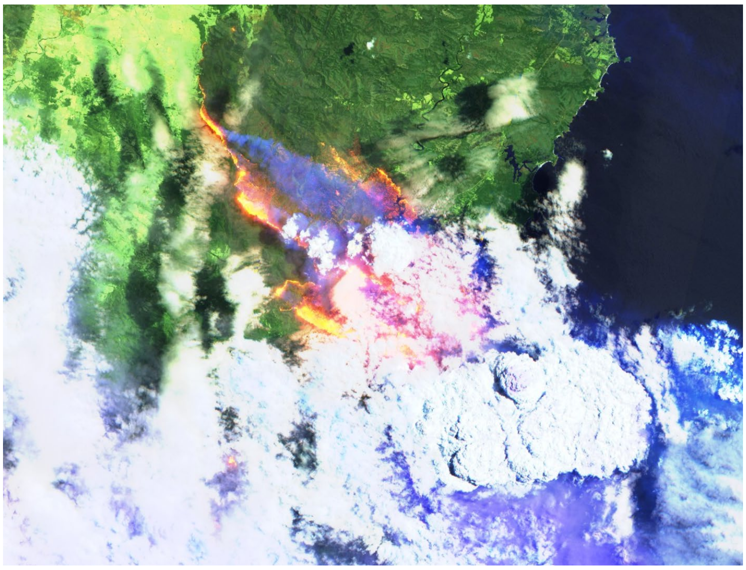
AUSTRALIAN FIRE PATTERN ANALYSES USING MODIS HOTSPOTS



Part 1: Overview

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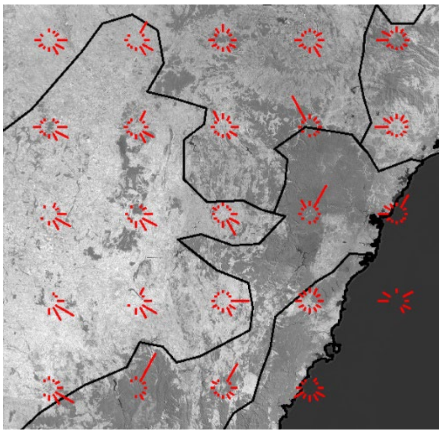
FINDINGS FROM ACROSS THIS SERIES

Part 1: Fire Seasonality

Original concept (Appendix to this report)

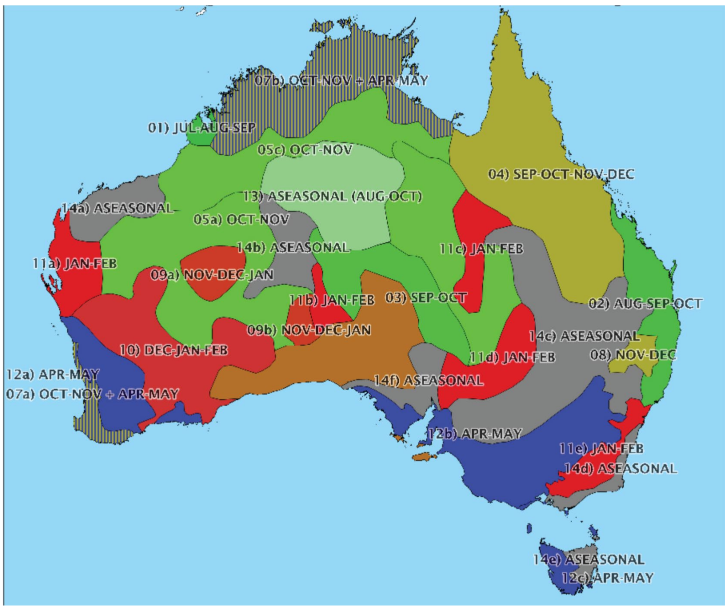
In the original paper that defined this work stream (McRae & Featherston, 2015) it was made clear that the fire seasons concept used by Australia's bushfire sector was insufficient to support fire services' response planning.

Using a one-degree grid that covered the continent, MODIS hotspots were aggregated and their frequency by month derived. Data from the 2002/2003 to 2013/2014 fire years were used. These were used to form a "rose", analogous to a wind rose, but with direction showing month, arranged like the hours on a clock-face. Critically the length of all rays in each rose summed to a constant value. It was found that there were extensive zones with similar roses. Some outliers were, of necessity, ignored.

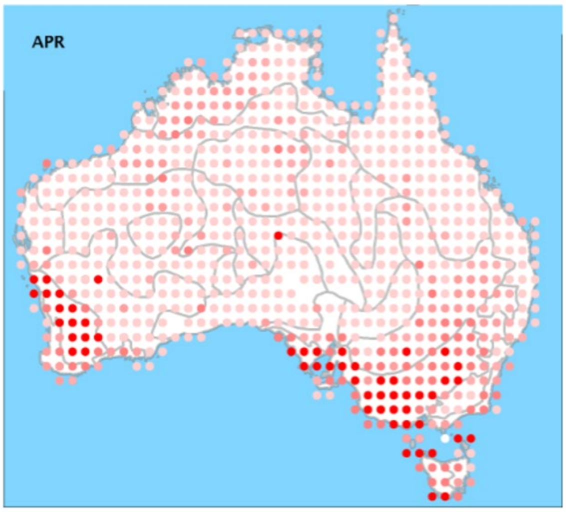


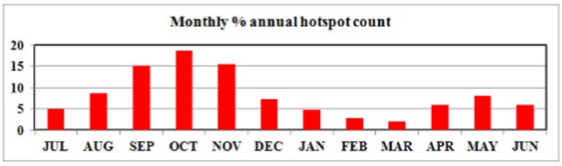
Example of roses and derived seasonality zones (around Sydney, NSW). Western zone: modes in April – May;
North-east zone: Mode in September;
Centre zone: mode in January;
South-east zone: aseasonal.

With a focus on seasonality, rather than absolute activity levels, the goal was to allow inter-annual comparisons of seasonal activity patterns at the level of the zones. With 29 zones for the continent, these are a broad-brush concept. However, the technique has worked well, as seen in the complex patterns shown in Part 2.



Also produced was a map of absolute hotspot density across the continent. Further continent patterns of *relative* frequency (percentage of annual count per month by 1° grid square) were produced. The continental version of this is very illuminating – in relative terms most of Australia's fire activity occurs in Spring.





The approach has some issues:

1. MODIS data does not distinguish between wildfires and prescribed burning.
2. MODIS data relies on a hotspot filtering algorithm that may not be fully discriminating at low FRP values.
3. Major blow-up fire events (BUFEs) burn so quickly that there may be insufficient heat to trigger the algorithm when a MODIS satellite next flies overhead.
4. Cloud and heavy smoke can block infrared signals.
5. Sub-pixel sized fires may be missed.

Issue 1 is partially addressed in part 4. Issue 3 can be compensated for by mapping BUFEs, using the technique in Peterson, et al., 2021.

