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Modelling Australia's Fire Seasonality

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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 season*

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.

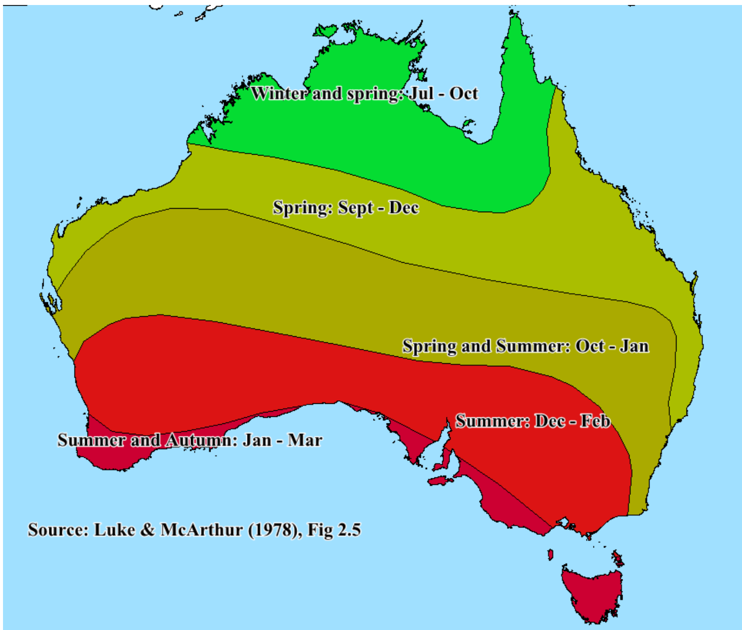

Figure 1. Seasonal fire occurrence map based on expert experience. This has been re-rendered to use the colour scheme in Figure 3. The colour gradient used shows modes in summer in red, those in winter in blue and those in spring in green. Aseasonal zones are grey.

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 of heat 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.

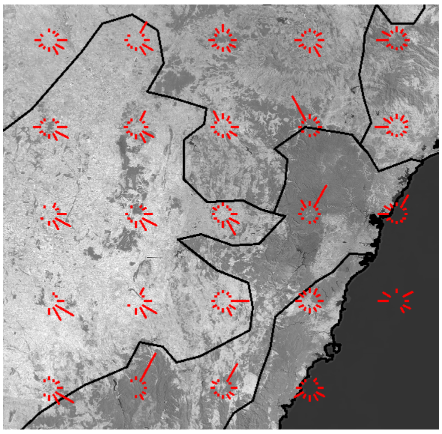

Figure 2. Example of roses and derived seasonality zones (around Sydney, NSW). Western zone: modes in April – May;
North-east zone: Mode in September;
Centre zone: mode in January;
South-east zone: aseasonal.

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.

