Integrating Understandings of a Yolngu Seasonal Calendar

A cross-disciplinary exploration of
Scientific and Indigenous Seasonal Knowledge
in North East Arnhem Land, Australia

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Candidate's Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge, it contains no material previously published or written by another person, except where due reference is made in the text.

Zac Hatfield-Dodds
May, 2016

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I acknowledge the Yolnu Elders of the Clan Nations of North East Arnhem Land, who have cared for country since creation, and maintained their law and sovereign responsibilities in this ancient land. Their wisdom and knowledge has been passed on to successive generations through ceremony, art and education. They have defended their sovereignty over ancestral lands and waters and their right to administer customary law.

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Abstract

Australia presents a challenging environment with highly variable climates. Better ways of understanding and managing our natural environment are urgently needed, and may be offered in the rich knowledge of Indigenous Australians – knowledge that is too often dissmissed, ignored, and undervalued. This thesis develops an approach which integrates traditional seasonal knowledge with quantitative science, demonstrated by investigating Yolngu seasons in north-east Arnhem Land.

Where previous studies of Indigenous seasons and calendars in Australia have recorded weather, social, and ecological characteristics of seasons – treating them as objects of study – this thesis treats Yolngu seasons as a framework for study, working with Yolngu participants to create a quantified calendar based on the observational weather record. No known previous research has quantified Australian Indigenous seasons in this way.

The methodology is cross-disciplinary and exploratory, drawing on the two-ways research literature. Informal, participant-led interviews with Yolngu people provide qualitative descriptions of the seasons and the structure of the calendar, and advice on how the seasons might be analysed. Consequently, some of the key findings are qualitative, derived directly from interviews (such as the structure of Yolngu calendars and definitions of the seasons), while others are the results of numerical analysis – quantifying and characterising the seasons.

Yolngu participants describe monsoonal, meteorological, and ecological seasons with distinct time-scales and indicators. Seasons can occur in any order, even 'interrupting' one another depending on indicator conditions. These properties are not recorded by previous research. Yolngu seasons are defined by environmental observations rather than the passage of time, the specifics of which vary substantially with location – as do their names and even what seasons are recognised. Detailed qualitative descriptions were collected to create a seasonal calendar. Each season was described in terms of daily weather and these definitions applied to the observational data, deriving the first known timeseries of Yolngu season occurence. This dataset allows characterisation of the seasons, and the first ever quantitative investigation of their timing. Accurate characterisation of this timing is another contribution of this research.

The methodology and methods developed in this thesis are suitable for use in similar research elsewhere. The code which quantifies Yolngu seasons in terms of weather conditions is robust and reusable, and could be adapted for study of the qualitative structure and definitions of other calendars. Flexible methodology for integration of Indigenous and quantitative scientific knowledge and knowledge systems is applicable in domains far beyond seasonal or ecological knowledge. Participant-led conversations followed by quantitative investigation uncovers and highlights unanticipated information and perspectives across cultural boundaries.

This thesis contributes to academic knowledge by developing methods to quantify Yolngu seasons, and demonstrating a research approach which integrates Indigenous and scientific perspectives. The outcomes suggest fruitful avenues for future research, which may consider seasonal calendars in other location or in greater depth or integrate Indigenous and non-Indigenous knowledge about other topics. These studies could extend scientific knowledge and understanding, as well as supporting concrete applications. Both approaches would contribute to a novel and genuinely local understanding of Australia, with implications for land and natural resource management, decision making, and policy.

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1 Introduction

Australia presents many challenges to good environmental management: its climate is among the most variable on Earth, combining years of baking droughts with flooding rainfall, the soils are relatively poor, and much of the flora and fauna is endemic or endangered (Davies et al. 1999). Since European colonisation, settlers have responded in many ways – drawing on their traditons, science, and social bonds among other strategies to cope with harsh landscapes and extreme climates. They have done well by some standards – agricultural and natural resource industries are large and stable. By other standards they have not: their practices and strategies have driven countless species to extinction, degraded ecosystems, and placed natural wonders like the Great Barrier Reef in serious danger (Flannery 1994). Much of this damage to the common heritage of Australians is irreversible or will take many generations to heal.

Australian people and institutions could learn from their colonial and exploitative mistakes, and appreciate the value in other perspectives. Alternatives are demonstrated by Indigenous Australian cultures, who have lived in and with 'country' for thousands of years – not as a generalised or undifferentiated type of place, but a complex, living entity made up of "people, animals, plants, Dreamings; underground, earth, soils, minerals and waters, surface water, and air" (Bird-Rose 2012, p7). To date, non-Indigenous Australians have all too often dissmissed, ignored, and undervalued Indigenous knowledge and perspectives. As recently as the 1960s schools taught that Indigenous people and cultures offered nothing of value and would inevitably die out (Flannery 1994).

More recently, Indigenous knowledges and knowledge systems have become recognised and valued in an increasing variety of contexts (eg. Berkes 2012, Cochran et al. 2015, Petheram et al. 2010). One way to realise this value is to deepen our understanding of natural cycles, especially as they may relate to land or natural resource management.

This thesis seeks to bring Indigenous knowledge together with western science, enriching both, in relation to a seasonal calender. Seasonal calendars are constructed by humans as a useful simplification of annual variation and cycles, coupled with domain knowledge – whether physical changes such as temperature, or social and economic events from birthdays to financial reporting. Effective land and natural resource management relies on local environmental knowledge of this kind.

Documenting and quantifying seasons defined by biophysical conditions or events allows researchers to draw on a significant body of existing, implicit knowledge about the environment. This knowledge supports decisions in a range of areas; from natural resource management to agriculture (Ens et al. 2012, Woodward et al. 2012), to energy demand forecasts, and the timing of meetings or holidays. Seasons have a profound impact on human societies, and understanding them matters. Knowledge of biophysical seasonality provides a nuanced basis for assessments of climate change impacts, or the success of adaptation or mitigation policies (Green & Raygorodetsky 2010, Prober et al. 2011, Stevenson 1996). This will only become more important as we move further into the Anthropocene (Steffen et al. 2007), and – for good or ill – humans exert increasing influence over the global environment.

Australian governments formally recognise four seasons, defined by Gregorian date: Summer begins on December 1st, Autumn on March 1st, Winter on June 1st, and Spring on September 1st (Wells 2013). This follows the meteorological standard for seasons, rather than the solar seasonal calendar marked by solsticies and equinoxes. Throughout the temperate zone, seasons are informally recognised more by temperature than date (summer being the hottest and winter the coldest time of year), and thus varying from year to year. While rainfall is often strongly seasonal, the relationship varies from place to place and it is less recognised as an indicator. However, temperate seasons are essentially irrelevant to the tropical and equatorial climate of northern Australia. In these areas a monsoonal Wet and Dry season dominate, generally recognised by weather conditions (eg. Kingsley 2003, Willmett 2009) but lacking any of the nuance or local knowledge embedded in Indigenous calendars, which are defined by weather and ecological events. Indigenous seasons may vary in timing and length between years as their indicators vary. Seasonal onset is declared retrospectively, some days after the change.

An alternative way of defining seasonal cycles is by periodic ecological events, whether plant (date of first flowers, etc) or animal (eg. migration). The study of such events is called *phenology*, which forms an important complementary approach to meteorology in assessment of climate change (eg. Roy & Sparks 2000). Menzel et al. (2006) analyse spring onset timing at several sites across the United Kingdom and Germany, using dozens of plant phenophases and butterfly appearance data, and find a strong climate change signal in earlier onset and increased variability. Such research may also draw on written records, which generally begin in the 1700s for European data and as early as 1180 in China (Yoshino & Ono 1996, p97) or the eighth century for Japanese observations (Sparks & Menzel 2002). Indigenous knowledge is derived from a significantly longer tradition. The ecological and phenological knowledge embedded in Indigenous calendars may provide a rich complement to written records, or an alternative in the many cases where such records do not exist.

Previous research on Australian Indigenous calendars (eg. BoM 2016, Baymarrwana & James 2014, Clarke 2009, CSIRO 2016, Davis 1989) has been qualitative, and focussed on the social or ecological aspects of the seasons. Many communities are justifiably proud to share their knowledge through CSIRO's poster project (see eg. Figure 2.3). Quantitative research on Indigenous seasons or even nuanced tropical seasons is rare in Australia, and may be valuable in informing traditional or western land and natural resource management. This thesis will therefore treat Indigenous knowledge as a *framework for* research, not simply an *object of* research.

This research investigates Yolngu seasons in North-East Arnhem Land, with the aim of developing an approach to integrating traditional seasonal knowledge with a quantitative analytical approach, in order to better understand the climate of a place. Yolngu seasonal calendars are complex – see Section 4.1.1 – with five (Davis 1989), six (Baymarrwana & James 2014), or seven (Barber 2005) seasons defined by weather and ecological events depending on location. The exact definitions are highly localised, and vary even between communities sharing the same language.

The project adopts a four-step methodology: understand the system to ask meaningful questions; identify key qualitative information; apply insights to construct exact definitions; and finally conduct quantitative analysis followed by comparisons and interpretation. Within this framework, it addresses the following research questions:

1. How are Yolngu seasons and calendar defined, and what are the definitions for each season?

2. How do these definitions of seasons vary between people or places?

3. Can a Yolngu seasonal calendar be developed which is consistent with Indigenous understanding and appropriate for cross-disciplinary analysis and interpretation?

4. What are the defining experiential, meteorological, and climatological characteristics of this calendar?

5. How can this calendar be defined by and applied in numerical analysis of weather observations?

Because research integrating Indigenous Knowledge with physical sciences is unusual, it is important to articulate a clear scope and statement of delimitations. This study will explore a single Indigenous calendar, with respect to recent weather data and contempoary Yolngu understandings. It will not attempt to address historical or pre-colonial perspectives, linguistics, or the implications of climate change – except as recommendations for further study.

The novelty and value of this work is in synthesis, bringing togther Yolngu perspectives on the natural environment, and the data-oriented approach of climate science. A review of the literature finds previous work on Indigenous seasons focused on qualitative description, but no quantitative or numerical research (see Section 2.3). Such synthesis provides a crucial long-term perspective on anthropogenic environmental change, and may produce novel and valuable results for both scientific and Indigenous stakeholders.

Thesis Structure

The chapters of this thesis follow the usual convention for a scientific report: Introduction, Literature Review, Methods, Results, Discussion, and Conclusion. Use of iterative methods makes the structure of the Methods and Results chapters slightly more complicated. These chapters can be read by sections, coming back to the second-stage methods after reading first-stage results, a pattern which reflects the research process.

This chapter (the Introduction) briefly introduces the topic of Indigenous seasons, the contribution of this research, context and study area, and outlines the structure and scope of the thesis. The Literature Review (Chapter 2) reviews prior research on Indigenous knowledge and seasons, tropical seasonality in northern Australia, and qualitative research methods. Chapter 3 lays out the methods used in the qualitative research with Indigenous participants, quantitative meteorological descriptions, and the methodological approach to synthesis. Chapter 4 presents qualitative and quantitative results, whih are then discussed and interpreted in Chapter 5. This chapter also includes reflection on the methods, novelty, and potential implications of the results. Chapter 6 summarises the findings and impact of the research, and proposes directions for further study.

The appendices are split into two parts. The printed appendices, Appendix A at the end of this document, contain additional figures which would interrupt the flow of the main text. The second part is the electronic appendices, which contain all other material judged to be useful for further study - including all numerical data and original computer code needed to reproduce the results.

2 Literature Review

This thesis seeks to investigate Yolngu seasons from two main perspectives: a cross-cultural, qualitative exploration of Indigenous knowledge; and numerical definition and analysis based on this exploration. The literature review first gives a general overview of the literature on Indigenous Knowledge and methods for respectful research with Indigenous people. The second section describes a scientific understanding of monsoon systems and tropical seasonality, along with previous approaches to quantitatively describing seasons based on weather events. The third and final section covers previous research on Indigenous seasons in northern Australia, and identifies a gap in the literature that this thesis aims to fill.

2.1 Indigenous Knowledge

There is growing recognition among ecologists, natural resource managers, and scholars worldwide that Indigenous peoples hold important knowledge about the natural environment (see eg. Clarke 2009, Ens 2014, Prober et al. 2011, and many others). The literature on Indigenous knowledge is well-established and vibrant, across a wide range of topics. Berkes (2012) defines Indigenous Ecological Knowledge as "a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission". Indigenous knowledge systems need not be related to ecology to be widely recognised in this literature, and are described by a variety of terms: Clarke (2009) refers to 'land-based knowledge', Petheram et al. (2010) and Turner & Clifton (2009) use 'traditional ecological knowledge', while Cochran et al. (2015) simply use 'Indigenous knowledge'. This thesis uses the term 'Indigenous knowledge', following the letter of invitation for this research (Figure A.1, on page 60) and emphasising that ecology is not the only subject of Indigenous knowledge.

Turner & Clifton (2009) distinguish Indigenous knowledge systems from 'objective' scientific knowledge on the basis that Indigenous knowledge of practical matters is value-laden and observations or experience are tangled with beliefs, philosophy, law, and spirituality. Woodward (2012), working in northern Australia, describes Indigenous seasonal knowledge systems as having strong connections to ecological knowledge, weather knowledge, resource collection, and spirituality.

In Australia and around the world, Indigenous knowledge is recognised in areas as diverse as climate change and sustainability assessment (eg. Cochran et al. 2015), holistic fire management (eg. Clarke 2009, Price et al. 2012), customary economic activities including aquaculture (Woodward et al. 2012), and natural resource management (eg.

Prober et al. 2011). A partnership approach to environmental protection and biodiversity conservation is increasingly common at local and state levels in Australia (Ens et al. 2012).

Just as written records can be used to construct records of historical weather events (eg. Rodrigo et al. 1999), Indigenous knowledge can improve western scientific understanding of seasons and climate – as demonstrated by Clarke (2009), Green & Raygorodetsky (2010), and others (though Green & Raygorodetsky (2010) found participants attribute recent 'strange changes' to local environmental damage rather than climate change). Observations and knowledge are passed down for generations, forming a tradition of incredibly detailed understanding at very fine scales (Barber 2005). This unsurpassed detail and nuance makes Indigenous Knowledge highly valuable in land, environment, and natural resource management applications. The literature provides a rich context for synthesis of Indigenous Knowledge and western climate science to investigate Australian seasonality.

There are real challenges involved in cross-cultural research with Indigenous people. Individuals and institutions may find it difficult to invest time and resources in building relationships which may not acheive existing research goal. For example, when Petheram et al. (2010) investigated perspectives on climate change adaptation in NE Arnhem Land, the community instead discussed housing, drugs, and land degradation – issues that are crucial to general as well as climate change resilience.

Respectful and appropriate processes are absolutely essential to research with Indigenous communities, following a long history of disappointment. Smith (1999) writes that "the term 'research' is inextricably linked to European imperialism and colonialism ... one of the dirtiest words in the Indigenous world's vocabulary". This connection is practical as well as theoretical – Woodward (2010) notes that "the way research agencies engage with Indigenous knowledge authorities creates a legacy for the next researchers who arrive", and that community engagement had been made more difficult by previous researchers who failed to follow through.