Overall the technique has proven useful, especially for validation of seasonal bushfire outlook products from the BNHCRC and from AFAC. As McRae and Featherston state:

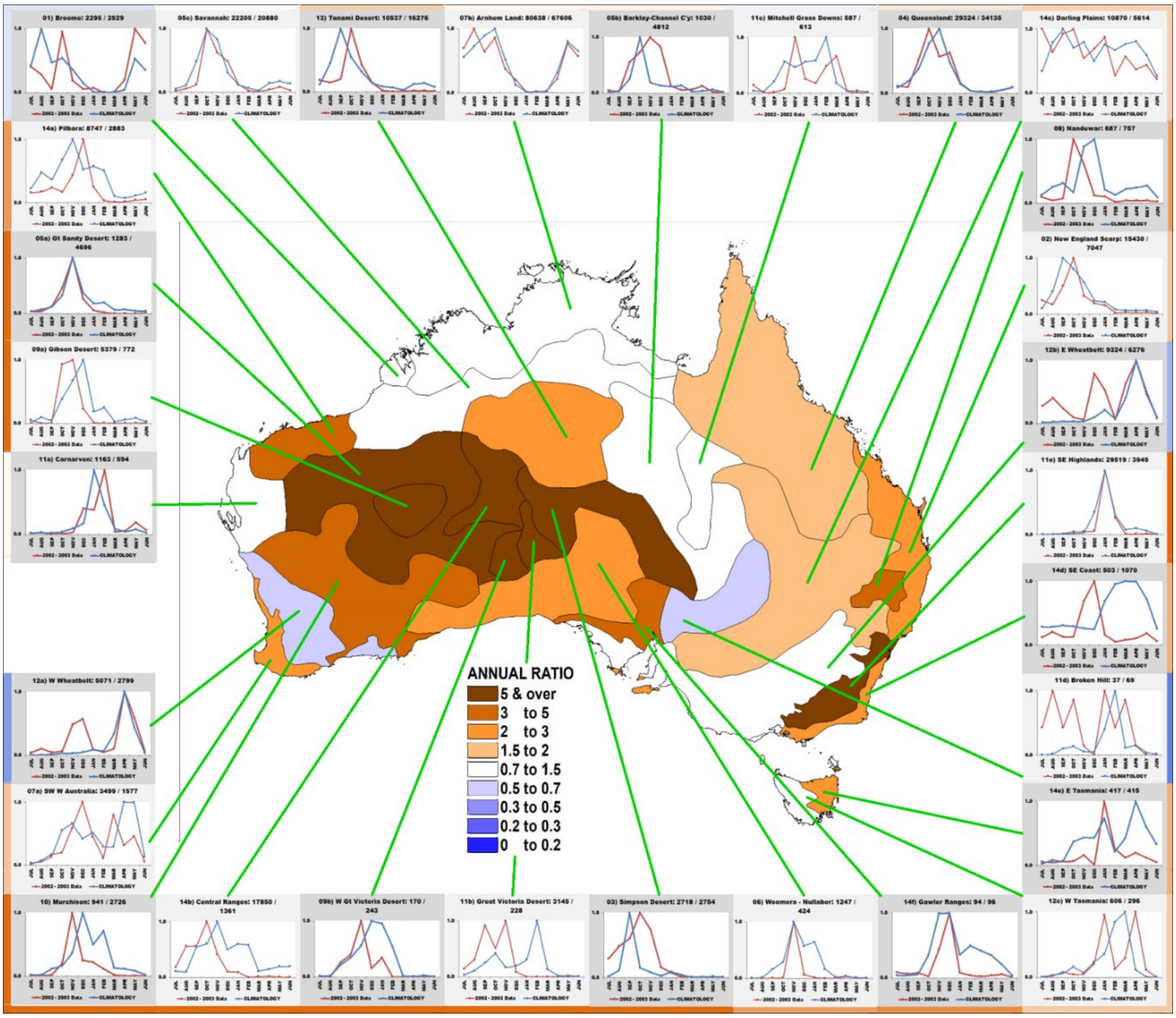
> "Given the broad range of vegetation types covered, it is expected that the detail in this climatology may prove useful when modelling of fire risk in each type is developed.
>
> "This work should also prove useful for detecting the impacts of climate change. By forming a national, consistent baseline, it should be practical to detect changes in frequency and seasonality. It may be possible to detect the onset of bimodality. Changes may arrive as a set of sporadic annual anomalies which, over time, form a new seasonality pattern."

Part 2: Annual activity patterns

For some years the technique described in Part 1 was used to produce standardised graphics summarising the previous fire year's activity patterns. Part 2 shows these, along with some annual climate graphics. For each zone, the following are presented for each fire year:

- The year's rainfall, as a percentage of normal.
- The year's temperature anomaly.

- A graphic showing hotspot seasonality patterns.



The relationship between these is not always obvious. A forested area will have a drought factor that reflects recent drought and heat including in the spring lead-up to summer, while a wet spring will favour grass growth that may become flammable in the following months.

Away from the temperate south-east, the impacts of tropical cyclones and tropical-extratropical cloud bands may dominate some years. The tropical wet season is the main cause of non-summer-centric fire activity. On a decadal time-scale, major inland rain events can occur when multiple ocean areas configure to push moist air inland (the end of the Millenium Drought and the end of Black Summer where the two main events during the MODIS epoch). These can lead to major biomass build-up in arid regions, which become highly flammable in subsequent dry years.

Taken together these interact to form complex activity patterns most years.

Added to this is extra complexity due to climate change. El Nino events were the primary drivers of fire activity cycles when first understood in the 1980s. With many of the world's oceans warming, the strong dipoles that drove climate cycles are no longer present. An additional issue is that the warmer the air, the more water vapour it can hold. This creates more rainfall, and at times more intense storms. This makes the overall impacts of wildfire risk difficult to predict.

Part 3: Time Series Patterns

As useful are the patterns in Part 2 are, they do not give absolute detail on the build-up of fire seasons.

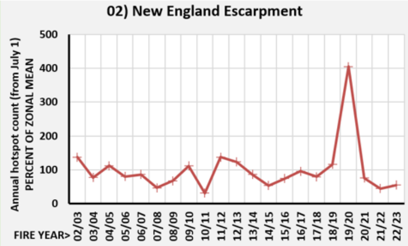
This part achieves that by providing graphs of the annual accumulation of hotspots. There is a graph for each zone, and a line for each year. This Part uses averages for the full set of MODIS years, so that (where relevant) the effects of Black Summer are included.

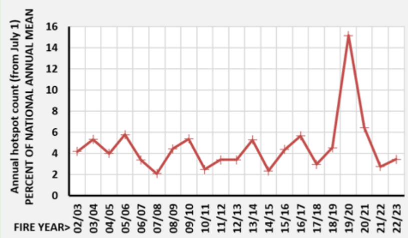
These show the following:

- Consistency and duration of fire seasons.
- Stand-out years.
- Overall variability.

Also provided, to aid in interpretation are:

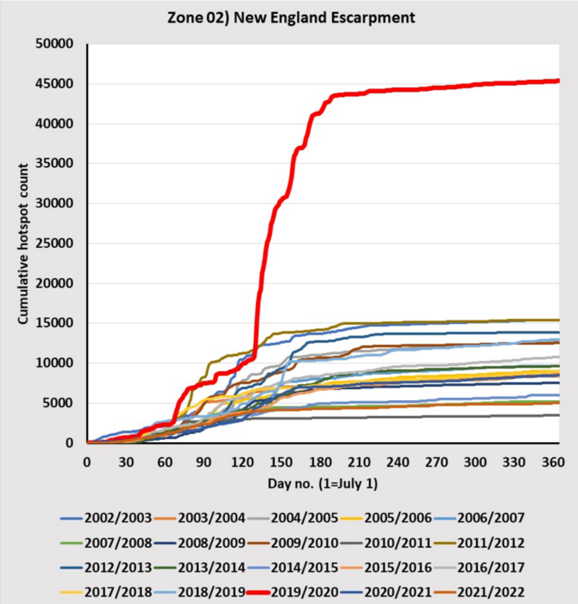
- A graph showing the total count for each year, as a percentage of the zonal average.
- A graph showing the total count for each year, as a percentage of the national average.
- A set of three graphs, showing the distribution across the fire years of hotspots between the 10th and 90th deciles – the core period of activity. Superimposed on that is the annual count on a logarithmic scale. This is because the graphs are done for three intensity ranges: for all hotspots; for hot hotspots with FRP over 100MW and for severe hotspots with FRP over 500MW, typically with a thousand-fold range in frequencies.