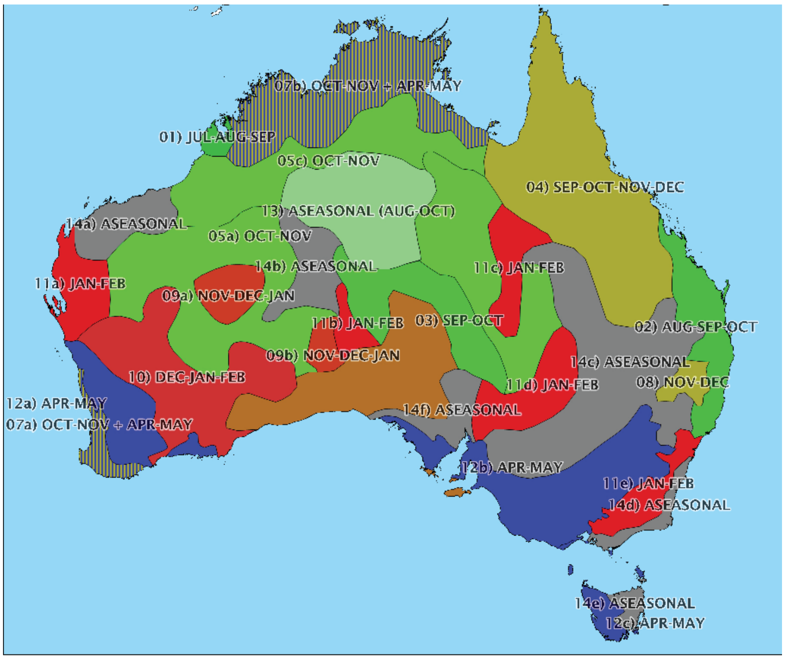

Figure 3. Hotspot climatology zones for Australia. The colour gradient used shows modes in summer in red, those in winter in blue and those in spring in green. Aseasonal zones are grey.

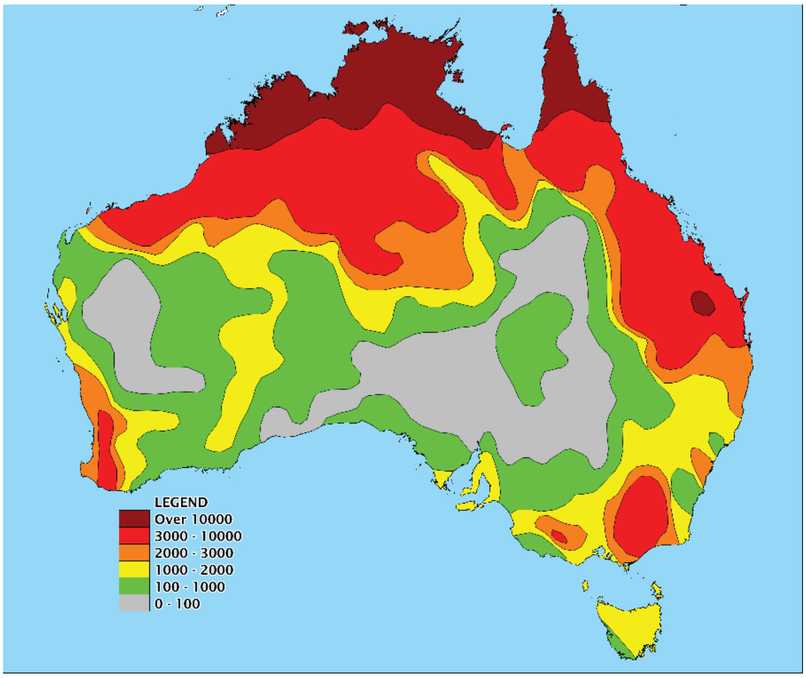

Figure 4. Hotspot frequency map.