One form of good process for research with Indigneous people is 'two-ways' research, which has seen growing interest internationally and in Australia (Prober et al. 2011, Turner & Clifton 2009). Two-ways research "uses combinations of Indigenous and non-Indigenous knowledge and methods, and with the involvement of both Indigenous and non-Indigenous people towards a common goal" (Ens 2014). Marika et al. (2009) offer Yolngu perspectives and metaphors for good process and governance involving Yolngu and non-Indigenous people, standing in sharp contrast with the 2007 'Intervention'. They make the point that Yolngu have had to adopt or recognise many aspects of non-Yolngu law and culture, and criticise the failure of non-Indigenous governments to reciprocate.

The research reported in this thesis is situated largely in the two-ways tradition, as a natural continuation of pre-existing collegiate relationships between the author and several participants. Without the trust and respect built over years in these relationships, and the opportunity to follow up outside of academic deadlines, a good process for this study may have been impossible.

2.2 The Tropical Climate and Seasons

This section presents a short introduction to the quantitative scientific perspective on the tropical climate and seasons, covering the large-scale drivers of the seasons, detection of monsoon onset, and previous weather-based season definitions in northern Australia. Tropical climates and seasons are driven by three global patterns of atmospheric circulation: the Hadley cells of the general circulation of the atmosphere, the Coriolis effect, and the axial tilt of the Earth.

Hadley cells are a feature of the global atmospheric circulation caused by the variation in insolation (solar energy delivered per unit area) by latitude, which is greatest at the equator. As the warm air rises and cools, rain condenses out and forms the distinctive wet band of the tropics before air spreads towards the poles at high altitude. Air at the surface tends to move towards the *inter-tropical convergence zone* (ITCZ), causing the trade winds when deflected east or west by the Coriolis effect (Figure 2.2) (Kump et al. 2010). The mid-latitude and polar cells shape climates at higher latitudes, but are not directly relevant to tropical seasonality.

Monsoon seasonality can be understood as the ITCZ moving north or south with the latitude of greatest insolation, which changes due to the axial tilt of the Earth as it orbits the sun. While this is strongly associated with rainfall, the fundamental indicator is the direction of the prevailing wind: generally south-easterly below the ITCZ, and generally north-westerly above (Kump et al. 2010). Figure 2.2 shows how this pattern manifests in reversed seasons between India and Northern Australia. The presence of the ITCZ is associated with the Wet season and greatest rainfall, and its absence with the Dry season (Sturman & Tapper 2005).

At a local scale, a monsoonal cycle is often described with 'Wet' and 'Dry' seasons, sometimes with a separate pre-wet 'buildup' (Kingsley 2003). In the Northern Territory of Australia both are warm to hot, with distinctive changes in humidity and wind direction. The characteristic pattern of tropical seasons – distinct hot/wet and cooler/dry periods – is clearly visible in monthly averages of temperature and rainfall, which are given for the study area in Table 4.3 and Figure 4.1. Note that the more nuanced patterns described by Indigenous seasons are not visible in these summaries; Chapter 4 shows that this level of detail requires analysis of daily observations.

Monsoon onset is quantitatively characterised using a variety of approaches. Fasullo & Webster (2002), Sultan & Janicot (2003), and Wu & Zhang (1998) use wide-scale definitions – based on moisture transport, rainfall, and regional climate indicies. Hendon & Liebmann (1990), using observational data from a single station, base their analysis on prevailing high-altitude wind. Each definition uses a locally appropriate proxy for the state of the ITCZ, which is the ultimate driver of monsoon seasonality.

There is a considerable body of literature dealing with seasons defined by observed environmental change – from temperature thresholds in Sweden (SMHI 2015) to 'leaf out' for botanists (eg. Allstadt et al. 2015) or butterflies for zoologists (eg. Forister & Shapiro 2003, Roy & Sparks 2000). Indicators which cycle through qualitatively distinct states, such as deciduous leaves, are relatively accurate and easy to interpret but may be unavailable in some contexts.

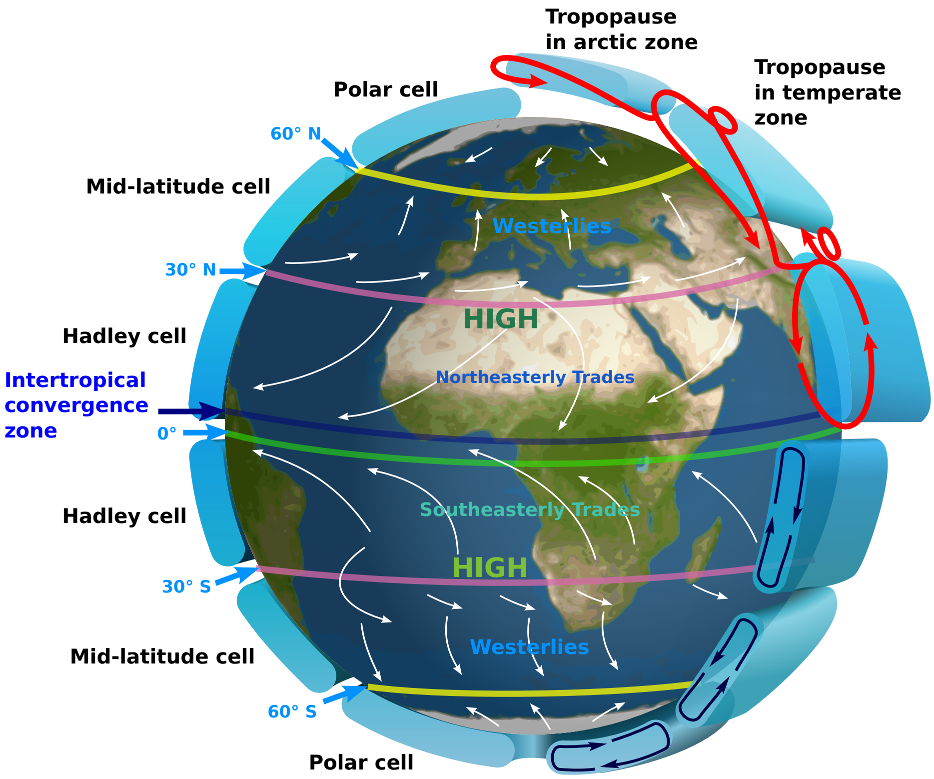

Figure 2.1: Diagram showing surface-level prevailing winds (white arrows), Hadley Cells, and the Intertropical convergence zone ('ITCZ'). Air rises at the ITCZ, heated by the highest - intensity sunlight. This causes a low-pressure band of trpoical rainfall, and the trade winds – deflected towards the west by the Coriolis Effect. (image: Kaidor 2013)

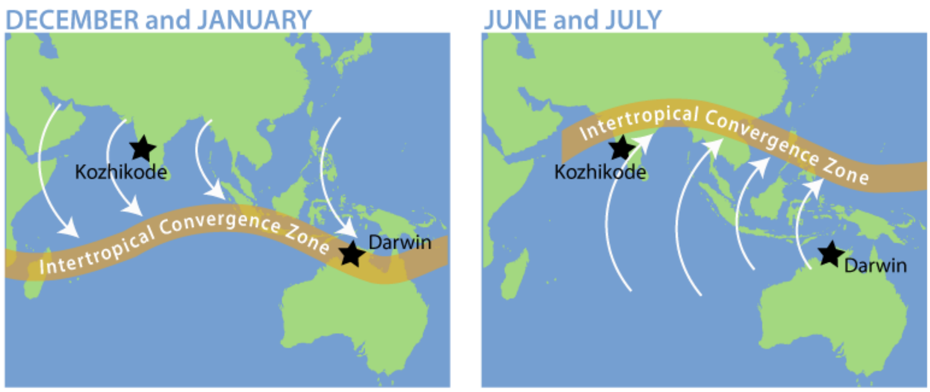

Figure 2.2: Approximate location of the inter-tropical convergence zone (yellow band) during the northern and southern monsoon. White arrows show prevailing wind direction; rainfall is associated with the ITCZ. (image: Boos 2014)

In Australia, Holland (1985) considers rainfall-based definitions of the monsoon, which demonstrate good agreement with definitions based on zonal wind in the lower troposphere. He concludes that pre-monsoon rainfall varies too much between sites (due to local conditions and events) to serve as a useful definition on a wider scale. However, surface-level station observations may still form a useful basis for understanding Indigenous calendars, which are non-comparable between sites for similar reasons.

A slightly different approach to the seasonal cycle of Northern Australia describes ‘dry’, ‘rainy’, and ‘wet’ seasons, with the wet as a subset of the longer rainy season. The dry season is defined as the period where the probability of no rain for ten days is greater than 50%. The rainy season is defined by the complement (<50% chance of no rain), beginning slightly before the monsoon (defined by wind) and ending slightly after. Within the rainy season, the wet season is defined as having less than a 10% chance of a ten-day dry spell. Cook & Heerdegen (2001) develop and justify these definitions based on their close relationship with ecological patterns, especially spatial patterns in tropical vegetation, and argue that a proper understanding of tropical seasonality in Northern Australia must account for rainfall events outside of the monsoon period.

2.3 Australian Indigenous Seasons

The European seasons of Summer, Autumn, Winter, and Spring are adapted for agriculture in temperate regions with low inter-annual variability, which allowed formal definition in terms of date rather than temperature or rainfall. These seasons begin and end at dates given either by the solstices and equinoxes, or by Gregorian calendar month.

Australian Indigenous seasonal calendars serve a similar purpose in informing resource use and management, but manifest in qualitatively different ways. Instead of date, seasons are defined by weather events and ecological cycles, with all the sensitivity to local context and variation between years that this implies in the Australian context (Davis 1989). An enormous volume of ecological and resource-management knowledge is embedded in these calendars, and passed down over many generations in complex ways (Barber 2005). Woodward (2012) explains that Australian Indigenous seasonal knowledge consists of four key aspects: “a focus on resource use, knowledge of complex ecological indicators to facilitate resource collection, knowledge of meteorological phenomena and a strong metaphysical/spiritual understanding”. This emphasises the nuance and value of Indigenous knowledge of tropical seasonality, which goes far beyond the Wet/Dry/Buildup cycle recognised by non-Indigenous Australians in the tropics (Kingsley 2003).

Despite the novelty and potential value of combining Indigenous seasonal knowledge with quantitative climate science, this topic remains a gap in the Australian literature. Cochran et al. (2015) demonstrate this potential in assessment of climate monitoring methodology in the Tiquie River basin, in South America. Keyword searches in the ANU library collection, Google Scholar, and a number of publishers did not return any relevant results. With a relatively short and sparse instrumental record, and little investigation of proxy records in northern Australia, Indigenous knowledge and oral histories are a promising avenue for characterisation of historical climates

Previous studies of Yolngu seasons have tended to treat Indigenous knowledge as

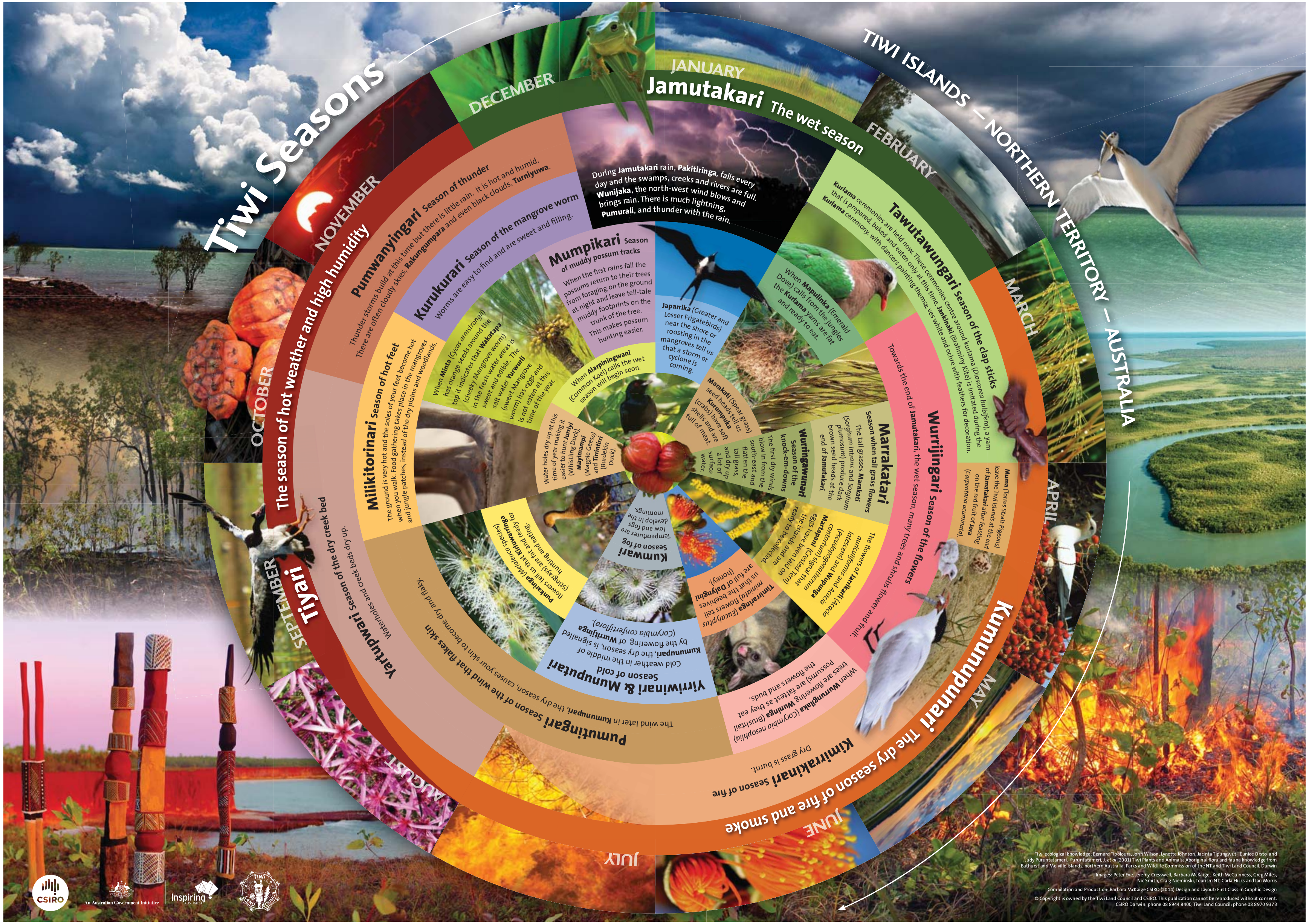

Figure 2.3: The Tiwi Seasons Calendar (CSIRO 2016). This calendar shows month of year in the outermost ring, then three 'major' Tiwi seasons recognised by weather. Note that Kumunupunari does not have a sharp boundary with Tiyari! Within this ring are smaller seasons, recognised by weather or ecological events and associated with particular activities.

