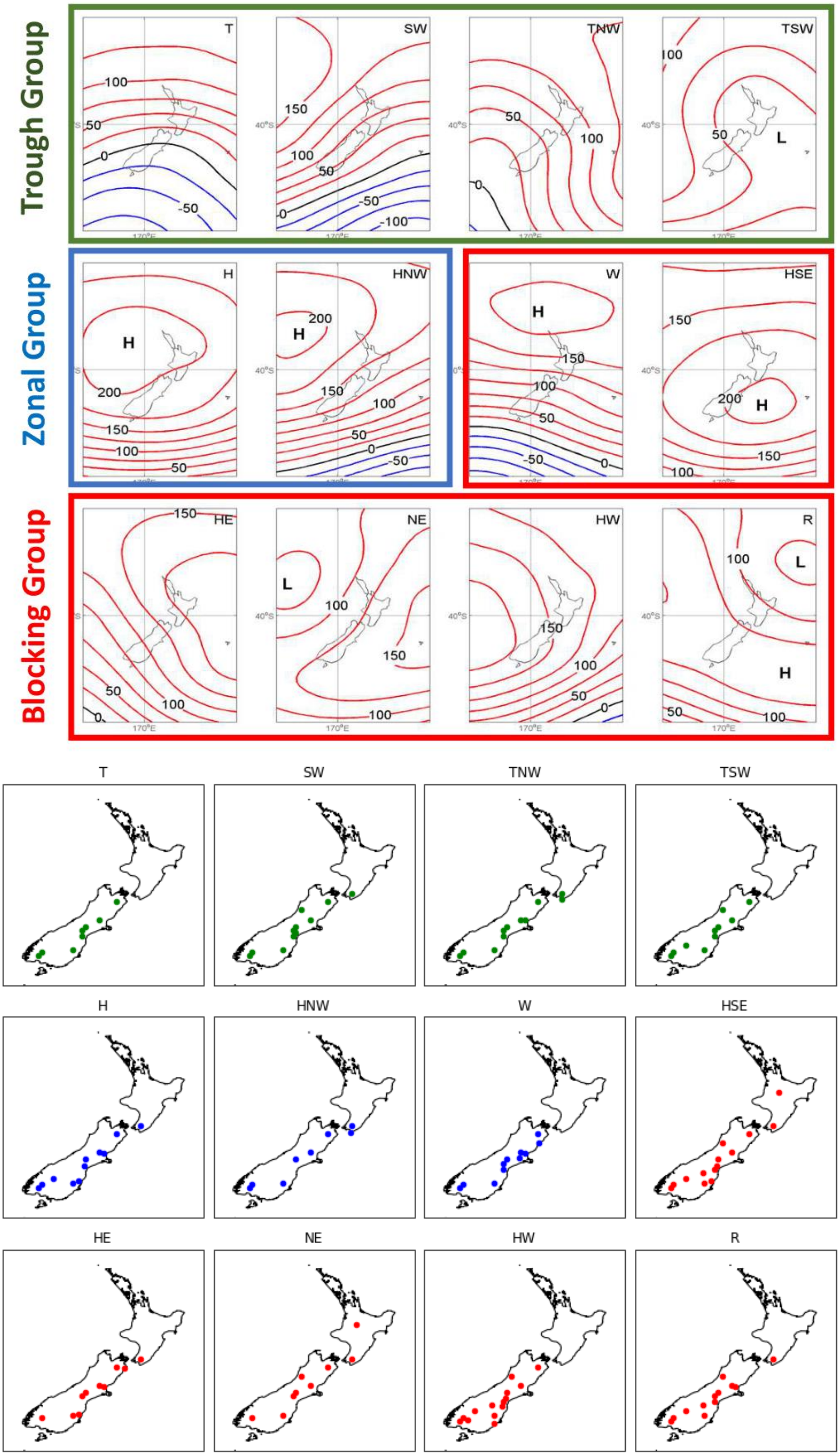

Figure 3- A) Synoptic Regimes in New Zealand (Kidson, 1999; Renwick, 2021). B) High Risk (Top 20% of Vector Wind Change and Lowest 20% Kurtosis) within each Synoptic Type, November 2020-2021.