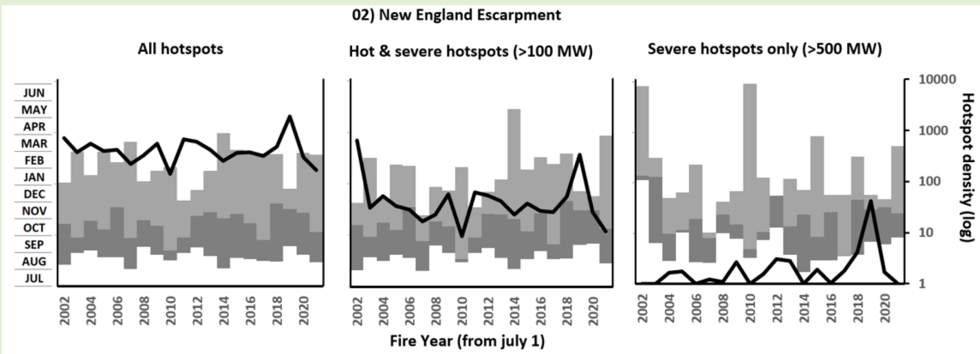




WIDTH 7

- Steady activity levels, swamped by BS – 300% above previous record..

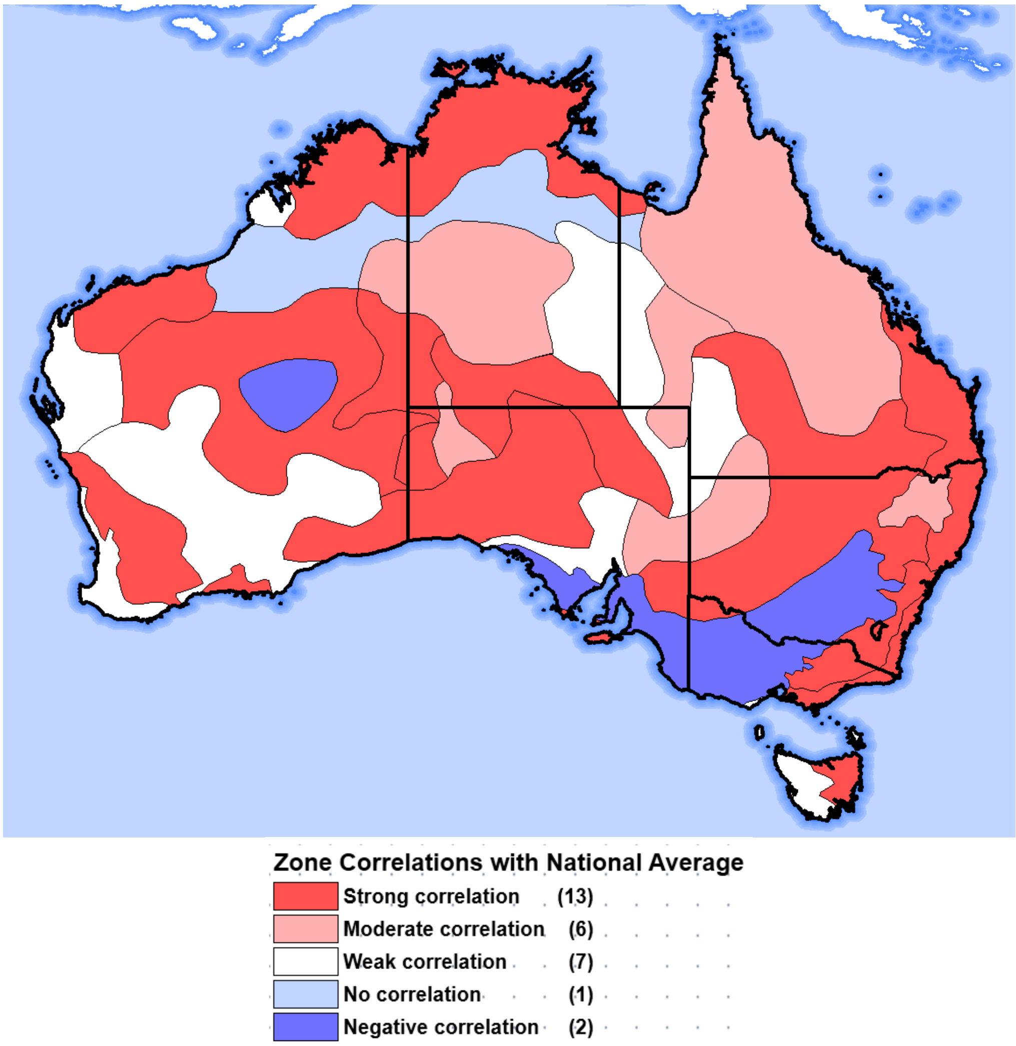




The following conclusions arise from these graphics:

- The zones can be grouped into higher-order patterns:
  Black Summer dominated;
  Dominated by the end of the Millenium Drought;
  Major zig-zag swings;
  Dominated by various active years;
  Uniform pattern; and
  Longer-term activity swings.
- The big events, like Black Summer, drove new records well beyond previous ones.
- Some trends are seen at the zone-scale:
  Queensland – for low FRP to start date shifted from October to September;
  SW Western Australia – the start date change after 2005 from November to October;
  W Tasmania – After 2018 the start shifted from December to October;
  E Tasmania – a decline in count for all hotspots intensity classes; and
  Nandewar – the 50th percentile for intensities up to 500MW shifted from November to February.
- Some zones strongly follow national trends, while other do so to a lesser amount. Some showsl reversal of activity levels. The table and map below show the correlation coefficients. A value of 1.0 suggests that the zone completely follows continental patterns, a value of 0.0 suggests a random relationship, while a value of -1.0 suggests a reverse relationship.

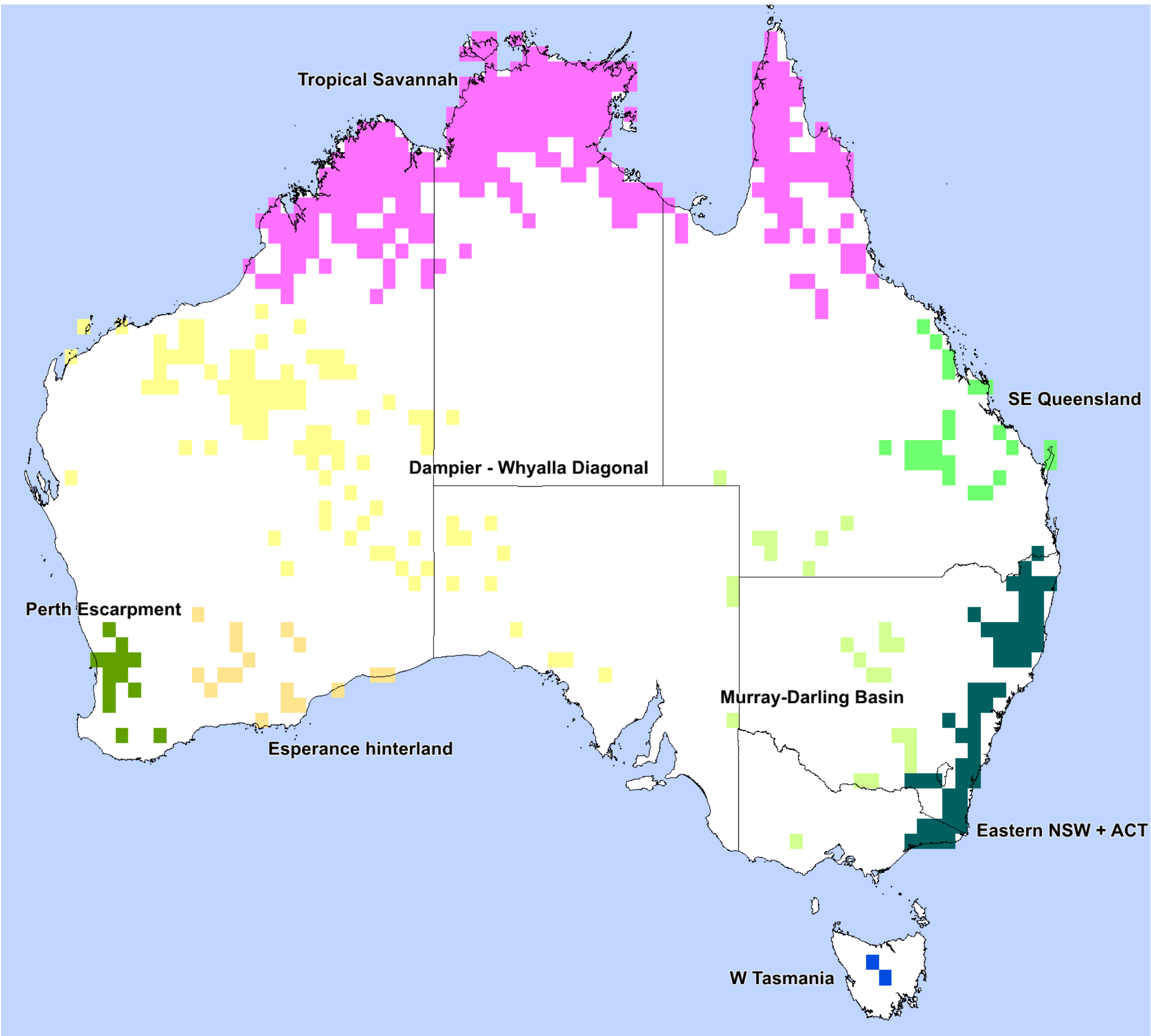
Zone	Correlation Coefficient	Zone	Correlation Coefficient
01) Broome	0.122	11b) Great Victoria Desert	0.378
02) New England Escarpment	0.768	11c) Mitchell Grass Downs	0.282
03) Simpson Desert	0.718	11d) Broken Hill	0.441
04) Queensland	0.347	11e) SE Highlands	0.785
05a) Great Sandy Desert	0.611	12a) W Wheatbelt	0.58
05b) Barklay - Channel Country	0.193	12b) E Wheatbelt	-0.43
05c) Savannah	-0.2	12c) W Tasmania	0.128
06) Woomera - Nullabor	0.68	13) Tanami Desert	0.392
07a) SW Western Australia	0.189	14a) Pilbara	0.586
07b) Arnhem Land	0.541	14b) Central Ranges	0.741
08) Nandewar	0.233	14c) Darling Plains	0.642
09a) Gibson Desert	-0.47	14d) SE Coast	0.73
09b) W Great Victoria Desert	0.804	14e) E Tasmania	0.569
10) Murchison	0.181	14f) Gawler Ranges	-0.06
11a) Carnarvon	0.165		