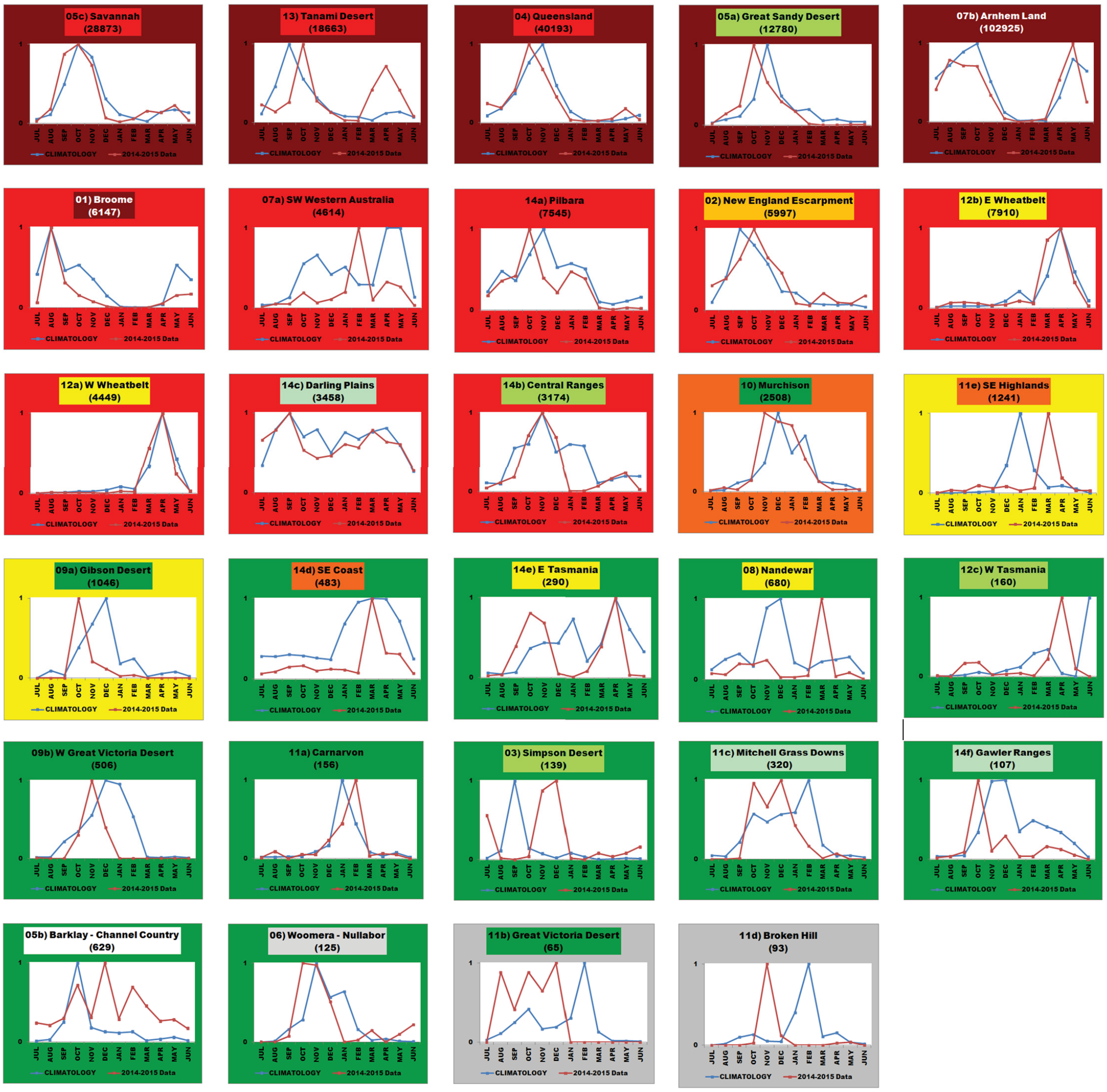

Figure 5. Monthly frequency graphs for the zones. These show climatological data and data for the 2014-2015 fire year. Both lines are scaled to a maximum of 1. The actual values are indicated through the background colours of graphic elements – the climatology through the chart title background and the 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.