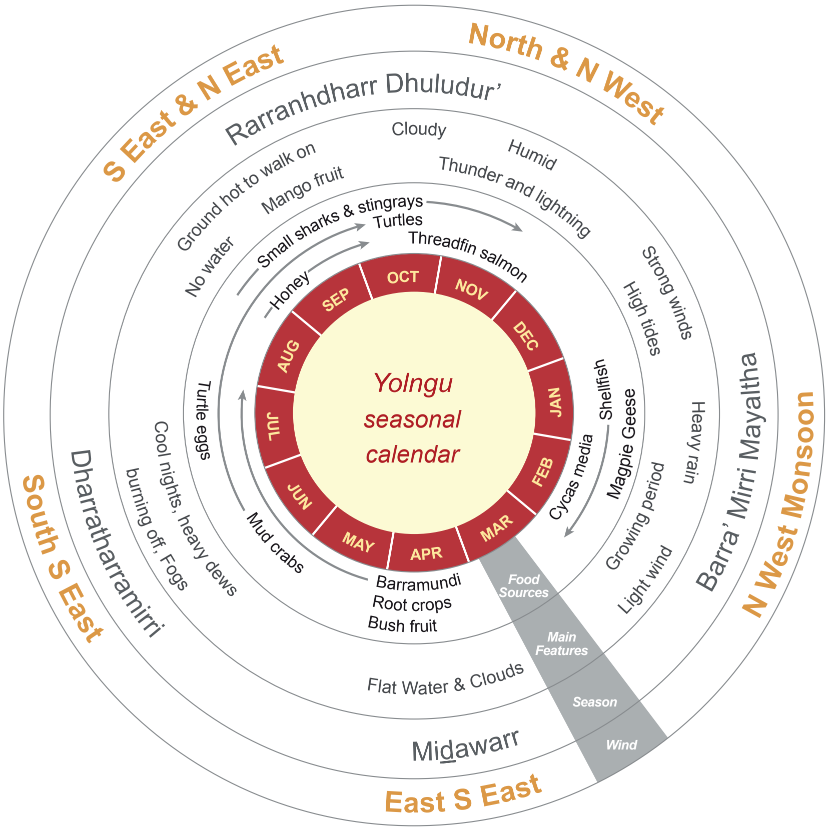

Figure 2.4: Yolngu seasonal calendar for Milingimbi, redrawn from Davis (1989, p2). This calendar shows a glimpse of the relationships between season, prevailing wind, typical conditions, and available foods. It also shows typical gregorian months, for non-Indigenous readers. Barber (2005, p.107) draws a similar figure – also following Davis – for the distinct Yolngu calendar at Blue Mud Bay.

an *object of* academic research; this thesis additionally treats Yolngu knowledge as a *framework for* research. These studies have generally been motivated by academic study, project work by government agencies, or Indigenous people sharing their knowledge – in most cases, several of these factors are at work. A more useful distinction is therefore between posters (produced for the Indigenous and general communities), shorter material such as articles or web-pages, and long-form theses or books.

The best-known representation of Indigenous seasonal calendars in Australia is the poster series developed by multiple researchers and Indigenous communities, driven and collated by CSIRO (2016). This series started with the Ngan'gi Seasons Calendar in 2009 (on the Daly River, NT) and includes the Tiwi Seasons Calendar (Figure 2.3). The process is driven by Indigenous participants who want to record and share their knowledge to be recognised by all people (O'Connor & Prober 2010, Woodward 2010). The main focus is ecological knowledge and customary activities or resource use. These posters have become a source of pride for Indigenous people beyond the participating groups; one interview for this research was relocated to visit a poster display. Guthadjaka (2012) demonstrates that the value of this process and format is recognised outside CSIRO; and during fieldwork I saw many more such calendars in the 'grey literature' – mostly produced for remote-area schools and community centers.

The recent increase in research on Australian Indigenous calendars can be traced to the 2002 creation of a 'Indigenous Weather Knowledge' website by the Australian Bureau of Meteorology (2016*b*), in partnership with Monash University and the Aboriginal and Torres Strait Islander Commission. In 2016, the website describes eleven Indigenous calendars in varing levels of detail, from a simple summary of what seasons are recognised, to posters produced with CSIRO and accompanying reports. Kingsley (2003) speculated that this project might eventually lead to widespread adoption of local Indigenous calendars, and the trend since is promising. A range of articles and reports have accompanied the CSIRO posters, mostly focussed on the process (eg. O'Connor & Prober 2010, Woodward 2010). Other publications have considered Indigenous calendars in the context of climate change (eg. Green et al. 2010, Green & Raygorodetsky 2010), ecological assessment (eg. Ens et al. 2012, Prober et al. 2011), and other topics. Few document the structure or content of Indigenous knowledge of seasons, with the notable exception of Woodward (eg. 2012).

The most substantial sources of published information about Yolngu seasonal knowledge identified in the literature review are *Man of All Seasons* (Davis 1989), and the *Yan-nhangu Atlas and Illustrated Dictionary* (Baymarrwana & James 2014). *Where the Clouds Stand*, a PhD thesis by (Barber 2005), is available online and provides a third perspective. These references cover the content and context of Yolngu seasons and knowledge in substantial detail, with a strong anthropological focus. Davis (1989) writes about the seasons at Milingimbi in detail, describing the weather, wildlife, and customary activities of each. The book draws on his experience as a teacher at Galiwinku, and includes numerous original photographs. The *Yan-nhangu Atlas* is intended to safeguard the language and traditional knowledge of the Crocodile Islands (NW of Milingimbi and east to Galiwinku, see Figure 3.1). It has relatively little content related to seasons – only a few pages – but may be regarded as authoritative. *Where the Clouds Stand* is a PhD thesis in Anthropology, drawing on more than a year living with Yolngu at Blue Mud Bay (aproximately 150 km south-east of the study area). Barber highlights the depth and complexity of Yolngu knowledge, with seasonality playing a pervasive role in everyday life. Within the same language group Barber gives a calendar with seven seasons, of which only three are shared with the study sites for this thesis. Specific quotations from each of these three sources are included here in *A Qualitative Yolngu Seasonal Calendar* (Section 4.2), supporting the descriptions of seasons gathered through fieldwork.

3 Methods

3.1 Methodology

My methodological approach is cross-disciplinary and exploratory. The cross-disciplinary aspect is inherent in the topic; it would be impossible to characterise Indigenous seasons in this way without integrating both qualitative and quantitative methods. It is exploratory because there is no known precedent or published method for quantification of an Australian Indigenous seasonal calendar. This novelty means that the specific quantification methods used were not known ahead of time, as they are informed and shaped by interview data. It also means that these methods themselves form a novel contribution, which breaks ground for further research.

Project methods align with four distinct stages of the research:

1. Analysis of literature describing the Yolngu seasonal calendar
2. Interviews with Yolngu and non-Indigenous people who understand the Yolngu calendar
3. Quantitative analysis bridging literature and interview descriptions to the observational weather record, to characterise Yolngu seasons
4. Analysis of the derived seasonal record, such as typical conditions for each season and correlations with climate indices.

These stages reflect the cross-disciplinary or mixed-methods approach, with literature informing the direction of the research and qualitative methods providing the framework for well-founded numerical analysis.

Qualitative research methodology is particularly important when working across cultures, for example when collaborating with Indigenous people on western-style scientific research. "Research" is something of a dirty word in many Indigenous communities, even where the people involved are trusted. An experience of exploitation or unequal benefits, where researchers come and go but leave nothing for the Indigneous participants, remains too common (eg. Smith 1999).

Without strong pre-existing relationships, in my case through several years of engagment through the Uniting Church, this research would not have been possible. The trust earned through ongoing engagement allowed me to commit to share my results and ensure that Yolngu participants will also benefit from this study (see Section 5.3). Without the introductions and logistical assistance generously provided by the Uniting Church, it would have been impractical or impossible to conduct such research for an Honours thesis. In a letter inviting collaboration on this research (Figure A.1), a senior Yonlgu man explained that

> *For Yolngu (the people of North Eastern Arnhem Land) it is the Liyagadhaman who carry within them the wisdom and knowledge of these matters. It is right that in this research you have approached me to talk about these things. I can also introduce you to others who have this knowledge. ... Yolngu have made careful observation of the ways of nature and the seasons over the millennia and have passed on that knowledge down the generations. We know the changes that are taking place in the seasons and I am willing to talk with you about what I have seen happening around me.*
> —*Rev. Garrawurra*

Data scoping is a key influence on methodology. What data is within scope or relvant to the research question – and what isn't? The decision should be principled and pragmatic. The data must be sufficient for robust and well-founded analysis, and it must also be possible to aquire and understand with limited resources. Secondary considerations include the potential applications of the results, and avoiding undue difficulty for replication.

Interviews do not attempt to investigate historical understandings of seasons or calendars, and are conducted in English – linguistic study is firmly out of scope. Options for historical and projected weather data were considered, including gridded reconstructions from observations, satellite datasets, and climate model outputs (eg. CMIP5 or ACCESS). Each of these failed to deliver the required required detail, frequency, and variety of data required to detect Yolngu seasons. Direct weather observations provide a simple and robust basis for the analysis, which focusses on the recent past.

All numerical weather data are drawn from daily direct observations at surface weather stations (Table 3.1). Other datasets – such as satellite observations or climate models – generally do not have both the spatial and the temporal resolution required, or are missing key variables such as separate surface wind vectors for morning and afternoon. The Australian Bureau of Meteorology generously provided the data for each weather station in the study area at no charge (included in the electronic appendices). Similar data – with the exception of wind – is freely available online for many weather stations (BOM 2016*a*), facilitating replication for other calendars.

Context is important for this locally-based exploration of Yolngu seasons. The townships of Galiwinku and Milingimbi are used as a case study for practical reasons. Personal connections and logistical support from the Uniting Church facilitated fieldwork with limited resources. Yolngu seasons emphasise meteorological indicators, which allow principled quantification based on the observational weather record. The study area is on the north-east coast of the Northern Territory, shown in Figure 3.1, about five hundred kilometers east of Darwin. These sites fall within the Arnhem Coast bioregion. The landscape is dominated by tropical woodland, from mangroves on the coastline through to dense forest to more open woody grasslands further inland (Ens 2014).

Qualitative seasonality is described for Galiwinku and Milingimbi; quantitative weather observations from the neighboring communities of Waruwi, Maningrida, and Nhulunbuy

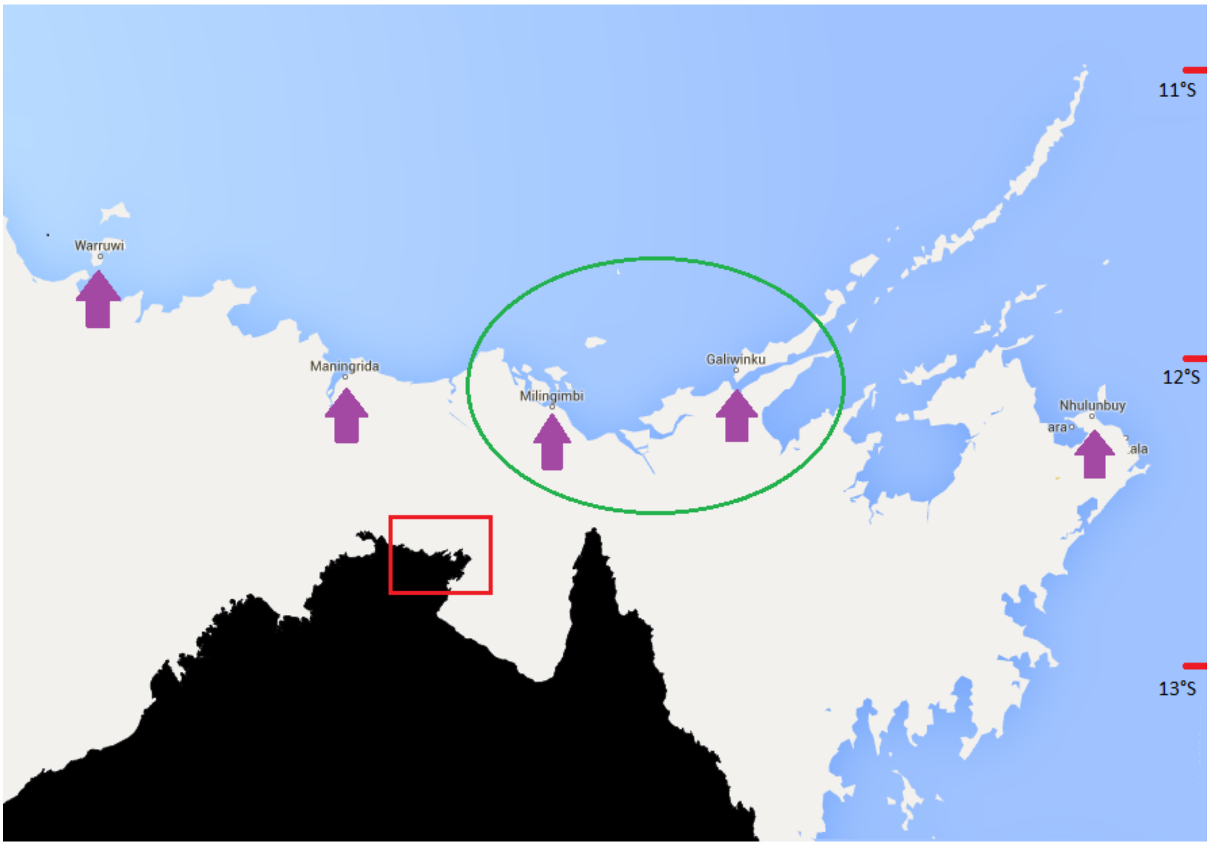

Figure 3.1: Map of north-east Arnhem Land, showing the study area, with inset silhouette of northern Australia showing map area (red box). The five weather stations are located at airports serving the towns indicated by purple arrows. The green oval highlights the region for which qualitiative data is collected. Tick marks (east side) show latitude.

are also analysed. Waruwi and Maningrida are in areas described by other calendars, but provide a longer weather record in a similar climate to the study area. These stations were intended to provide validation data for a model fitted to the Galiwinku and Milingimbi observations, as the record is too short to split into training and validation sets temporally. Analysis demonstrates that Yolngu seasonal definitions are highly localised, and the seasonal records from these stations are not usefully comparable. Tables and figures for these weather stations can therefore be found in the electronic appendices only.

Season recognition is difficult to encode, and my methods can best be described as exploratory. The specifics are described in Section 4.4, as they closely follow qualitative findings and constitute a result in themselves. Alternative approaches which were tried and rejected are described in Section 5.1.3.

The general approach is to observe that seasons are recognised or defined at least partially by weather conditions on a day-to-day basis. It is therefore possible to construct criteria for each season that describe it in terms of daily weather observations, and derive a daily index for each season. Normalising these indices by z-score makes them directly comparable, and the season with the greatest index on some day is said to occur on that day. Alternative approaches, such as definitions by trend change in weather or onset thresholds, are not supported by the qualitative data. See Chapter 4 for details.