Part 4: Recent changes in fire activity across Australia

In a bid to resolve long-term activity pattern changes at a finer-resolution, this national study used a regular grid for aggregation of hotspots. The MODIS data were split into consecutive decades, activity changes between those two were detected mathematically. This produced eight areas of change:

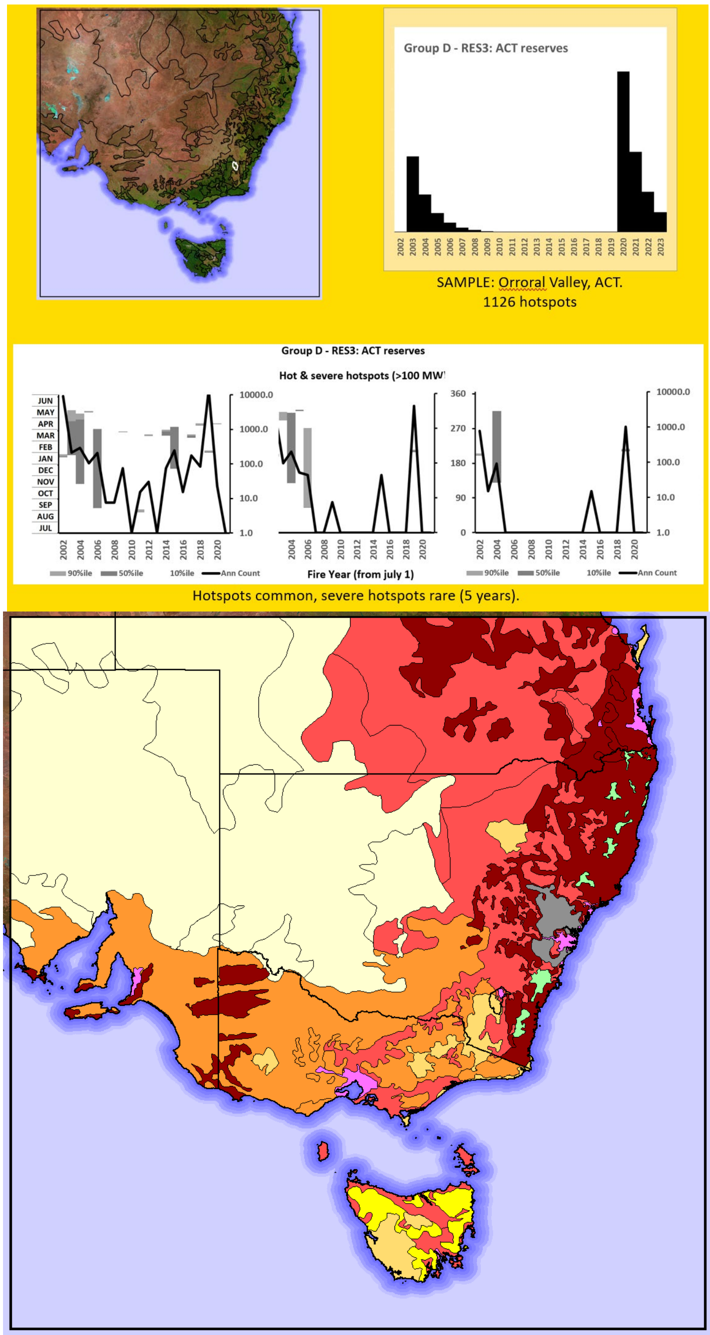
- The Perth escarpment, site of many intense fires and BUFEs.
- The Esperance hinterland, one of Australia’s pyroCb foci.
- The tropical savannah, where there is so much activity that minor trends can be significant.
- The Dampier-Whyalla diagonal, along the main low-pressure trough involve din inland fire weather.
- SE Queensland, which is seeing a steady increase in wildfire threats.
- The Murray-Darling Basin, seeing isolated patches where activity is increasing.
- W Tasmania, increasingly seeing major wildfires threatening Gondwanan vegetation.
- Eastern NSW + ACT, where major fire events in 2006, 2006, and 2019 are having major impacts on forest stand dynamics.



Part 5: A synthesis of fire regimes of south-east Australia

This study of south-east Australia used thirty-four detailed, district-level land-use areas to assess fire regimes. These did not align with biodiversity mapping, but did show consistent fire activity patterns. Some findings from this are:

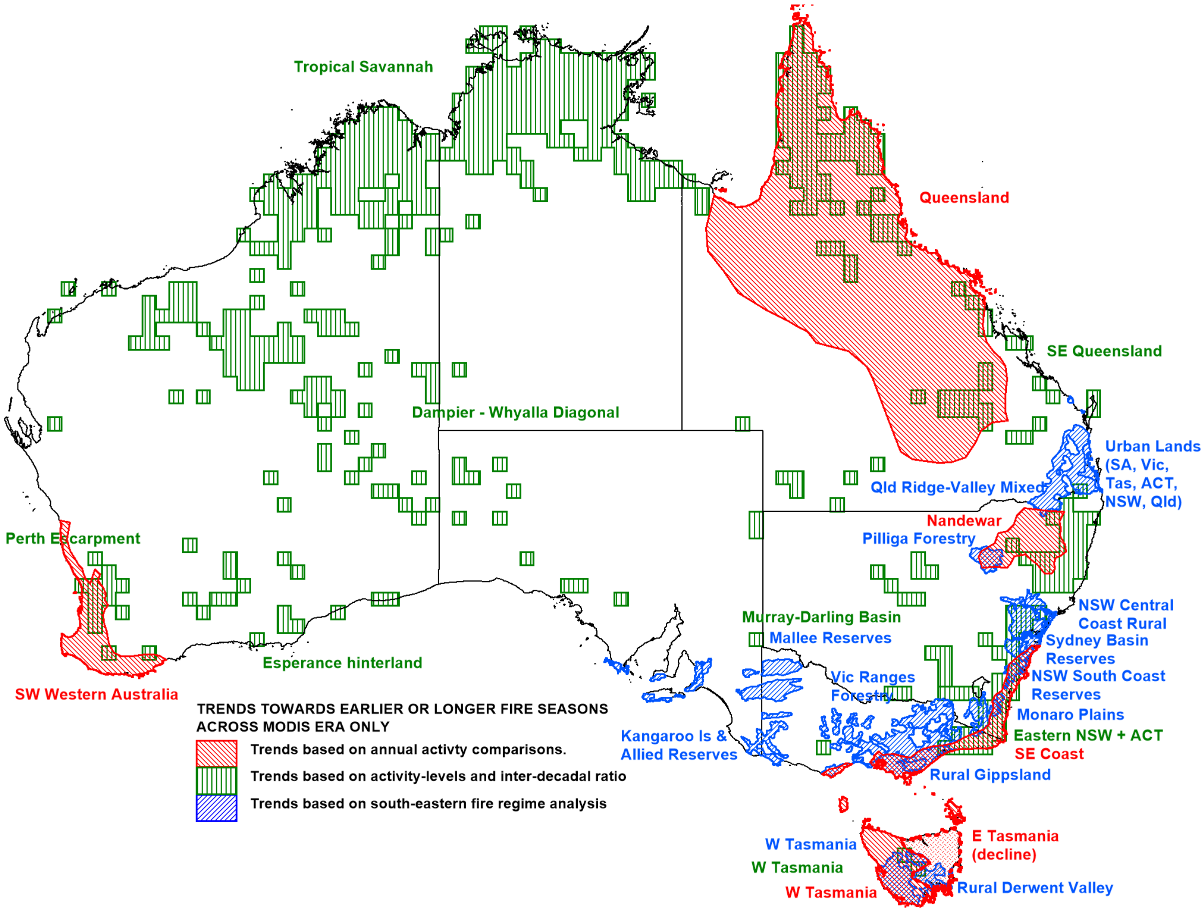
- Most areas have around 200 hotspots per 100km^2 per annum. Of these, roughly one percent are severe, and roughly ten percent are hot.
- Reserves, rural lands and rangelands have less than that frequency.
- Urban then broad-acre land-uses have the most hotspots overall, except….
- South-east Queensland forests have by far the most hotspots.
- Some areas have imbalanced fire age distributions due to repeated large fire events. This will make recovery difficult.
- Sixteen of the areas experienced pyroCbs. This spanned a range of vegetation types (but not all).
- Thirteen areas showed evidence of a trend towards earlier or longer fire activity periods. Most of these are around major urban areas.



Group	Description	Includes
A	Protracted hot burning	Mixed land-use; western reserves
B	Extended variable seasons	Reserves near Sydney
C	Extensive autumn burning	Southern forestry; wheatbelt
D	Variable summer & autumn burning	Most reserves; inland forestry
E	Variable spring & summer burning	NSW Coastal reserves
F	Protracted low-frequency burning	Rangelands
G	Protracted mid-frequency burning	Rural land
H	Protracted summer & autumn burning	Tasmania forestry
I	Protracted limited-intensity burning	Urban land

Part 6: Beyond MODIS - VIIRS

Using techniques at a range of spatial and temporal scales, the work reported here has allows a quantification of trends in fire activity in Australia. Reported in detail in the various parts, and summarised above, they can be brought together on a map:



To re-state what this shows:
green areas have district-level inter-decadal trends;
red areas show inter-annual trends across zones with consistent intra-annual activity seasonality patterns; and
blue areas show inter-annual trends across regions with consistent fire regimes.

In the coming years the MODIS carrying satellites are expected to run out of fuel. They are already changing orbital parameters ahead of that. Their replacements carry the VIIRS sensors. This is already in orbit on the SUOMI and NOAA20 satellites, with another scheduled. They are a marked improvement in ground resolution. However, VIIRS produces up to 14 times as many pixels per fire area than does MODIS. This will require detailed analyses if the MODIS climatology is to be extended into the VIIRS era.

Some areas show up in all techniques – for example major fires in Eastern Tasmania have required intensive interstate assistance. Some, such as the trend in the Tropical Savannah zone are more subtle, but perhaps for more challenging in the longer term. This example is particular will require care in the transition into the VIIRS era. The SE highlands have been hammered on multiple occasions across the MODIS era, so the step-up is not resolved here, even though it is perhaps the most significant on the continent.

Much has been said about fire seasons starting earlier or lasting longer. This set of papers aims to quantify or disprove those claims. By doing so, it becomes possible for those involved in bushfire risk reduction to better plan for and mitigate those risks.

Climate change is a major challenge. It is causing major fire events and changing the balance between climate drivers. If we are to protect our communities, our assets, our water resources and our biodiversity, then we need to understand how fire activity patterns are changing across the continent and with time.

APPENDIX

Below is a copy of a paper published after peer-review in the Proceedings of the 2015 MODSIM Conference, held at the Gold Coast. It is reproduced in full because it defines the technique used fro the various analyses that follow.

McRae, R. and Featherston, G. (2015). Modeling Australia's fire seasonality. Proceedings, 2015 MODSIM Conference, Gold Coast. www.mssanz.org.au/modsim2015243

Modelling Australia's Fire Seasonality

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[a]ACT Emergency Services Agency, Canberra. [b]Australasian Fire and Emergency Services Authority Council, Melbourne.

Abstract: There are now enough years of high quality MODerate-resolution Imaging Spectroradiometer (MODIS) hotspot data to attempt a review Australia's fire seasons. MODIS is carried on both the Aqua and Terra spacecraft. Standard algorithms assess the spectral signature of each pixel and the pixel's neighbourhood to tag some as indicating fire. The databases of these are now readily available for analysis.

Hotspots are point objects with some positional uncertainty due to viewing angle, terrain and orbital instability. They are fully attributed with data about collection time and assessed intensity. Aggregation of these for the purposes of identifying patterns is not straightforward.

Australia's fire industry still largely relies on fire-season maps produced decades ago, long before modern remote sensing technology. Changes in land use, social structures and even climate can be expected to have potentially altered the seasonality pattern.

A seasonality pattern derived from hotspot data was produced on the following basis. Firstly, month was the temporal unit for aggregation. Secondly, all fire hotspots were used, including both wildfire and higher intensity fuel reduction burns. While this produces issues, it is suitable for a range of key applications.

Thirdly, aggregation was done by means of a 1° grid. Finally, all hotspots from July 2002 to June 2013 were included.

Spatial software was used to produce, for each grid cell, a “wind rose” type diagram, with twelve spokes radiating out from a central core. The length of each spoke was proportional to the relative frequency of hotspots in that grid-cell, with months arranged like on a clock-face with January being month one.

It was found that to a large degree there were extensive, coherent groups of these roses, referred to as zones.

In all 29 zones have been identified. Many have a clear unimodal distribution, while some are clearly bimodal. Six were classified more by a lack of a clear modality, in contrast to their neighbouring zones. These were termed “aseasonal”.

The results were also used to produce a national hotspot frequency map. This identified some areas where the existing climatology may be insufficient to have confidence of a stable zonation. Dynamically extending the climatology may resolve this in future years.

It was found that the seasonality is very different from that current in use. This may be due to the conflation of deliberate and wildfire hotspots. It is not currently practical to separate all wildfire hotspots, but those due to major wildfires will be identified as part of on-going research.

Keywords: Satellite hotspot, MODIS, fire season21st International Congress on Modelling and Simulation, Gold Coast, Australia, 29 Nov to 4 Dec 2015

1. INTRODUCTION

Australia has widely varying climatic regimes. In response to these, the vegetation exhibits diversity in its floristic composition, structure and seasonal dynamics. In association with terrain patterns, the result is a complex mix of fire seasonality. This pattern has two major additional sources of heterogeneity: firstly, the impacts of human land management, and, secondly, anthropogenic climate change.