3.4. Vector Wind Change and Fire Weather Index

The FWI was calculated for the 130 national FENZ weather stations at a daily time scale and averaged over the same period year long period as the VWC. The top 20% FWI stations were then mapped (Figure 4) to compare to the top 20% of the VWC and WDC stations. Interestingly, the same spatial trends appear in the high FWI stations as the high-risk stations, with most of the stations on the South Island. In contrast to the VWC stations, however, high FWI stations are found both coastal and inland. Out of the ten high VWC and WDC stations, four of them also appeared in the high FWI stations. The overlap in stations suggests that VWC and WDC could be useful additional parameters to FWI calculations around New Zealand to provide FENZ with additional information relating to microclimates in complex terrain to better inform fire risk and extreme fire behavior.

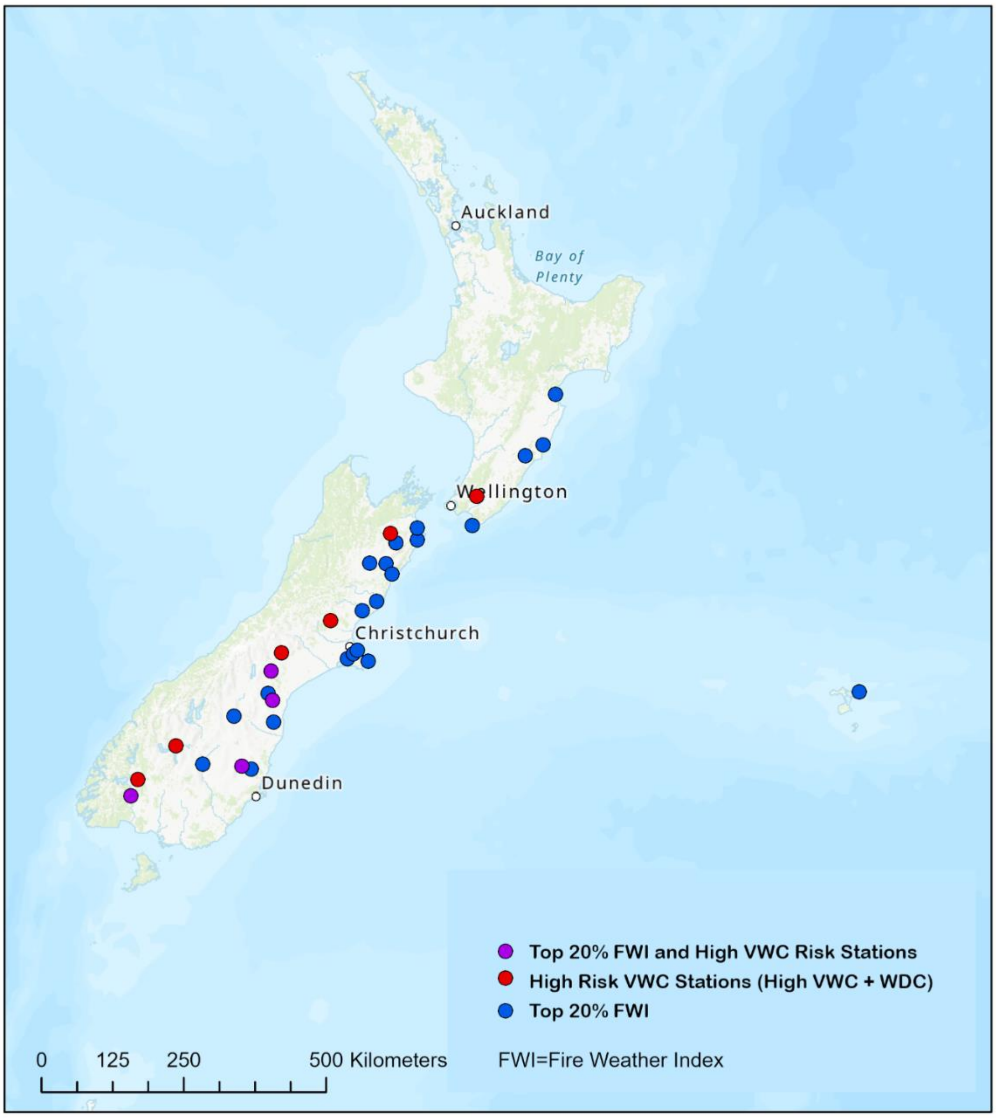

Figure 4- Top 20% VWC and Top 20% FWI Stations around New Zealand, for November 2020-2021.