Quantitative summaries are an important aspect of this research, but do not form a key part of the scope and come at the last stage of iterative methods. This analysis is therefore limited to the extent that it either informs comparisons with earlier work or demonstrates potential for further study in a particular area. In practice, this means calculating and plotting a small number of summary statistics – those which are meaningful for a complex calendar and supported by the data. Further discussion of this issue can be found in Section 5.1.4.

3.2 Qualitative and Interview Methods

This research was approved by the ANU Human Research Ethics Committee, as protocol `2015/543` on 06 October 2015. Calendars and seasons are not usually considered secret business by Indigenous people, though there may be particular sacred topics associated with them – an explicit invitation to come and learn minimises the risk of inappropriate sharing. I rely on three sources of knowledge of and context for the Yolngu seasons. Interviews with Yolngu people form the basis of my qualitative research, and are the definitive source of information about Yolngu seasons. Interviews and discussion with non-Indigenous researchers or teachers with experience in Yolngu communities contextualise this knowledge, and warn of common misinterpretations - as well as pointing out nuances in the material.

The two primary sources are contextualised and supported by published literature on cross-cultural research (eg. Smith 1999), Australian Indigenous seasons (eg. O'Connor & Prober 2010, Prober et al. 2011), and Yolngu seasons (Baymarrwana & James 2014, Davis 1989). Secondary sources shape the specific methods and interview questions (below). Grey literature such as calendar posters produced for remote schools and workbooks for cross-cultural teacher training provided a starting point for informal conversations.

Prior to fieldwork, the planned sample was ten to twenty Yolngu people of varied age and gender; interviews were to be conducted at Galiwinku on Elcho Island, with supplementary interviews in Darwin. Unfortunately Rronang Garrawurra, who had offered his assistance with introductions and accomodation (see Figure A.1), was in Darwin due to health issues and accomodation at Galiwinku was unavailable. Fieldwork and interviews were conducted in Darwin. Sample recruitment followed a 'snowball' pattern, where participants were asked to suggest further potential participants (Patrick et al. 1996). The 'seeds' of this pattern were personal contacts in the Uniting Church and CSIRO staff who worked on the Tropical Rivers and Coastal Knowledge project. The final interview sample consisted of three older Yolngu men, four past or practising teachers with several years experience in Arnhem Land, and an experienced research team at CSIRO. Most participants asked not to be identified, so comments are not attributed to individuals.

I conducted a series of informal, semi-structured interviews discussing seasons and climate, as avoidable paperwork or formalities tends to promote mutual frustration rather than mutual learning when English may be a fourth language. Thematic questions include:

- What are the names of the seasons?

- When does [a season] usually occur? How do you know when it starts (definition)?
- How long does [a season] last? What weather or events usually occur in this season?
- Do you think the seasons have changed over your lifetime? Why/why not? How can you tell?
- Are there some years where a season is skipped? What happens?
- Do you remember any unusual events? What happened?
- What might the calendar be like if [example climate impact] happened? (eg changes to wind, temperature, rainfall patterns)

Interviews generally took the form of participant-led discussion prompted by one of the thematic questions. The most consistently productive were focussed on teaching about seasons: names and definitions, typical conditions and timing, and extreme events or outliers. These discussions took place in venues suggested by the participant, often under a tree by the ocean, at a cafe, or in their home. Each discussion lasted between one and two hours, and I met with some participants multiple times to discuss various aspects of Yolngu seasonality.

Just as Yolngu people offered their knowledge of seasons, discussions with non-Indigenous people provided context and interpretative assistance as well as their perspective on Yolngu seasons. Immediate clarification and feedback allowed for ongoing refinement of the questions, and pointed to new directions or overlooked details which were elicited in subsequent interviews. Following the interviews, I also engaged in substantial reflection on the nature of my questions and the ambiguity of the responses and data I collected. In this process, allowing participants to discuss whatever they felt relevant was a key way to remain open to unexpected information – including insights which changed my understanding of what a Yolngu seasonal calendar was.

3.3 Application: from Qualitative to Numerical Data

This research quantifies one Yolngu seasonal calendar, with six seasons each year defined by weather conditions and events. Section 4.1.1 provides a brief explanation of other Yolngu seasonal calendars and justification of this scope.

3.3.1 Weather Observations

The key meteorological aspects of Arnhem Land seasonality are temperature, rainfall, humidity, wind strength, and wind direction. The annual cycle is driven primarily by the Indian Ocean monsoon. The climate is hot and humid, with daytime temperatures between 25 and 40 degrees year-round. This section describes the raw numerical data, quality checks, and handling of missing data. The record begins with the installation of automatic weather stations at several airports between 1990 and 2003, and continues to the present with only minor gaps (where earlier observations exist they do not include all required variables). The results do not support speculatation on the past or future state of Yolngu seasons. The methods however are applicable to data such as climate models, which provide a clear direction for further work proposed in Section 6.2.

Table 3.1 shows the name, ID, and location of the weather stations used. The weather

Table 3.1: Summary description of weather stations used. Locations are visible in Figure 3.1

Station no.	Name	Location	Latitude	Longitude	Altitude	Opened
014401	Warruwi Airport	Warruwi	11.6500S	133.3797E	19m	Jan 1916
014404	Milingimbi Airport	Milingimbi	12.0932S	134.8919E	15m	Mar 2003
014405	Maningrida Airport	Maningrida	12.0569S	134.2339E	28m	Oct 2003
014508	Gove Airport	Nhulunbuy	12.2741S	136.8203E	52m	Jan 1944
014517	Ngayawili	Galiwinku	11.9971S	135.5726E	08m	Oct 1999

variables of interest are:

- Rainfall in the 24 hours before 9am (local time), in milimeters.
- Maximum temperature in the 24 hours after 9am (local time), in Degrees C.
- Minimum temperature in the 24 hours before 9am (local time), in Degrees C.
- Humidity measured as average daily dew point temperature, in Degrees C.
- Wind speed measured in kilometers per hour, at 9am and 3pm local time.
- Wind direction recorded as 16 compass points, at 9am and 3pm local time.

Yolngu participants suggested that due to the effect of the sea breeze, 6pm would be more suitable than 3pm wind direction for season detection. Figure A.2 shows wind direction by year and day-of-year, as in Figure 4.4. Similar charts for wind speed and other stations are included in the electronic appendices. These charts show a northerly sea breeze, generally strong in the noon, 3pm, and 6pm data. Analysis and results are therefore based on the 3pm wind data, which maintains consistency with the standard meteorological afternoon and has longer record than 6pm at some stations.

The data are cleaned by discarding observations accumulated over multiple days. Observations which have been quality-controlled by the BoM and are considered 'wrong', 'suspect', or 'inconsistent with other known information' are discarded. Observations which have not been assessed are retained. Missing data are not filled in any way, to convey the coverage of the record and accurately represent missing data in the figures. In scalar calculations, missing data are propagated (eg $NaN + 10 = NaN$); in some aggregation it is omitted from the sample (eg $mean(1, NaN, 5) = 3$, though $mean(NaN, NaN) = NaN$).

3.3.2 Detection of Seasons

Seasons are detected at daily resolution, matching the input weather data. Each of these methods assigns a confidence rating for each season to each day of observations. These ratings are then reconciled to a single season, or unknown, for each day. The reconciliation draws on participants' comments to drop inconsistent ratings before comparing normalised season ratings.

For each season, I construct a set of boolean criteria based on participant descriptions. A raw index for each season is defined by running these conditions over each day of data (giving True, False, or NaN), and summing the values for each season for each day (giving NaN, 0, 1, ...). Box 4.2 shows the code used to build raw seasonal indices.

Season-detection criteria can be defined in two ways: based on thresholds in absolute measurement, or on trends. Experimental analyses of trend-based detection did not yield reliable results. The threshold approach is more practical and strongly grounded in qualitative season definitions, but both wouuld merit investigation in future research. Thresholds are set based on the calendar described in Section 4.2. For categorical criteria such as wind direction or the absence of rain days they are reasonably rigorous; for quantitative criteria such as "very hot", "humid", rain on "most days" or "less frequently", rigour is more dificult.

The ideal solution would be to find a historical record of what season it was on various days; regression analysis, (un)supervised classification, or machine learning techniques could then associate seasons with typical conditions. Unfortunately, no such record exists – in searching for one I spoke to Yolngu people, current and ex-mission workers, CSIRO staff, and academics from Charles Darwin University and Nungalinya College. Future studies may wish to prioritise the ongoing creation of such a record, for example via SMS surveys of Yolngu participants over one or more years.

Instead, I tried a range of values and selected those which appeared to best reproduce the described timing of each season in the Galiwinku and Milingimbi data. This selection was on the basis of normalised season indices before aggregation, so it tested for specific descriptions rather than merely expected results. This is probably the weakest step in the quantification method, but the data required for more rigorous fitting of these parameters are not available. Examination of figures for unfitted weather stations (see electronic appendices) shows good agreement, suggesting that this method is sufficient for exploratory analysis.

The final step normalises the index timeseries for each season by conversion to a z-score, as the variation in data completeness and number of conditions between seasons would not otherwise permit direct comparison between seasons. This index is my representation of how well the season characterises that day's conditions. Aggregation of these indices is discussed in the next section.

3.4 Quantitative Analysis

All numeric tables and data visualisations in this thesis are produced with Python scripts written by the author. The raw data supplied by the Bureau of Meteorology are included in the electronic appendices, as are the analysis scripts. This greatly facilitates reproduction of all quantitative results and replication of the methods for other calendars or datasets. Running the scripts requires Python version 3.5 or later, as well as the Pandas (0.18+) and Seaborn (0.7+) libraries with their dependencies.

Seasons may occur multiple times in a given year in any order, as explained in Section 4.1.2. This presents a significant challenge to reliable detection of seasonal onset, as respecting this Indigenous interpretation of seasonality rules out the simple approach of detecting an event and forward-filling the associated season to the next detected event. Instead, the research uses a local analysis approach which seperately analyses each day of data, smoothed with a short rolling mean. The cost of this well-grounded system is increased 'jitter', rapid switching between seasons in periods when more than one is a close match for conditions. It is unknown to what extent this instability reflects Yolngu understandings. Future studies may explore algorithms which represent a degree of path dependence (‘remembering’ recent decisions), to account for Yolngu advice that season change requires several days observation. This study prefers to avoid the risk of over-fitting, sensitivity to initial conditions, and implementation challenges such an approach brings.

In any case, Yolngu seasons cannot be well characterised by onset timing. Instead of asking “when does [this season] typically begin?”, which implies that each season begins once per year, at a roughly constant date, a more coherent question is to ask which season best matches conditions at a date, or which is most commonly observed. The benefits and drawbacks of various ways to characterise typical or onset timing for seasons are discussed in Section 5.1.4.

4 Results

The results are reported in four sections. Section 4.1 reflects on the approach to interviews and how I underestimated the complexity of seasonal calendars. It also outlines the structures of the Yolngu seasons, and presents advice on season detection and some hard-to-categorise findings. Section 4.2 describes a Yolngu calendar of six seasons defined by weather conditions, constructed from participant input. Section 4.3 presents and characterises the observational weather record in NE Arnhem Land. Finally, Section 4.4 covers the quantified seasons.

4.1 Unexpected Complexity in Seasonal Calendars

Participant-led informal interviews provided an indispensible foundation for this research, revealing complex knowledge structures along with deeper definitions of the seasons than are available in the literature (eg. Baymarrwana & James 2014, Davis 1989). While I anticipated finding some unsought information, the unexpected results were crucial. This section summarises the structurally-relevant 'unexpected results', which are vital to an accurate understanding of the Yolngu seasons.

I began this project with many assumptions about Yolngu seasons, which were slowly broken down by engagemnt with the literature on Indigenous knowedge, fieldwork and interviews, and analysis of these results. Relationships and trust built over several years allowed participants to correct misinterpretation of their contribution, and helped both parties to notice and work through concepts that do not translate directly across language or cultural barriers. Focussing on Yolngu ideas with similar function or importance to non-Indigenous calendars revealed a much richer understanding than simply asking about seasons.

This technique was inspired by one Yolngu participant's comment to me several years ago on why he often addresses a meeting via a translator: while he is fluent in English, simultaneously translating complex language and cultural frameworks is slow and difficult. Speaking in English but without 'translating' perspectives, this man showed me aspects of seasonal calendars that could easily be missed, simply because Indigenous people may not mention things without a European analogue, and non-Indigenous researchers may neglect to ask. I found that 'easy questions' demanded careful consideration and reflection, or assumptions ruled – in cross-cultural research, there's no such thing as simple fact finding.

The breakthrough moment for me came after the third day of interviews. At this point I had spoken to two Yolngu men and one non-Indigenous person, and written plenty of notes about anticipating unexpected information, but it was only when listening again and transcribing one of the recordings that I actually heard: *There is no such thing as 'the' Yolngu calendar!* There are many Yolngu seasonal calendars – they vary from place to place, have differing details for men or women, occur on varied temporal scales, and exist for various purposes.

This is basic, crucial information that I had been told repeatedly over several days – and repeatedly missed, due to my preconceived idea of what 'the Yolngu calendar' was like. I could only agree with my next interviewee: *"We [white Australians] can be so ethnocentric and dumb it embarrasses me."*

4.1.1 Characterising Yolngu seasons, by location and temporal scale

Yolngu participants discussed multiple types of seasons at three distinct temporal scales within each year, each type recognised by different indicators.

- 'Monsoon seasons' are recognised not by rainfall but by the direction of the pravailing wind – north-west in the Wet and south-east in the Dry.
- The six 'meteorological seasons' are defined primarily by wind, rain, and temperature. They can begin and end at any time during the year – weather permitting – and may occur multiple times and in any order.
- Complex 'ecological seasons', where changes in plant or animal life signal appropriate resource use or other activities for that time. A particular community may recognise tens of ecological seasons, all of which are highly localised.

This three-level typology emerged from interview data, prompted by patterns in Yolngu participants' descriptions of seasonal timescales and indicators. While it forms a more nuanced view than seasonal calendars characterised by six sequential and implicitly date-based seasons, a three-level approach still falls far short of the richness and detail of Yolngu understandings. Ian Morris, an ecologist and former teacher at the Galiwinku mission, told me

> *Mums and Dads had all this seasonal information in their heads, really a lot more but seasons were the key. ... I now feel pretty embarassed about the circular seasonal calendar; it's two dimensional with the Balanda [non-Indigenous] calendar in the middle. It should be going out to the stratosphere if you put every [ecological detail] in! ... The detail is like a galaxy, and you really need three dimensions to visualise it.*
> —*Morris*

A similar three-level pattern of seasons is visible in the Tiwi Seasons Calendar published by CSIRO (2016) (Figure 2.3, on page 10). The Tiwi seasons are shown at a monsoonal level, as well as by weather or ecology – the latter categories are not clearly distinguished in this figure, though weather is generally further from the center.