Fire agencies need to prepare for annual peak demands on their services and land managers need to be able to identify windows within which fire can be used as an effective land-management tool. Many elements of the Australian community face annual peaks of threat from wildfires, requiring preventative measures being put in place in the lead-up months.

It is clear that there is a need to fully understand the seasonality pattern across the continent.

Over much of the tropics, there are seasons where extensive fires are allowed to spread unimpeded, as nothing is threatened and there may be benefits from removal of rank vegetation. In southern regions the wheat-belts may be subject to post-harvesting stubble burns. Also in southern regions are the majority of urban areas which may come under attack from severe wildfires, driving the majority of media coverage of wildfire. Beyond these broad patterns there are significant elements that are not generally appreciated.

In the 1970s initial wildfire season maps were produced (Luke & McArthur, 1978, see Figure 1). However these are still used in modern research papers (see for example, Lucas et al., 2007 and AFAC 2015), perhaps applied well beyond their intended purposes. Most papers on climate change and bushfire include such a map.

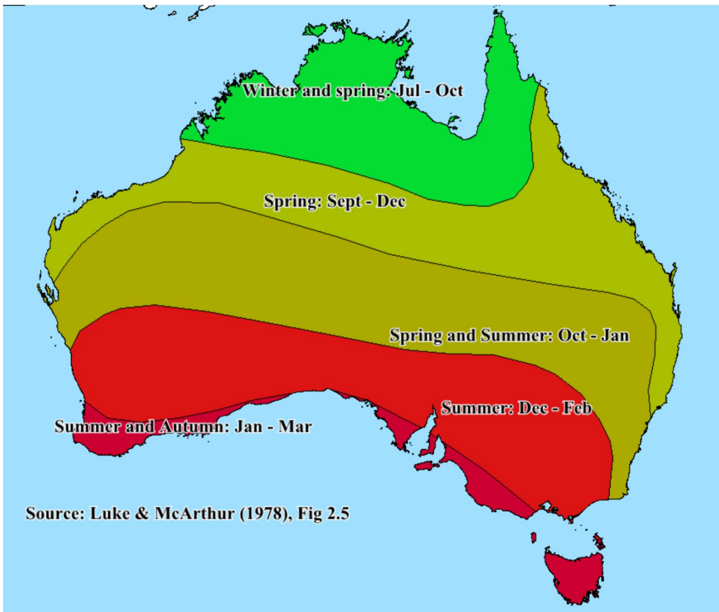

Figure 1. Seasonal fire occurrence map based on expert experience. This has been re-rendered to use the colour scheme in Figure 3. The colour gradient used shows modes in summer in red, those in winter in blue and those in spring in green. Aseasonal zones are grey.

The introduction of suitable satellite technology allowed a consistent database of fire detections to become a goal. Past studies on using this to understand Australia's fire patterns include Turner et al., 2007, Turner 2009, Maier & Russell-Smith, 2012 and Russell-Smith, et al., 2007. As these focused primarily on fire regimes, and with an emphasis on drier climatic regimes, there was still a need for a review of fire seasonality to support fire services' response planning.

The MODerate-resolution Imaging Spectroradiometer (MODIS) sensors on the TERRA and AQUA satellites had suitable parameters (World Meteorological Organization, 2015) to form the foundation of a hotspot- derived seasonality analysis. Algorithms were developed to scan MODIS images for spectral signatures ofheat sources that could be reliably assigned to fire (Giglio 2013). This database is now sufficient to capture most of the inter-annual variability that further complicates fire patterns. This includes La Niña events in 2007, 2010 and 2011, as well as minor El Niño events in 2002, 2004, 2006 and 2009. An interim climatology has been developed from this, using data from July 2002 to June 2013. This uses 2,881,800 hotspots.

There are clear limitations to using the technology, well identified in the literature. These include: detection of sub-pixel fires; duplicate records from multiple overpasses; blocking by cloud and dense smoke; orbit instabilities; rapid cooling after intense wildfires failing to pass the pixel filters; and the mixing of wildfires and prescribed burning (defined and discussed in AFAC, 2015) in the database. However a consistent national database provides benefits, including: no difference between jurisdictions and agencies; detection of all fires able to be detected; uniform accuracy and precision.

2. DATA

All data were sourced from NASA's Fire Information for Resource Management System (FIRMS) system (NASA, 2015). This has a record for each hotspot, containing location, timing and intensity data. These are created using standard algorithms (Giglio, 2013).

3. METHODS

The spatio-temporal variability of the dataset required an approach that was able to detect broad patterns. To do this a national 1° grid was established (on the GDA94 spheroid, equivalent to WGS84), with 792 entries.

All hotspots were assigned to the month of capture (January = 1). The data were then aggregated into the grid and month.

Grid-cells were defined as polygons, and hotspots as points. Hotspot frequency for each grid-cell were based on the "within" Boolean spatial operator. Month of a hotspot was derived from its "Acquisition Date" attribute. Monthly frequencies were then used to generate a wind-rose diagram, placed at the grid-cell centroid, with 12 arms radiating out from a central core (see Figure 2). Each arm was oriented like on a clock-face with month number (January = 1) treated like hours would be. Each arm's length was proportional to the monthly frequency, with the summed lengths of all arms equal to 0.5° on the ground. MapBasic software was used to generate the roses and place into a spatial file in MapInfo. (MapBasic and MapInfo are Trademarks of Pitney Bowes, Stamford, CT, USA.)

Mapping these rose diagrams indicated that there were often spatial patterns based on strong similarities between adjacent roses. There was a significant level of noise imposed on these patterns, but the high level of coherence over large spatial distances indicated that there were real patterns to be extracted.

Some of these zones were easily identified, with continent-scale areas with closely related roses. Others were less homogeneous, in part being identified by their lack of similarity to adjacent zones. Finally some zones were delineated due to their consistent internal heterogeneity, and were labelled "aseasonal".

There were, however, large tracts with relatively low hotspot frequency, and these indicated that a longer time-span would be needed before definitive zones of fire pattern could be determined. On that basis a visual classification was performed for this version, with a clear objective of applying numerical taxonomy principles in perhaps five or ten years when all zones could be defined with high confidence. This could also be triggered by the end-of-life of the TERRA and AQUA satellites.

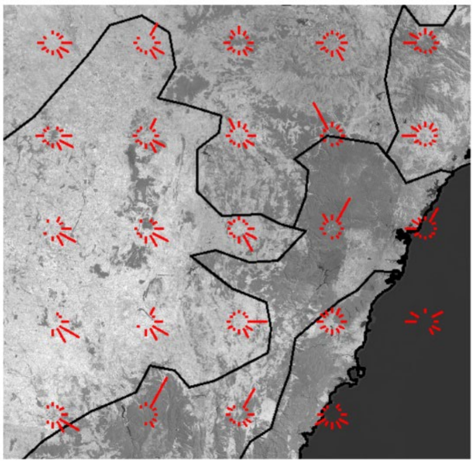

Figure 2. Example of roses and derived seasonality zones (around Sydney, NSW). Western zone: modes in April – May;
North-east zone: Mode in September;
Centre zone: mode in January;
South-east zone: aseasonal.

4. RESULTS

29 regions were erected, and are shown in Figure 3. Figure 4 shows the hotspots frequency pattern as an interpolated thematic map. Note the wide range of values (spanning three orders of magnitude). The higher frequency areas in the south are due primarily to sporadic extreme wildfires. Most zones showed a unimodal distribution (see Figure 5), some are bimodal and six are aseasonal.

In delineating zones, it was found that there were few clear relationships to boundaries of vegetation types, bioregions (Department of the Environment, 2013) or land-uses. The main exceptions were in the southern wheat-belts, where stubble burning was the dominant fire type. It is evident in Figure 3 and Figure 4 that the zones are often heterogeneous in hotspots frequency, which was not considered to be a component of seasonality in this study.

Figure 6 shows the overall distribution of hotspots between months, scaled to show temporal variability not absolute counts.