4. Conclusions

Vector Wind Change, as well as Wind Direction Change, are useful near-surface variables for understanding potential wildfire occurrence conditions and its severity around New Zealand. These metrics are primarily forced by the impact of complex terrain on wind speed and direction and can be studied at the micro- and/or mesoscales and provide insight to the hourly wind changes across New Zealand. Given the importance of windspeed and direction on fire spread as well as extreme fire behavior, VWC and WDC could be important additional metrics in analyzing fire risk in New Zealand. When combined with Fire Weather Index data, VWC and WDC may provide additional information in predicting extreme fire weather and risk of unpredictable fire behavior. The next step for this project is to complete a comprehensive analysis of New Zealand meteorology using gridded weather data from numerical weather simulations providing 20 years of data to calculate the FWI, VWC and WDC, and analyze the trends spatially and temporally, across both an individual fire season as well as larger inter-annual trends. These trends will be explored further in an upcoming publication.

5. References

AFAC. (2017). Independent Operational Review Port Hills Fires February 2017.

AFAC. (2019). A review of the management of the Tasman fires of February 2019.

Dong, L., Leung, L. R., Qian, Y., Zou, Y., Song, F., & Chen, X. (2021). Meteorological Environments Associated With California Wildfires and Their Potential Roles in Wildfire Changes During 1984– 2017. Journal of Geophysical Research: Atmospheres, 126(5). https://doi.org/10.1029/2020jd033180

Foley, J. (2020). Fire and Emergency New Zealand Wildfire Investigation Report Lake Ohau.

Harris, S., Mills, G., & Brown, T. (2017). Variability and drivers of extreme fire weather in fire-prone areas of south-eastern Australia. International Journal of Wildland Fire, 26(3). https://doi.org/10.1071/wf16118

Hilton, J. E., Miller, C., Sullivan, A. L., & Rucinski, C. (2015). Effects of spatial and temporal variation in environmental conditions on simulation of wildfire spread. Environmental Modelling & Software, 67, 118-127. https://doi.org/10.1016/j.envsoft.2015.01.015

Kidson, J. W. (1999). An Analsysis of New Zealand Synoptic Types and Their Use in Defining Weather Regimes. International Journal of Climatology, 20, 299-316.

Kitteridge, M. (2021). Tethysts. In https://tethysts.readthedocs.io/en/latest/license-terms.html

Langer, E. R. L., & Wegner, S. (2018). Wildfire risk awareness, perception and preparedness in the urban fringe in Aotearoa/New Zealand: Public responses to the 2017 Port Hills wildfire. Australasian Journal of Disaster and Trauma Studies, 22: Port Hills Wildfire Special Issue.

Mandal, A., Nykiel, G., Strzyzewski, T., Kochanski, A., Wrońska, W., Gruszczynska, M., & Figurski, M. (2021). High-resolution fire danger forecast for Poland based on the Weather Research and Forecasting Model. International Journal of Wildland Fire, 31(2), 149-162. https://doi.org/10.1071/wf21106

Mills, G., Harris, S., Brown, T., & Chen, A. (2020). Climatology of wind changes and elevated fire danger over Victoria, Australia. Journal of Southern Hemisphere Earth Systems Science, 70(1). https://doi.org/10.1071/es19043

New Zealand Modeling Consortium Open Environmental Digital Library. (2021). https://www.envlib.org/#Data_access_updated

Pretorius, I., Sturman, A., Strand, T., Katurji, M., & Pearce, G. (2020). A Meteorological Study of the Port Hills Fire, Christchurch, New Zealand. Journal of Applied Meteorology and Climatology, 59(2), 263-280. https://doi.org/10.1175/jamc-d-19-0223.1

Renwick, J. (2021). Kidson Type Time Series New Zealand 1948-2021.

Van Wagner, C. E. (1987). Development and structure of the canadian forest fire weather index system. Canadian Forest Service.

Werth, P. A. P., Brian E.; Alexander, Martin E.; Clements, Craig B.; Cruz,, Miguel G.; Finney, M. A. F., Jason. M.; Goodrick, Scott L.; Hoffman,, Chad; Jolly, W. M. M., Sara S.; Ottmar, Roger D.; Parsons, Russell, & A. (2016). Synthesis of Knowledge of Extreme Fire Behavior: volume 2 for fire behavior specialists, researchers, and meteorologists.