Monsoon Seasons (Wet/Dry)

Each year, there is a wet season and a dry season. These seasons are recognised by the monsoon winds from the north-west and south-east respectively. In some years there is a gap between the Wet and Dry, and *Mayalta* (see below) may be 'promoted' to the monsoonal level. Of the three levels of seasons recognised by Yolngu, the wet/dry monsoon seasonal cycle is most likely familiar to non-Indigenous people - especially in the tropics. Yolngu participants emphasised that these seasons are *not* recognised by rainfall, but rather the direction of prevailing winds.

> *I know when seasons start – the wind told me, when a storm rolled in and everything changed. But the west wind has begun. That's how I know the wet season has begun already, even before it rains.* —*Yolngu man*

Interestingly, this mirrors the meteorological definition of monsoon, where rainfall is less important than the location of the intertropical convergence zone and consequent direction of prevailing wind (eg. Cook & Heerdegen 2001, Holland 1985). This shared understanding of monsoon seasonality by Indigenous and scientific knowledge is remarkable, and indicates that this research on local seasonal patterns may find further commonalities.

Meteorological Seasons

At the middle timescale, Yolngu recognise six seasons. The Wet season is divided into *Dhuludur*, *Barramirri*, and *Mayaltha*, followed by *Midawarr*, *Dharrathamirri*, and *Rarrandharr* over the Dry. Detailed descriptions of each season from interviews, supported by literature, can be found below. These seasons are primarily defined by weather conditions and events, which are shared across communities in the area. Ecological indicators also play a role in recognising meterological seasons, which people *mangutji bulthanaway* ("possessing the quality of telling the eye") can interpret (Baymarrwana & James 2014, p35). The distinction from ecological seasons is supported by local differences in indicators.

Quantification and analysis focusses on meteorological seasons. Data availability is one reason: the installation of automatic weather stations at Arnhem Land airports in the 1990s and early 2000s provide short but high-quality daily observational records of many weather variables. By contrast the Monsoon has been the subject of many studies (see Section 2.2, while detailed ecological or phenological records at the required temporal resolution are very rare.

Meteorological seasons also match up reasonably well with European ideas of what a season should be. Wet/Dry is well-known but permits little nuance, while ecological seasons are complex, detailed, and beyond the scope of an Honours thesis. Six seasons per year defined by weather is not *too* exotic for productive collaboration across varied ideas of what seasons are like!

Variable timing appears to be a simple difference; seasons might start earlier or later depending on the weather. One participant said *"It's a different time [each year], any season can start at any time."* In subsequent conversations, he clarified that this is more than just variable onset, but rather that seasons can 'interrupt' one another!. Each season will occur when conditions are appropriate, at any time and in any order. There are some restrictions: each season occurs every year, without exception, and typically dominates a fairly predictable period of time (simplified and summarised in Table 4.2). These properties shape the detection algorithm used below, and determine which methods of aggregating or summarising seasonal data are appropriate.

Ecological Seasons

Ecological seasons are defined by observed changes in local vegetation and animal behaviour. They embody a depth and detail of Indigenous ecological knowledge that is difficult to imagine, and only possible due to the long connection between Yolngu and the natural environment.

Yolngu participants explained that these seasons vary between groups even within a single clan-nation or language group, meaning that each of the townships across Arnhem Land (see Figure 3.1) would have a different calendar. These seasons are closely tied to traditional activities such as travel, use of particular foods or other resources, and ceremony. On the Tiwi Seasons Calendar, Figure 2.3, the inner-most rings concern ecological seasons and observations, such as *Mumpikari*, when possums leave muddy tracks and hunting them is easy.

However, deeper exploration of ecological seasons is beyond the scope of this thesis. The same detail and diversity which makes these seasons so fascinating also mandates far greater investment of time and travel to speak with the relevant knowledge holders, and proper study would require living in each community for a significant period. Sensitive, sacred, or unpublishable stories and information are much more common around ecological seasons than the more general calendar, constraining dissemination of research findings. Generalisation between communities is difficult, and in some cases impossible. Finally, the limited availability of quantitative ecological data at the required level of detail makes this process especially difficult in remote Australia. Section 6.2 discusses how these seasons might be explored by further research, and some of the challenges to overcome.

4.1.2 Identification of Seasons

Recognising seasons is not always simple. Yolngu participants made several comments which, while not about the seasons themselves, are cucial to a well-grounded attempt to quantify them.

Variation between years
Yolngu seasons at all levels vary between years, depending on weather and other conditions. Participants said that the seasons had always been steady within this normal variation, meaning that no long-term trend was recognised.

Unordered or duplicated seasons
Seasons each occur at least once per year, but are not limited to a particular order. Any season may be 'interrupted' by another if the latter's characteristic conditions hold. Participants explained that this requires at least two or three days of 'new season' weather; elders avoid making hasty judgements. Where non-Indigenous people might discuss a summer 'cold snap', Yolngu might say that winter had interrupted summer.

Wind and the sea breeze
Wind plays a defining role in Yolngu seasons, but not all winds are seasonal indicators. In coastal communities, the day-time and especially afternoon wind is dominated by the sea breeze, and carries relatively little seasonal information.

A Yolngu participant said that morning wind at 9am would be useful, but that at 3pm the sea breeze overwhelms the seasonal changes. He suggested considering wind between 5pm and 8pm depending on time of year. Section 3.3.1 (page 17) explains what wind data are analysed below and justifies the timing of observations.

4.1.3 Other Observations and Findings

The participant interviews and other research yielded a number of other observations that are not directly relevant to the focus of this thesis, but may be of interest when planning future research.

Extreme Events

Extreme weather events do have a place on complex Yolngu calendars; one participant used the phrase *"cyclone season"*, and described conditions such as hot water on the ocean surface and strong winds. Participants did not discuss specific events in relation to seasonality. Extreme events only contribute to the definitions of the meteorological calendar described above through the conditions themselves.

Climate Change

Participants were generally not concerned about climate change due to the greenhouse effect, or its consequences. Questions about climate change generally elicited responses regarding local or regional environmental change, including weather, which Petheram et al. (consistent with 2010) was mostly attributed to local impacts.

'Strange changes'

Participants reported changes in recent decades, including difficulty reading seasons due to invasive species. One participant told me

> *[Changes in the seasons are] not a formal thing, just hard to read. I think it's because different climate, different trees. Changes are taking place because we bring plants and activities and trees for other countries too. Maybe I'm wrong or maybe right, I don't know. ... Every year, the wet season and the dry season changes, it's getting harder to read because there's more foreign stuff in Australia. But we have to learn! ... We have to try catching up to the changes, generation to generation.* —*Yolngu man*

Novelty

Several participants made spontaneous comments on the novelty of this research, and none were aware of any previous attempts to quantify Indigenous seasons. My other contacts in Darwin were likewise unaware of any similar study.

4.2 A Qualitative Yolngu Seasonal Calendar

The remainder of this thesis focusses on the six-season Yolnu calendar described by this section. It is based primarily meteorological definitions drawn from interview data, and is consistent with *Man of All Seasons* (Davis 1989) and *Yan-nhangu Atlas* (Baymarrwana

& James 2014, p36). Barber records an alternative calendar with seven seasons, three of which match the other sources, and notes:

> the words for these seasons are used in areas other than Blue Mud Bay, but the timing of the seasons can vary in different parts of Arnhem Land, as can the local phenomena that signify the change of season.
>
> —Barber (2005, p.107, App 1 p.18)

Recognising that each of these sources describe different communities and areas, when they conflict the research relies on participant comments from Galiwinku. This is not a definitive Yolngu calendar; no such thing exists. Instead it represents an attempt to construct a quantifiable Yolngu seasonal calendar from as many sources as possible, and illustrate some of the challenges of working with complex, incomplete, and sometimes missing information. Iterative discussions with participants indicate the result is fit for purpose, and when interpreted in the context of three-level seasonality (see Section 4.1) avoids misleading similarities to seasonal cycles more familiar to non-Indigenous people.

4.2.1 Dhuludur

Dhuludur marks the beginning of the seasonal cycle. It is the first of three predominantely wet seasons, before the heavy rain begins. *"The west wind has come and that means it's the wet season. Yes, even before it rains."* (Yolngu man) Clouds appearing to the north or south signal that winds from that direction may interrupt the season. The flow from west to east is very important in the wet seasons. One participant described the anticipation of the wet, and linked traditional burning systems to the beginning of the rain –

> *People can easily say 'I thought this was cyclone time, but what's wrong? Maybe later', or for big rain, or small rain. But the small rain always indicates big rain, says 'I'm coming!'. ... When we reach the limit, the climate of dry season, we burn all the bush. That smoke causes the developing cloud buildup, and makes the wet soon! We also do this to get rid of old leaves and bring new growth, to find an answer for ourselves. Stops bigger fires too. ... We're not saving the grass, burn it and another bigger shoot will come up. Clear out the first grass and wait for the second or third grass. Leave it, and a really big fire will build up – too dangerous.*
>
> *—Yolngu man*

"(October) The first rains come, and there is distant thunder and lightning." (Barber 2005) The *Yan-nhangu Atlas* says that in Dhuludur "there are not many fires, the wind blows at different times throughout the day. Now there is a lot of thunder." Davis (1989) calls Dhuludur the 'pre-wet' season:

> The weather is cool and still during the night, with mists settling in the night and rising in the morning after a light northwest wind during the day. ... The winds are mixed up, with southwest, southeast, northeast, and northwest winds each blowing at different times, often during the same day. ... The weather begins to get hot and humid as the clouds build up more and more each day. When the sky is covered by heavy cloud, the 'female' thunder brings the first rain [often from the southeast]. After the first rain, other winds bring heavy rain. ... Towards the

> end of the pre-wet season the rain is being brought only by the northwest wind. It rains almost every evening. This is the start of the next season, which is signified by heavy rains and growth. —Davis (1989)

4.2.2 Barramirri

Barramirri is the season of heaviest rain. Typically the very heavy rain falls for a few weeks, with even amounts of lighter rain and clear skies in between. Maintaining a fire to keep warm is very difficult without a cave. The wind blows only from the west during rain and the east while it is dry. A northerly or southerly wind indicates changing weather – the wind changes from day to day in the Wet, but the prevailing pattern is less variable than in the Dry. The *Yan-nhangu Atlas* says that "in Barramirri, the late wet, heavy rain falls almost every day, encouraging the grass to grow tall and quickly." Davis (1989) calls Barramirri 'the season of heavy rain and growth':

> The heavy rain is brought by the northwest wind. It comes every day, indicating that the seasons have changed. ... As the northwest wind brings daily storms, the sea is dirty and rough. ... The inundation is so extensive that much of the inland is now one continuous sheet of water which will not drain until the dry season. ... Many plants flower, and the rain becomes infrequent and sometimes stops for several weeks. These are indications that the season of heavy rain is drawing to a close. —Davis (1989)

4.2.3 Mayaltha

Mayaltha is marked by north-westerly winds and decreasing rainfall at the end of the Wet. It does not appear in Figure 2.4 (Davis 1989), but was described by participants and appears in the *Yan-nhangu Atlas*. The *Yan-nhangu Atlas* says that "Mayaltha is a time of sunny days with an occasional shower. Now we will visit the outer islands again.". Davis (1989) calls Mayaltha the 'flowering' season:

> [The Flowering Season] is marked by an abundance of plants that flower, bright sunny days, cool breezes, and occasional rain. ... During the early wet season strong winds often brought the rain. The wind then stopped as the rain fell. Now the winds blow hard even when it is raining. The rains do not come daily any more, but only every week or two. —Davis (1989)

While this is while usually a meterological season, in some years Midawarr and Mayaltha are combined into a monsoonal season called *Blowderra* which fits between the Wet and the Dry. This was most common with Yolngu participants from Galiwinku, some of whom did not separate these seasons. In this monsoonal context it is the ideal season, not too wet nor too dry. One Yolngu man described eager anticipation of the season when *"everything is ready, your favorite foods... fruit, fish, stingray, crab..."*. In addition to weather, Mayaltha is recognised by the variety of flowers.

4.2.4 Midawarr

> The season just after the wet when ... the wind blows more softly from the east (dhimurru). ... The [easterly] wind dhimurru/bulunu is associated with white berries (called bulunu) and sometimes the rains come when they are ripe.
>
> —Barber (2005)

Midawarr is the beginning of the dry seasons, with gentle wind and occasional light rain. The *Yan-nhangu Atlas* calls Midawarr "the time of flat water when the yams become abundant in the bush.". Davis (1989), writing at Milingimbi, calls Midawarr the season of plenty (making Mayaltha the 'flowering season').

> The east wind signals the beginning of the time of abundant food ... The first southeast wind blows gently in the early morning. ... The daily storms and strong winds are nearly over. The northwest wind changes to the northeast, bring rough seas. Early in the season the storms still bring heavy rain daily. ... By the middle of the season the wind has changed to the east and heavy storms are less frequent. Light easterly winds blow throughout most of the day bringing cooler weather. ... Shortly after sunrise the east wind blows and continues for the rest of the day. Towards the end of the fruiting season, the days are becoming more like the early dry season with morning mists. One last storm of the wet season comes and flattens the tall dry grass. This storm is brought by strong southeast wind, which is the main dry season wind. —Davis (1989)

The potential merging of Midawarr and Mayaltha is a concrete example of the variation in calendars between communities, and the complexity and richness of seasons as a source of ecological knowledge. This this thesis treats Midawarr as a seperate season due to participant comments and the distinctive weather conditions described in *Man of All Seasons*.

4.2.5 Dharrathamirri

Dharrathamirri, or Dharratharraway, is the first part of the true dry season. The weather is pleasant, with low humidity and cool temperatures. One Yolngu participant referred to Dharrathamirri as *"winter"*, as distinct from Rarrandharr *"the dry season"* – marked more by south-easterly wind and low temperature than the lack of rain. The prevailing wind is easterly; while fairly consistent from day to day it varies substantially over the season. The *Yan-nhangu Atlas* says "the east wind turns westerly and the dew becomes heavier". Davis (1989) calls Dharrathamirri the 'early dry' season:

> In the early dry season the night sky is again mostly clear and the three stars of *Djulpan* (Orion's Belt) are seen in the west in the early night sky, and reach the horizon before people go to sleep. This is the time when the storms come and knock the grass down. ... When the rain has stopped and the southeast wind is blowing constantly, the dry season has really started. After the first storm the wind varies in direction. Heavy dews come with the light ESE to SE wind that blows every night. When we are well into the season the wind swings SE to SSE and becomes stronger ... The southeast wind blows stronger in the latter half of the season. The

> next season does not start immediately. The northeast, southwest, and southeast winds vary for a few weeks.
> —Davis (1989)

4.2.6 Rarrandharr

Rarrandharr is the final and deepest part of the Dry season, *"when the rain has stopped. ... We say 'Oh, I'm too hot. Don't worry, soon we'll have rain.' We call Rarrandharr, 'the very dry one'."* (Yolngu man) Temperatures may still fall at night, but it is very hot during the day and the sun is directly overhead. One participant described how to travel in such hot conditions – starting the journey early in the morning, resting in shade through the heat of the day, and tricks for walking over very hot sand and rocks in bare feet. "September-October is the late dry season when it is hot." (Barber 2005) The *Yan-nhangu Atlas* observes that "Rarrandharr season brings the north-east wind of the late dry that burns your feet". Davis (1989) calls Rarrandharr the 'main dry' season:

> The east-southeast wind blows; the cold mornings and mist are nearly gone. This is an intermediate season between the early dry and main dry seasons. It is very short, lasting only a few weeks. ... The warmer southeast wind starts to blow... When the wind dies down, soon the three stars of *Djulpan* will begin to rise in the east before people go to sleep at night. ... When the mangoes are nearly finished, the dry season is also near its end. The weather changes and thunder begins.
> —Davis (1989)

4.3 The Observational Weather Record in North East Arnhem Land

Before conducting detailed analysis, it is often useful to summarise and visualise the raw data. This section presents an overview of the observational weather record in NE Arnhem Land, with a particular focus on Galiwinku and Milingimbi.