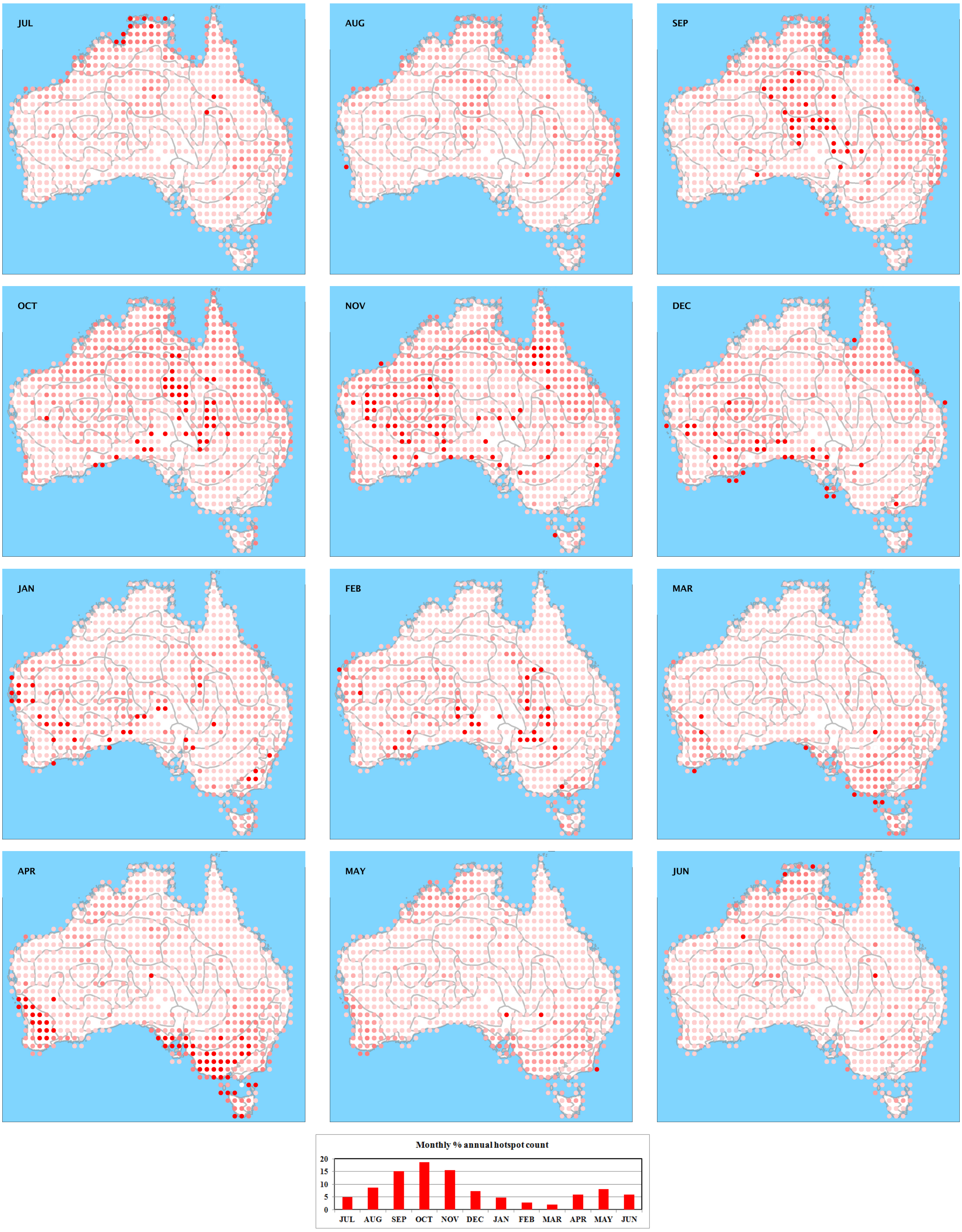

Figure 6. Continental monthly hotspot frequency distributions, scaled so that solid red shows the maximum value for each month. Absolute frequencies, as a percent of the annual total, are also shown.

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.

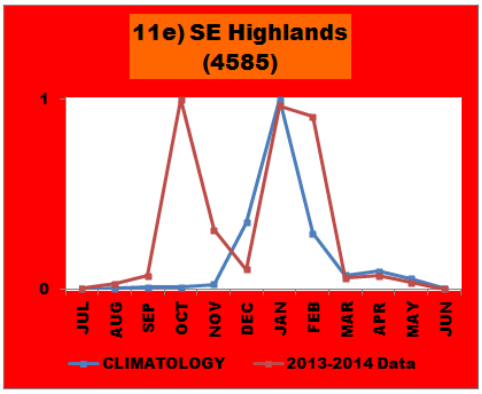

Figure 7. Example of an annual frequency anomaly**.**

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.

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