5. DISCUSSION

The technique proved relatively effective. In the low frequency areas there may need to be more years of data collected before seasonal patterns stabilize. These are semi-arid and arid areas that mainly carry fire in seasons after heavy rain. This is often due to decaying tropical cyclones or to La Nina events.

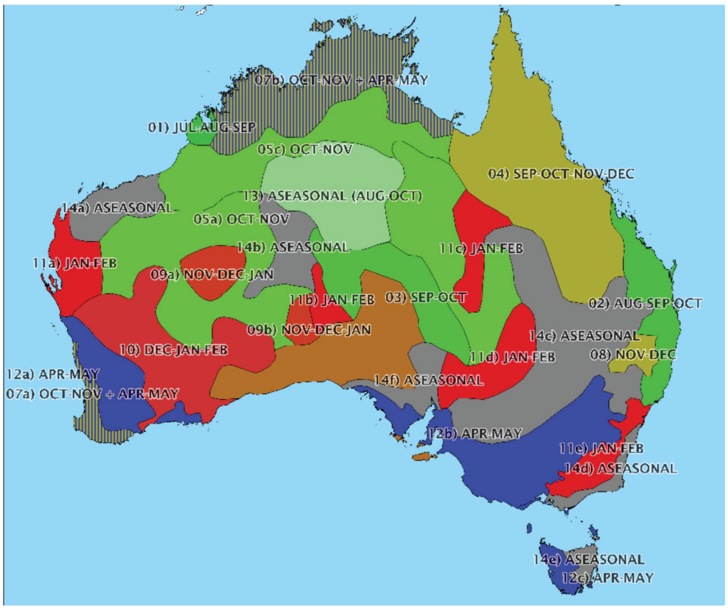

Figure 3. Hotspot climatology zones for Australia. The colour gradient used shows modes in summer in red, those in winter in blue and those in spring in green. Aseasonal zones are grey.

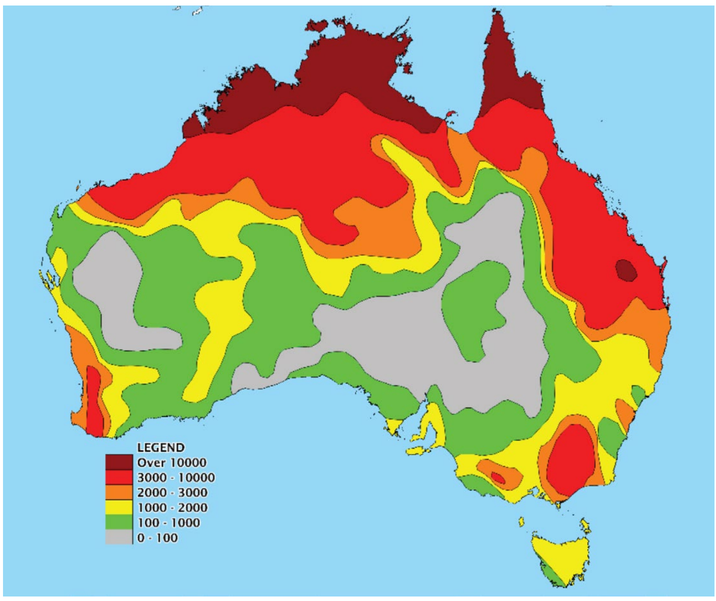

Figure 4. Hotspot frequency map.

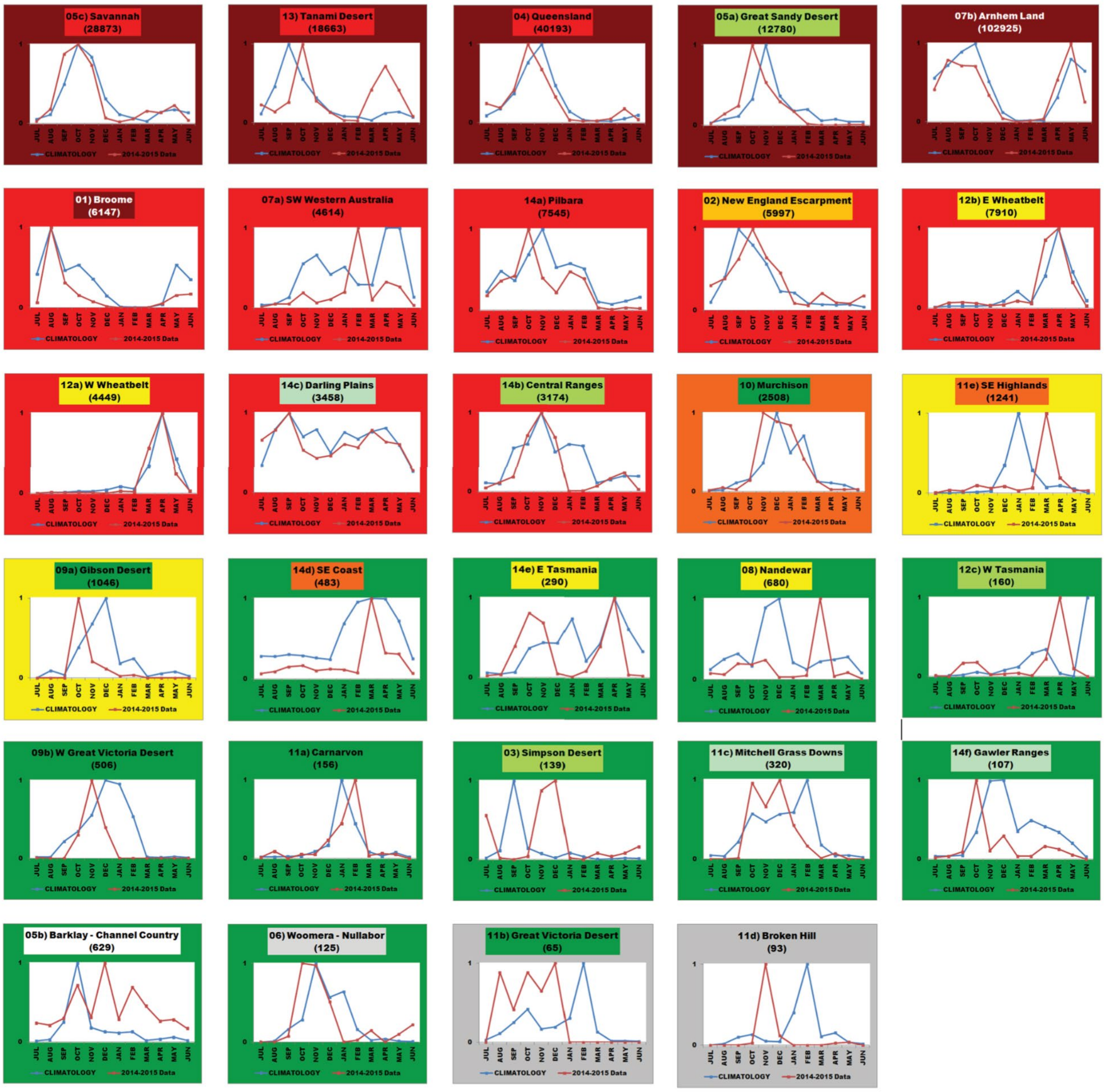

Figure 5. Monthly frequency graphs for the zones. These show climatological data and data for the 2014-2015 fire year. Both lines are scaled to a maximum of 1. The actual values are indicated through the background colours of graphic elements – the climatology through the chart title background and the 2013-2014 data through the plot area. The frequency colour scheme of Figure 4 is used. The 2013-2014 hotspot count is given in brackets below the title.

The climatology can only be extended for the life of the TERRA and AQUA satellites. Their currently planned replacements will have different characteristics and inclusion of data from them will introduce biases.

The results are significantly different from what is currently in general use. This is, in part, due to the confounding of wildfire and prescribed burning. Further work could explore resolving this, but would require data not presently available. This would require reconciliation of datasets relating to fires from all jurisdictions and fire agencies. Many fires cannot be neatly classed as wildfire or prescribed burn, especially long-lived uncontained fires in remote areas which, while intentionally lit, may from time-to-time threaten assets.