While some stations have been in operation for many years – the first observations at Warruwi Airport were taken in 1916 – the complete record is more recent. All data required for season detection have been collected beginning with the installation of airport automatic weather stations across Arnhem Land in the late 1990s and early 2000s. Table 3.1 shows the five weather stations from which I draw an observational record.

Average conditions for each month at Galiwinku are shown in Table 4.3. These data are graphically represented in Figures 4.1 and 4.2 – a monthly climograph of rainfall, maximum and minimum temperature, and dewpoint; and vectors showing proportional occurence of wind from each direction by month and time of day. Note the low variation in temperature, and strong seasonal patterns in rainfall and humidity in the climograph, and the monsoonal wind (westerly, south-easterly, and northerly over the year) and sea-breeze (decreased diversity of directions in the afternoon).

The mapping of hue to wind direction shown in Figure 4.3 is used for Figures 4.2, 4.4 and 4.5. These colours are equidistant in the HSL colour space, which uses a polar (cylindrical) coordinate system for hue, saturation, and lightness (hence, "HSL"). By

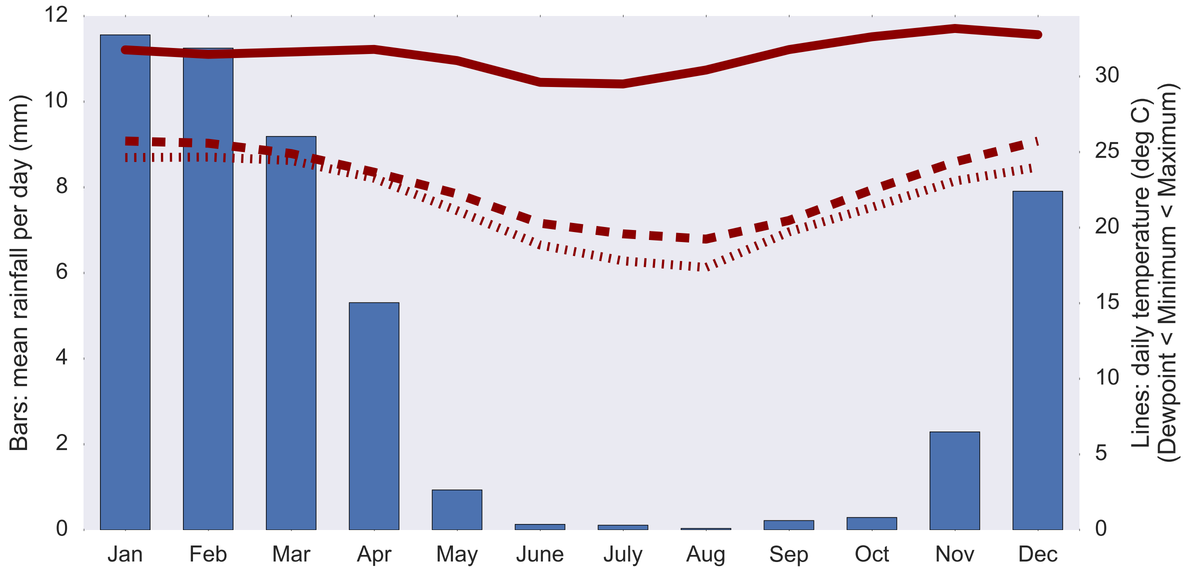

Figure 4.1: Monthly summary of climate statistics at Galiwinku, showing the per-day mean for each month. Rainfall (vertical bars), maximum temperature (solid line), minimum temperature (dashed line), and dewpoint temperature (dotted line). Dewpoint temperature is a measure of humidity.

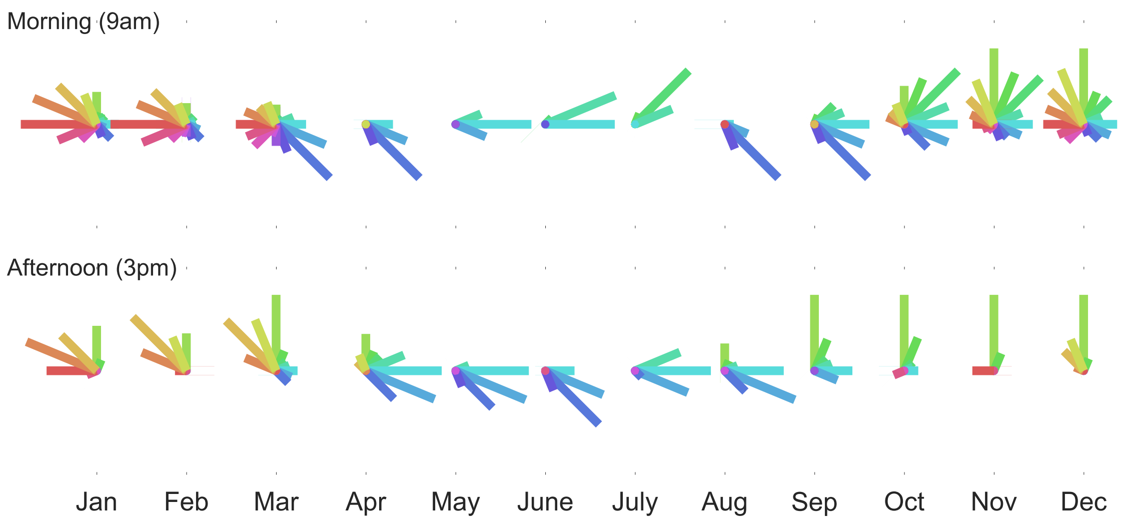

Figure 4.2: Prevailing wind direction by month and time of day. Each set of lines shows the proportion of wind coming from the corresponding point of the compass, with colours given by Figure 4.3. Note that each set of lines is scaled to the longest in that set; this trades comparability for clear visualisation – sets with few lines had just as much wind, but from fewer directions.

Table 4.1: Mean monthly weather observations at Galiwinku. All numerical values are per-day averages, wind direction shows the most common observation in that month.

Month	Daily mm Rainfall	Maximum Temp. °C	Minimum Temp. °C	Mean Dew Point °C	9am Wind Direction	3pm Wind Direction	9am Wind (km/h)	3pm Wind (km/h)
Jan	11.6	31.8	25.7	24.6	W	NW	19.9	23.4
Feb	11.2	31.5	25.6	24.7	W	NW	18.9	22.5
Mar	9.2	31.6	24.9	24.4	SE	N	14.0	18.4
Apr	5.3	31.8	23.7	23.3	SE	E	12.2	15.1
May	0.9	31.1	22.2	21.1	SE	ESE	14.0	15.4
Jun	0.1	29.6	20.3	18.9	SE	SE	16.4	17.3
Jul	0.1	29.5	19.6	17.8	SE	ESE	15.9	17.3
Aug	0.0	30.4	19.2	17.4	SE	ESE	14.2	18.2
Sep	0.2	31.8	20.5	19.7	SE	N	12.6	21.3
Oct	0.3	32.6	22.5	21.3	NE	N	14.0	23.0
Nov	2.3	33.2	24.3	23.1	N	N	13.8	23.2
Dec	7.9	32.8	25.7	24.0	N	N	15.1	22.2

contrast, the RGB colour space uses a Euclidean (cube-shaped) coordinate system for the intensity of red, green, and blue. With constant saturation and lightness, hue can be mapped directly to wind direction and equidistant colours have similar perceptual difference. The direction-colour mapping was rotated (red moving from north to west) to ensure that the contrast of prevailing monsoon winds is blue/yellow, avoiding a red/green contrast which risks disadvantaging colourblind readers.

Weather observations at Galiwinku and Milingimbi are shown in Figures 4.4 and 4.5 as a set of heatmaps (panels arranged vertically). Box 4.1 (on page 34) gives a detailed explanation of how to read these figures. Unlike the monthly climograph (Figure 4.1), these figures clearly show variation in timing of seasonal onset between years. This indicates that timeseries data at daily resolution are required for investigation of Indigenous seasons. The degree of seasonal variation in each indicator is also clearly visible: minimum temperature varies more than maximum; wind direction varies more in the morning while wind speed varies more in the afternoon (both due to the sea breeze).

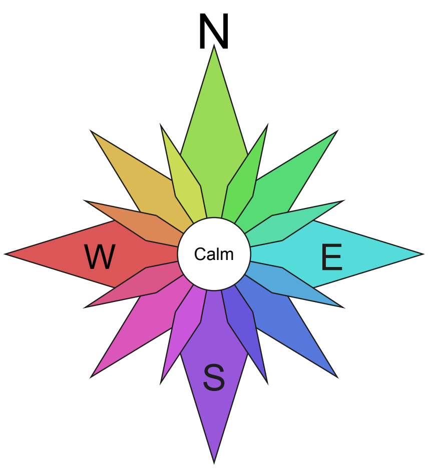

Figure 4.3: The mapping of hue to wind direction used for Figures 4.2, 4.4 and 4.5. These colours are equidistant in the HSL colour space, with constant saturation and lightness.

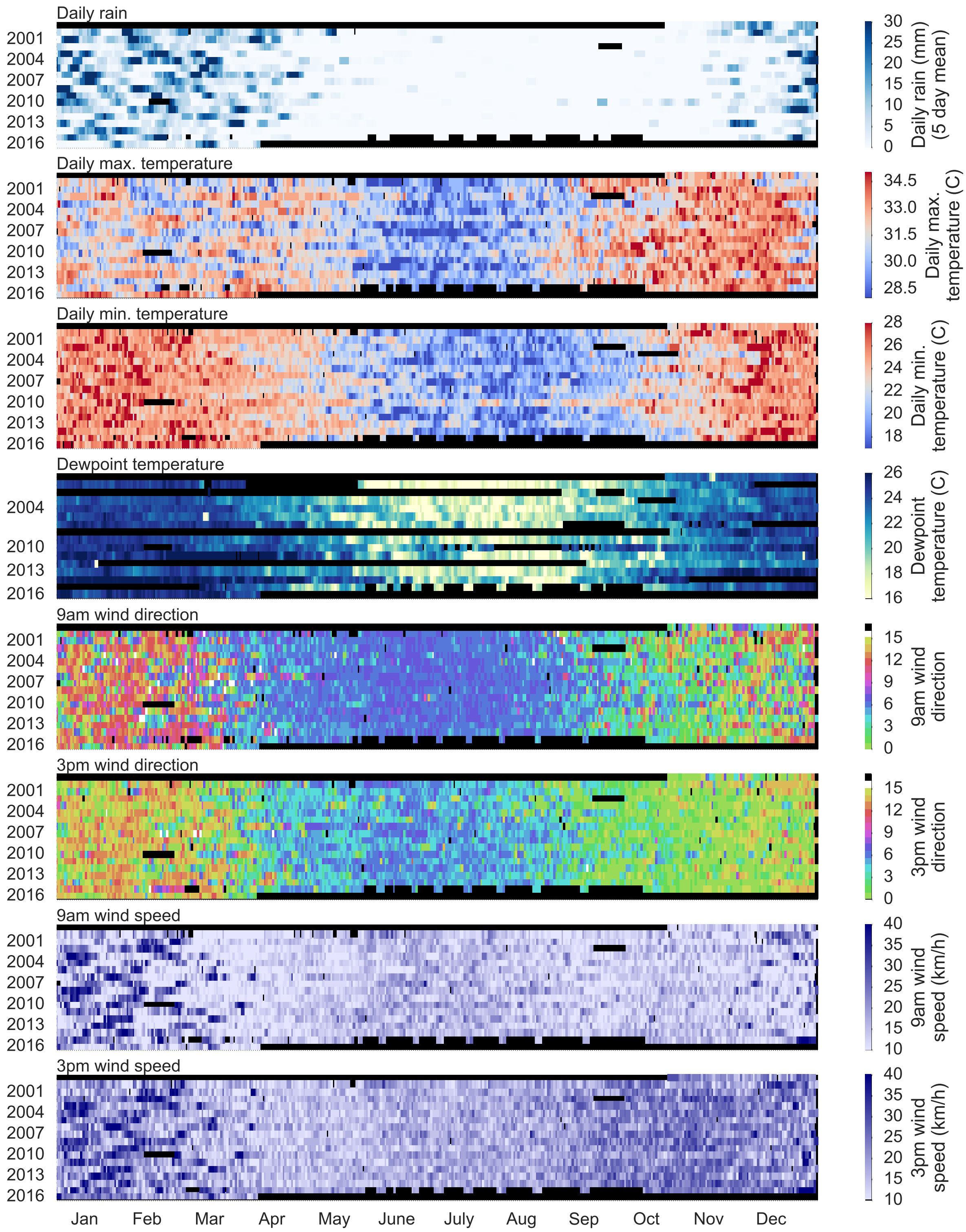

Figure 4.4: Weather observations at Galiwinku. Each panel shows a single variable, with years on the y axis and day-of-year on the x. Note that variables have distinct seasonal patterns, the details of which vary each year. Box 4.1 explains how to read this figure.

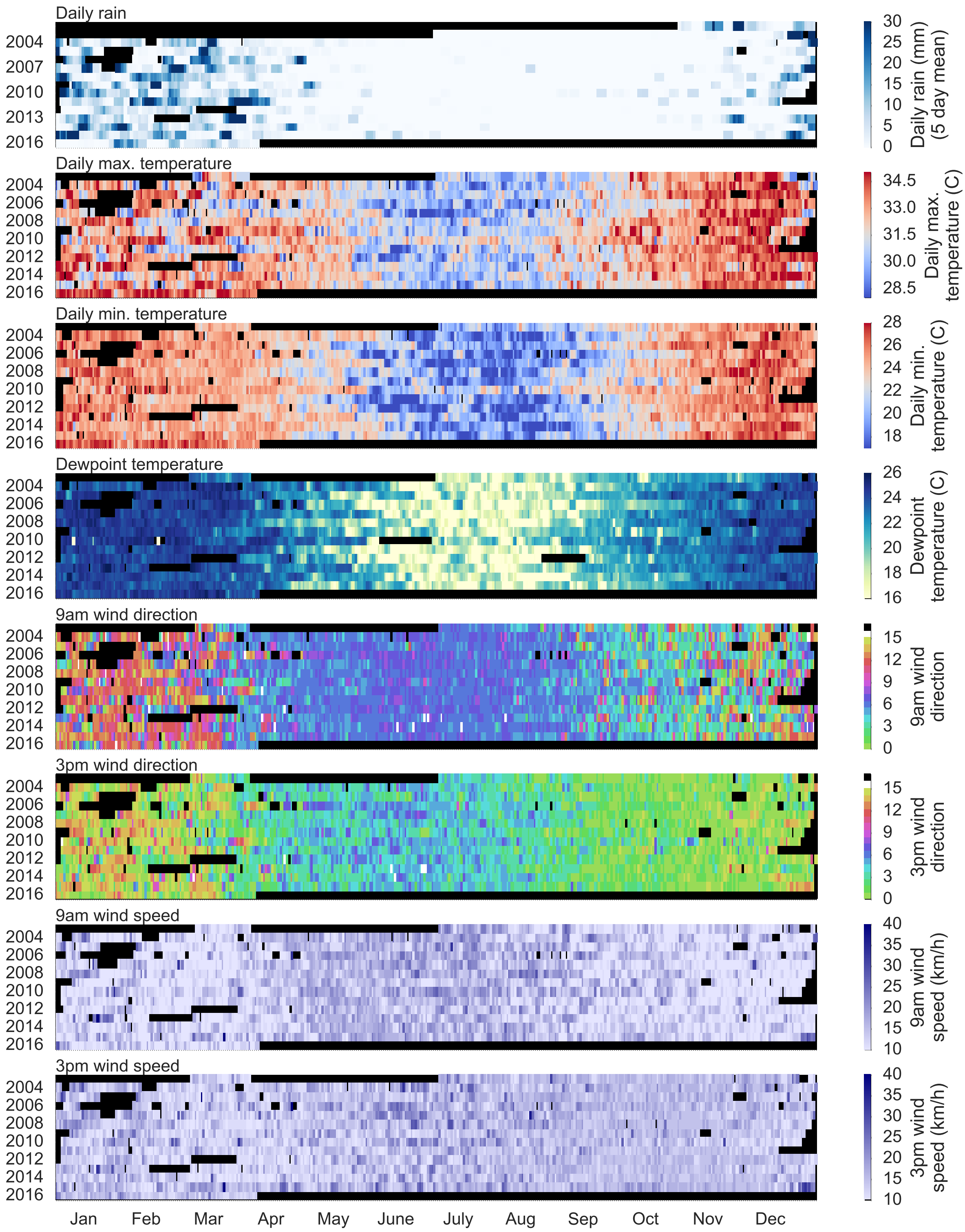

Figure 4.5: Weather observations at Milingimbi Airport. Each panel shows a single variable, with years on the y axis and day-of-year on the x. Note that variables have distinct seasonal patterns, the details of which vary each year. Box 4.1 explains how to read this figure.

Box 4.1: How to read multipanel heatmaps

Multipanel heatmaps concisely present a great deal of heterogenous data, showing all the details that would usually be hidden by aggregation or summarising. While this makes trends or variability between years clearly visible, such detail may come at the expense of readability and so this Box provides guidance on how to read and interpret the heatmaps in this thesis.

Each heatmap is a grid, with year on the y-axis and day-of-year on the x-axis. Each cell is then shaded according to the value observed on that day; days without data are shaded black. Years of observation are printed to the left of each panel, as y-axis labels. At the bottom of the figure, the x-axis is labelled by month – the data are daily, but numerical day-of-year labels are generally unintuitive. To the left of each panel is the colour key, and the name of the variable. This color key is identical for panels of the same variable across all figures, for easier comparison.

More than forty thousand weather observations taken at Galiwinku are visible in Figure 4.4. The topmost panel shows the five-day mean for daily rainfall. The first row of data is mostly black, indicating missing values – this station began observations in October 1999. Other gaps, where the record was interrupted for a few days or weeks, are visible in all panels; apparently the station was mostly non-functional between June and October 2015. Rainfall is clearly seasonal, but also intermittent: there are a series of large rainfall events in most years until late-April, then little if any rainfall until November.

The next panels show maximum and minimum temperature. Note the scale to the right of the panel - even the lowest minimum temperatures rarely drop below 18 °C. Daily maximum temperature fluctuates in the early months of the year, and careful inspection hints that relatively low temperatures may be related to heavy rainfall.

The bottom four panels form two pairs: multi-coloured panels showing wind direction in the morning (9am) and afternoon (3pm), and blue shaded panels showing wind speed at the same times. The multi-coloured panels show wind direction; Figure 4.3 gives the key for interpreting colours. The morning data show a clear westerly / south-easterly / northerly wind regime through the year, while the afternoon wind – sea breeze – tends to blow mainly from the north or (less often) south-east. An explanation of this regime is given in Section 5.1.2. The blue shaded panels show wind speed. Until March, wind speed at both times is dominated by rainfall events – knowing that the wind is also high, we could properly call them storms – and in later months a clear divergence is visible, showing that the sea breeze is most notable from September onwards.

4.4 Quantifying a Yolngu Calendar

In this section, the qualitative data describing a Yolngu seasonal calendar is applied to the observational weather record, deriving a numerical specification for each season and ultimately a best-effort timeseries of which season was 'observed' on each day. For readability, only figures for the seasons at Galiwinku (Ngayawili weather station) are included in the text. Corresponding figures for all other stations can be found in the electronic appendices.

Typical timing and recognition criteria for each season are summarised in Table 4.2. Python3 code implementing these criteria is listed in Box 4.2; the blue-shaded panels in Figure 4.6 display normalised output from application of this code to the weather record.

Box 4.2: Code listing of variables and conditions used to detect seasons. Seasons are defined by numerical criteria for each day, such as "rainfall greater than 15mm", or "maximum temperature below mean". Applying a criterion to the weather data gives a timeseries with 1 or 0 for each day, and the raw index for each season is the element-wise sum of these timeseries.

```
season["Dhuludur"] = sum([
    wind_between(data, "WNW", "NE"),
    quantiles(data[nameof.mintemp], 0.2, 0.6),
    quantiles(data[nameof.dewpoint], 0.3, 0.7),
    (weekly_rain_days >= 2),
    ])
season["Barramirri"] = sum([
    wind_between(data, "W", "N"),
    data[nameof.rain].rolling(5, center=True).mean() > 15,
    ])
season["Mayaltha"] = sum([
    wind_between(data, "WNW", "NNW"),
    quantiles(data[nameof.dewpoint], 0.6, 0.8),
    (weekly_rain_days <= 3) * 0.5,
    ])
season["Midawarr"] = sum([
    wind_between(data, "NE", "ESE"),
    (weekly_rain_days != 0) * 0.5,
    ])
season["Dharrathamirri"] = sum([
    weekly_rain_days == 0,
    wind_between(data, "ESE", "SSE"),
    ])
season["Rarrandharr"] = sum([
    (weekly_rain_days == 0) * 2,
    quantiles(data[nameof.dewpoint], 0, 0.4) * 0.5,
    quantiles(data[nameof.maxtemp], 0.5, 1),
    ])
```

Table 4.2: Quantifiable summary of the Yolngu seasons case study.

Season	Typical Months	Criteria to recognise
Dhuludur	Oct, Nov, Dec	Cool at night, mixed wind, first rain
Barramirri	Dec, Jan, Feb	NW wind, heavy rain most days
Mayaltha	Feb, Mar	NW wind, approx weekly rain
Midawarr	Mar, Apr, May	NE to E wind, less rain, last storm
Dharrathamirri	May, Jun, Jul, Aug	No rain, consistent ESE-SSE wind
Rarrandharr	Sep, Oct	Hot days, low humidity

Figure 4.6 is a multi-panel heatmap, using the same format as Figures 4.4 and 4.5 above. Each season has an individual panel showing the index for that season on each day, derived by taking the raw index as shown by Box 4.2 and applying a four-day rolling mean before converting to a z-score (standard deviations from the mean) to allow direct comparison between indices. The topmost panel is an aggregated version, showing which season on each day had the greatest index.

Note the clear distinction between Midawarr (purple), Dharrathamirri (yellow), and Rarrandharr (light blue) – the dry seasons. This clear pattern in the all-seasons panel arises from the distinctive and largely non-overlapping peaks in the index value for each season, forming a diagonal pattern over the lower three panels. On the other hand, Dhuludur (dark blue), Barramirri (green), and Mayaltha (red) are not clearly distinguished in their individual patterns. This manifests in mixed occurence shown on the top (detected season) panel, and is also visible in the summarising figures below.

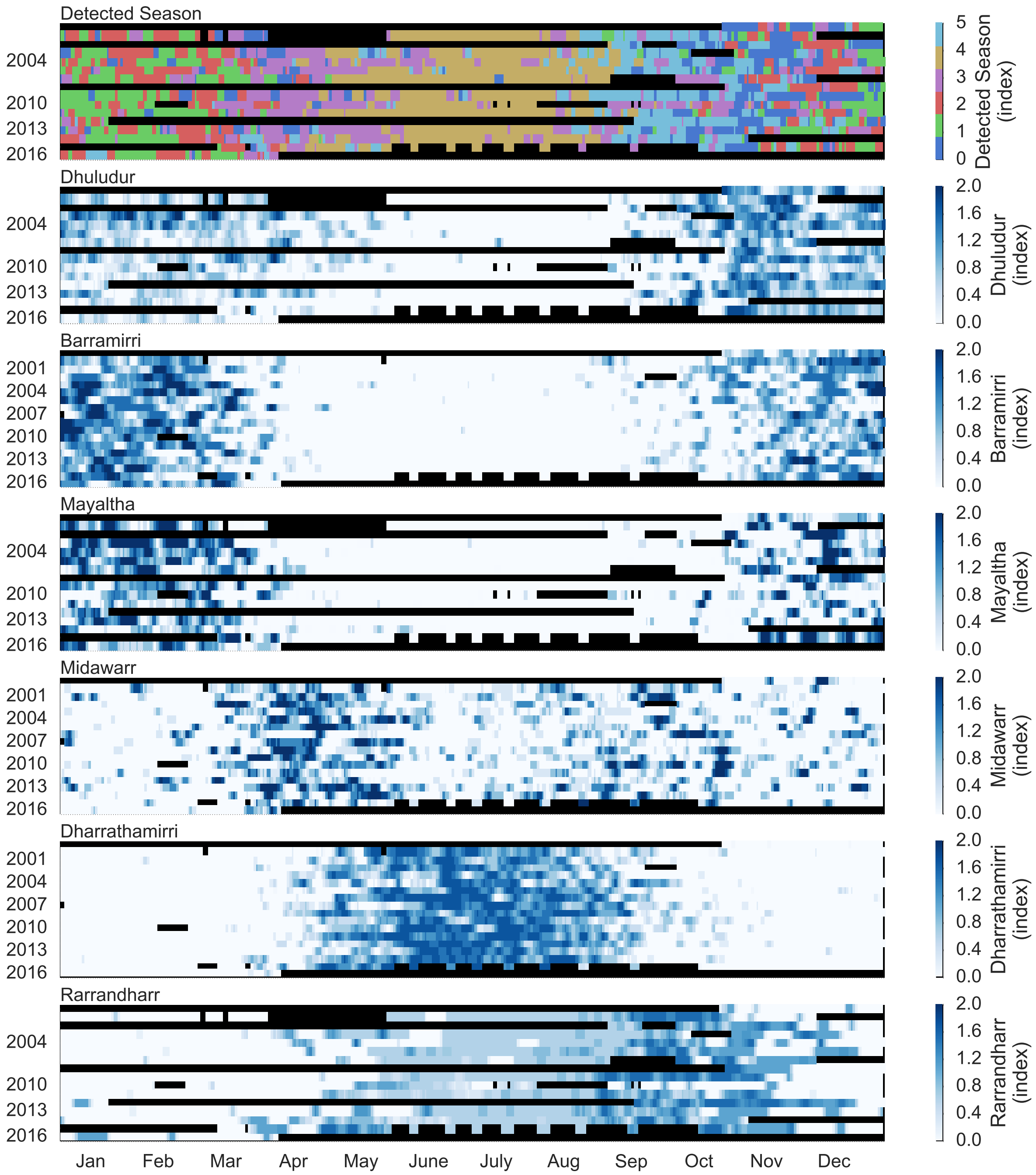

Figure 4.6: Detected seasons at Galiwinku, based on threshold conditions shown in Box 4.2. This figure shows the normalised index for each season – the mean and sum of each panel is zero. Higher values (darker) indicate a better match between weather conditions on that day and the description of that season. The topmost panel shows which season had the greatest index on each day, using the colour scheme of Figure 4.7.

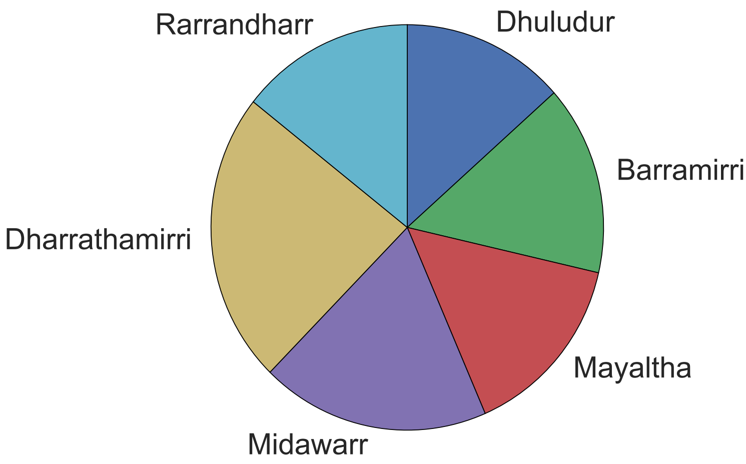

Figure 4.7: Proportion of days on which each season was observed at Galiwinku, over the period of available data. These colours are used for each season in all figures below. This figure shows proportional duration, as seasons do not always occur over contiguous periods.

Two distinct methods for characterising the timing of seasons by day-of-year are illustrated. The first considers the *normalised index of seasonal intensity*, which can be thought of as scoring how well weather conditions match the definition of each season. These data are shown by the blue-shaded panels of Figure 4.6. The second method considers *frequency of season occurence*, shown by the top (multi-coloured) panel of Figure 4.6. Both of these methods summarise the data without erasing or misrepresenting the variability that is a key characteristic of Yolngu seasons. Understanding their relationship is important to accurately interpret the figures.