The original fire seasonality map may have been drawn to show the fire danger periods whereas the current results show the seasonality of fire occurrence. In the southern zones many small wildfires are suppressed before they are detected by the satellite sensors, especially where close to assets. Proximity to assets also drives considerable effort in prescribed burning (AFAC 2015), some of which shows up in the database.

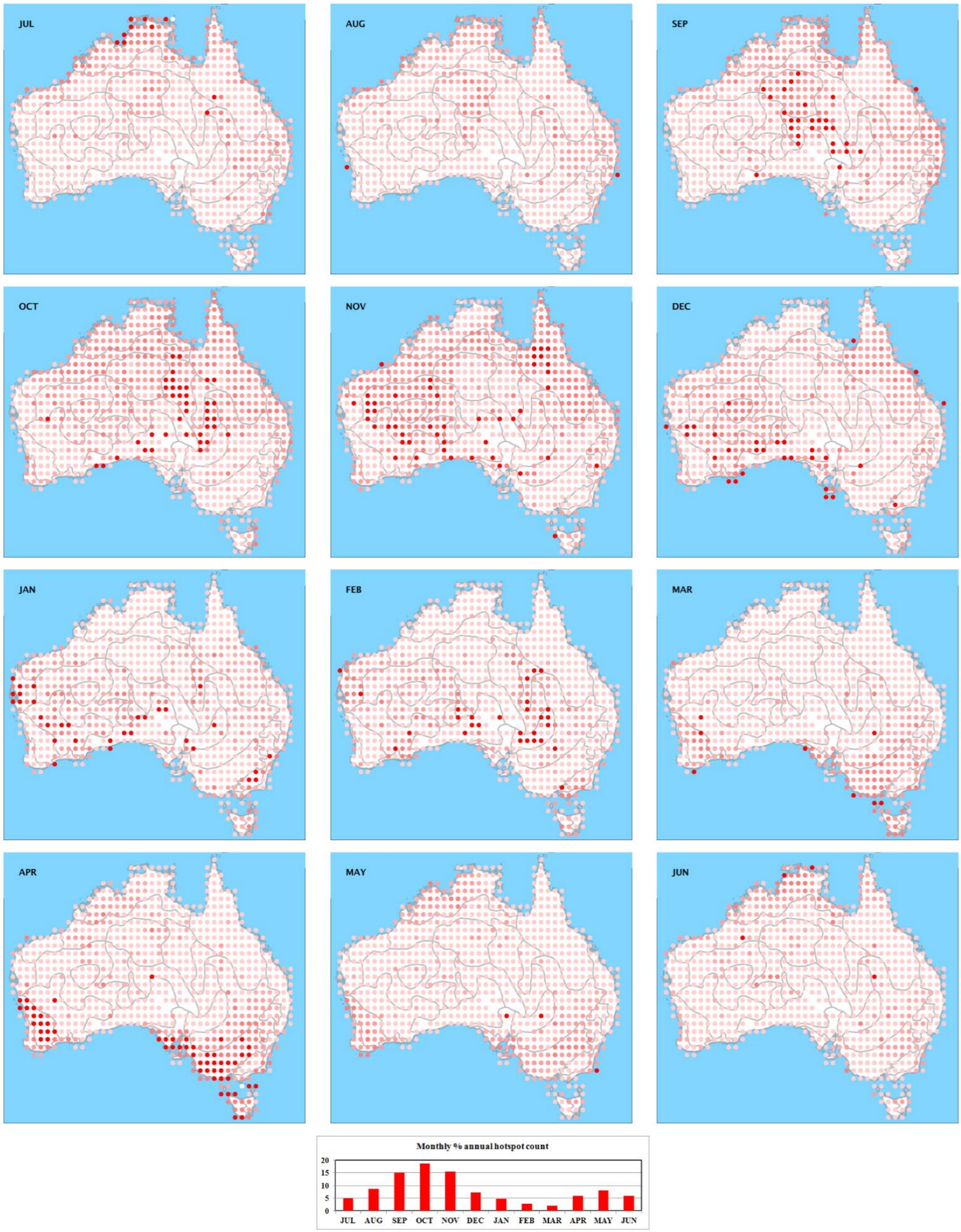

Figure 6. Continental monthly hotspot frequency distributions, scaled so that solid red shows the

maximum value for each month. Absolute frequencies, as a percent of the annual total, are also shown.

Annual anomalies, such as the major wildfires in the Blue Mountains in October 2013 (NSW Rural Fire Service, 2013), show out clearly – see Figure 7.

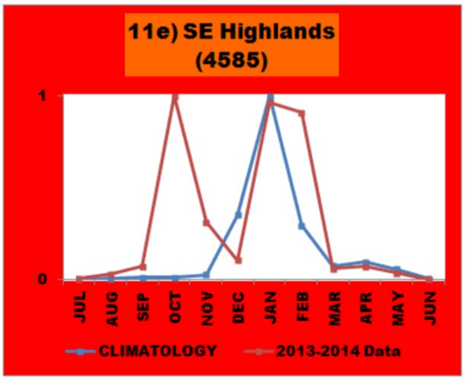

Figure 7. Example of an annual frequency anomaly.

Given the broad range of vegetation types covered, it is expected that the detail in this climatology may prove useful when modelling of fire risk in each type is developed.

This work should also prove useful for detecting the impacts of climate change. By forming a national, consistent baseline, it should be practical to detect changes in frequency and seasonality. It may be possible to detect the onset of bimodality. Changes may arrive as a set of sporadic annual anomalies which, over time, form a new seasonality pattern.

REFERENCES

AFAC (2015). Overview of Prescribed Burning in Australasia. Report for the national Burning Project – subproject 1. Australasian Fire and emergency Services Authorities Council Limited. March 2015.

Department of the Environment (2013). Australia's Bioregions (IBRA). URL: http://www.environment.gov.au/land/nrs/science/ibra. Retrieved 29 July 2015.

Giglio, L. (2013). MODIS Collection 5 Active Fire Product User's Guide. Version 2.5. Department of Geographical Sciences, University of Maryland, 61pp.

Lucas, C., Hennessy, K., Mills, G. & Bathols, J. (2007). Bushfire Weather in Southeast Australia: Recent Trends and Projected Climate Change Impacts. Report prepared for The Climate Institute of Australia.

Luke, R.H. & McArthur, A.G. (1978). Bushfires in Australia. Australian Government Publishing Service, Canberra.

Maier, S.W. & Russell-Smith, J. (2012). Measuring and monitoring of contemporary fire regimes in Australia using satellite remote sensing. In: Flammable Australia: Fire Regimes, Biodiversity and Ecosystems in a Changing World. Eds: Willians, R., Gill, A. and Bradstock, R. CSIRO Publishing

NASA (2015), Fire Information for Resource Management System (FIRMS). (URL: https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms, accessed 24 July 2015.)

NSW Rural Fire Service (2013). October 2013 fires. URL: http://www.rfs.nsw.gov.au/news-and-media/general-news/october-2013-fires. Retrieved 29 July 2015.

Russell-Smith, J. Yates, C.P., Whitehead, P.J., Smith, R., Craig, R., Allan, G.E., Thackway, R., Frakes, I., Cridland, S., Meyer, M.C.P. and Gill, A.M. (2007). Bushfires 'down under': patterns and implications of contemporary Australian landscape burning. International Journal of Wildland Fire, 16, 361-377.

Turner, D., Ostendorf, B. & Lewis, M. (2007). An introduction to patterns of fire in arid and semi-arid Australia, 1998–2004. The Rangeland Journal, 30, 95-107.

Turner, D. (2009). Fire in arid and semi-arid Australia: 1998-2004. PhD thesis, The University of Adelaide.

World Meteorological Organization (2015). Observing Systems Capability Analysis and Review Tool. URLs: http://www.wmo-sat.info/oscar/satellites/view/79 and http://www.wmo-sat.info/oscar/satellites/view/81. Retrieved 29 July 2015.249