Applying the first method, the degree of distinction between seasons is shown as a line chart in Figure 4.8. This figure illustrates the mean index by day-of-year for each season, reducing the data on blue-shaded panels in Figure 4.6 from three to two dimensions (dropping year). Lines of similar heights show seasons which describe typical conditions for that day of the year with similar predictive power. Dharrathamirri has the highest peak, meaning it is most distinct – southeast wind and no rain describe it well, and matches other seasons very poorly. Note however that these indices are calculated independently, and it is possible for all seasons to rise or fall togther (as in eg. Oct–Nov).

Applying the second method, the relative frequency of observing each season by day-of-year is illustrated in Figure 4.9 as shaded areas. This can be thought of as vertically sorting (again, removing the year-dimension) the topmost panel of Figure 4.6. These data are smoothed by a 7-day running mean to remove noise introduced by the small sample of 10-15 years. Unlike the index lines, these areas are not independent – if one season was observed more often on some date, others were necessarily observed less. This property amplifies the difference between indices on a year-by-year basis, which clearly shows variability between years or 'strong second' finishes on a given day.

The frequency data are further reduced in Figure 4.7, discarding both time dimensions to clearly illustrate the relative abundance of days of each season. The connection between the heatmap, shaded area, and pie chart is nonetheless clear – the proportional area of each season (or colour) is equal across these figures, as they represent the same data in more or less abstracted formats.

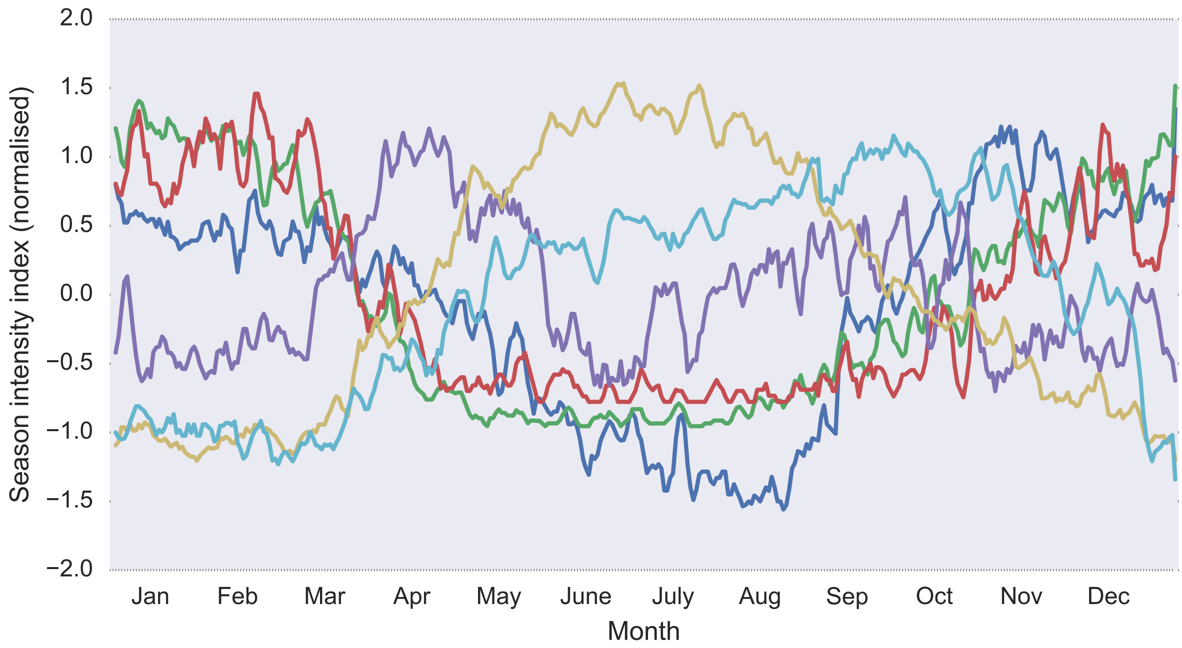

Figure 4.8: Mean normalised (z-score) index for seasons per day-of-year at Galiwinku. Note the clear distinction in the dry season, but muddle in the Wet (Dec-Feb). This is not indicative of poor detection on a single day, but rather that occurence varies more between years. The colour scheme is given by Figure 4.7.

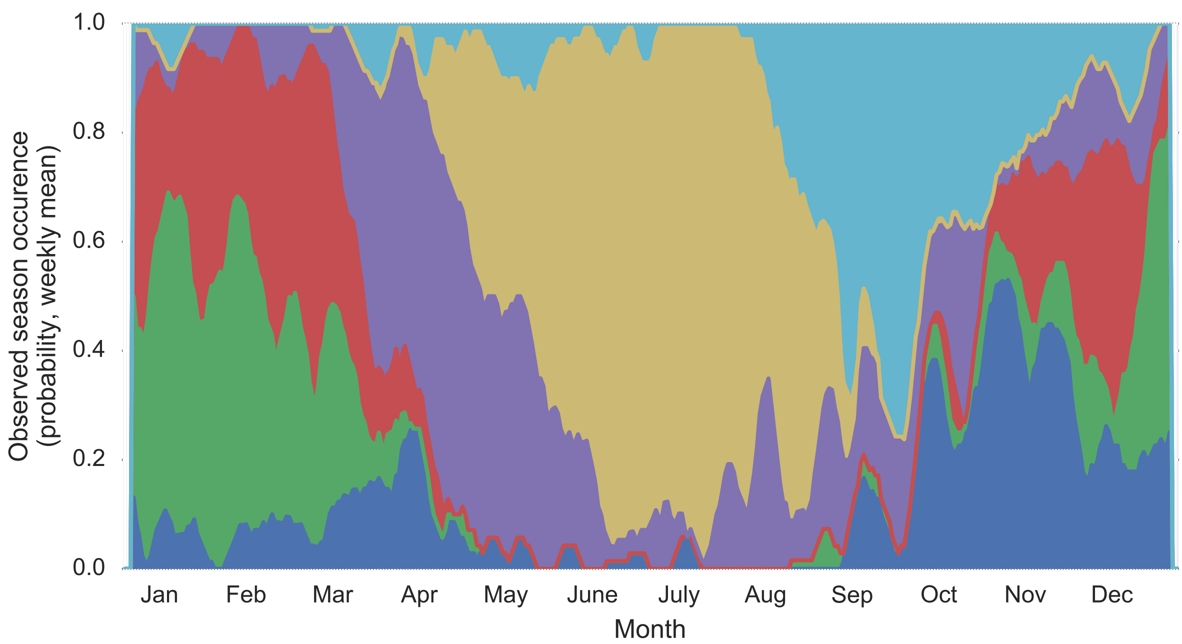

Figure 4.9: Observed probability of each season by day of year at Galiwinku. This figure does not show consistently strong ordering among all seasons; this may be attributed to a combination of imperfect detection, true variation in seasonal occurence, and details lost in aggregation. The colour scheme is given by Figure 4.7.

Table 4.3: Most common season at Galiwinku by month, and monthly mean season indices. 'Main Season' summarises the data shown in Figure 4.9, while the per-season index columns are equivalent to Figure 4.8.

Month	Main Season	Dhuludur	Barramirri	Mayaltha	Midawarr	Dharrathamirri	Rarrandharr
Jan	Barramirri	0.8	1.2	0.9	-0.4	-1.1	-0.9
Feb	Barramirri	0.6	1.1	0.8	-0.4	-1.0	-1.0
Mar	Midawarr	0.3	0.5	0.2	0.1	-0.8	-0.9
Apr	Midawarr	-0.6	-0.5	-0.5	1.0	0.0	-0.3
May	Dharrathamirri	-1.0	-0.9	-0.5	0.5	0.9	0.1
Jun	Dharrathamirri	-0.9	-0.9	-0.5	-0.5	1.3	0.2
Jul	Dharrathamirri	-0.8	-0.9	-0.5	-0.1	1.3	0.2
Aug	Dharrathamirri	-0.5	-0.8	-0.5	0.2	1.0	0.5
Sep	Rarrandharr	0.1	-0.5	-0.4	0.3	0.3	1.0
Oct	Rarrandharr	0.5	-0.0	-0.1	0.0	-0.2	0.9
Nov	Rarrandharr	0.6	0.5	0.3	-0.3	-0.6	0.4
Dec	Mayaltha	0.7	0.9	0.5	-0.3	-0.9	-0.3

Monthly means for the normalised index of each season and most common season in each month are shown in Table 4.3. This is a simplified textual form of Figures 4.8 and 4.9, with data aggregated to monthly means.

The key finding of analysis presented in this section is that Yolngu season can be detected from and characterised based on the observational weather record. Detection is robust for the dry seasons (Midawarr, Dharrathamirri, and Rarrandharr), but does not strongly detect Dhuludur and experiences substantial 'jitter' between Barramirri and Mayaltha. This may be attributable to the consistency of wind direction relative to rainfall over multi-day timescales. The structure of the characterised seasons are consistent with qualititive findings describing the Yolngu calendar, though further fieldwork would facilitate refinement of these methods. Representing normal or typical occurence of Yolngu seasons is complicated, and there are multiple well-grounded options.

5 Discussion

The key findings of this research are:

- Yolngu seasonal calendars are complex. They have three kinds of seasons, each with their own indicators and typical timescale. Seasons occur differently from year to year. Calendars vary between locations.
- A Yolngu calendar defined by quantitative weather observations can be constructed, and is consistent with interview data. Novel analysis demonstrates that these definitions can be applied to observational weather data to derive a record of season occurence.
- Consistent with qualitative data, the seasons record is complex and shows seasons interrupting each other without a clear order. Multiple approaches for characterising 'typical' seasonality are explored, and two are considered well-grounded.

In Section 5.1, these findings are interpreted and discussed in the context of relevant literature. Section 5.2 reflects on the methods and methodology developed in this thesis, and the limitations of the research. Benefits and potential applications of the research are discussed in Section 5.3.

5.1 Context and Interpretation of Findings

5.1.1 Qualitative and Interview Results

Interviews and informal discussions were an essential and integral part of this study.

Two goals necessitated fieldwork and in-person discussion of Yolngu seasons. The first goal of fieldwork was to learn about the structure of Yolngu seasons and obtain any important information that might otherwise fail to cross cultural barriers. The length of Section 4.1, on *Unexpected Complexity in Seasonal Calendars*, speaks to the importance of these results and validates the research approach. Without direct conversations, or if I had assumed that all relevant information could be gathered from published material, crucial information would have been missed. This would seriously impair the results, as there is little to no value in quantitative or numerical analyses founded on faulty premises, no matter how rigorous or technically sophisticated. An investment in cross-cultural understanding is well worth making, especially on complex topics that appear to be simple on superficial investigation.

The second goal was to collect detailed descriptions of the characteristics, definitions and timing of each season, and investigate related issues including extreme events and climate change. The qualitative results show that this was a success. However, in a sense this is preliminary work – enough to obtain exploratory results, that can be taken back to Indigenous research participants and partners to inform a deeper second-stage discussion. Future two-ways research might base such preliminary analysis entirely on secondary sources such as *Man of All Seasons* (Davis 1989) and this thesis, allowing researchers to demonstrate their intentions.

This thesis goes further and deeper than previous published descriptions of Yolngu seasons. Barber (2005) and the *Yan-nhangu Atlas* (Baymarrwana & James 2014) each provide a list of seasons, with names and typical conditions on a single page. Davis (1989) goes into much greater detail on the weather conditions and social or ecological events of each season, but spends little time examining the structure or fluidity of Yolngu seasons. Davis is nonetheless unusually detailed; some sources (eg. Australian Bureau of Meteorology 2016*b*) list seasons by months of occurence, without further explanation of their characteristics, onset definitions, or underlying variability .

This research has created the first known record of season occurence by day, based on season definitions and observational weather data. This enables investigation of the short-term ‘interruptions’ of seasons, and precise characterisation of both typical timing and variation in timing. Without such data, no previous study (eg. Australian Bureau of Meteorology 2016*b*, Barber 2005, CSIRO 2016, Davis 1989) has been able to characterise Australian Indigenous seasons in this way.

5.1.2 Weather Observations

The observational weather record in the study area, shown in Figures 4.4 and 4.5, displays several interesting patterns. Each variable has a distinct seasonality, the timing and in some cases intensity of which varies visibly between years. The rainy period begins at substantially different times from year to year, and rainfall intensity also appears to vary. This is consistent with known interannual variability of the monsoon (eg. Cook & Heerdegen 2001). Minimum and maximum temperatures follow slightly different patterns at Galiwinku to those at Milingimbi – for example, while both record their highest temperatures around November, while the following months are consistently cooler at Galiwinku.

Wind in NE Arnhem Land appears to be dominated on a seasonal basis by the monsoon, and is heavily influenced by the sea breeze at these locations. Background conditions can be seen in 9am wind, which is minimally affected by the sea breeze and displays a westerly or south-easterly regime depending on the phase of the monsoon. See Figure A.2 for three-hourly data; electronic appendices for wind speeds and data for other stations. Morning wind speed is steady throughout the year; at Galiwinku heavy rain is associated with stronger winds. At 3pm the situation is more complicated. The sea breeze blows from the north for most of the year, but shows a south-easterly influence from May to August. This is consistent with the seasonal northwards migration of the ITCZ, and resulting dominance of the south-east trade winds over the area in these months. Speeds are similar throughout the day at Milingimbi, while at Galiwinku wind speed peaks in the afternoon.

This analysis builds on weather-based characterisations of north Australian seasonality by Cook & Heerdegen (2001) and Holland (1985), considering a wider range of surface-level indicator variables than previous studies which were generally confined to rainfall or high-altitude wind. Notably, this thesis is grounded in Yolngu knowledge based on generations of observation rather than descriptive statistics which may not capture the fine variability of seasonal characteristics.

5.1.3 Detection of Seasons

In the absence of published literature as a guide several approaches to numerical detection of seasons were tested, conceptually based on (1) observed weather conditions at a specific time, (2) trend change in conditions, or (3) event- or threshold-based detection. Extensive exploratory analysis demonstrated that direct assessment from daily weather was the most robust approach, and was well grounded in the qualitative and interview data.

Trend-based detection would in principle detect seasons similarly in years which were, for example, consistently hotter or colder than the norm by recognising a relative increase or decrease in the weather variable of interest. In practice, this approach was highly dependent on arbitrary parameters. Most were too stable, excluding the possibility of 'interrupting' seasons – in some cases not changing at all. Other parameters led to constantly changing seasons, while still occasionally failing to change for a year or more of the observational record. Event-based or trend detection is therefore not supported by the qualitative definitions of Yolngu seasons. Many of these problems could be disguised by adding a notion of time to the season-detection algorithms. However, this would impose a non-Indigenous character on the analysis, inconsistent with Yolngu explanations that the date is fundamentally unimportant to Yolngu seasons.

The suite of algorithms developed to detect seasons (Section 4.4) appears to give good results, noting that an objective assessment is not possible without some independent record of season occurence (which as mentioned in Section 3.3.2 likely does not exist). The season detection analyses (Figures 4.6, 4.8, 4.9 and 5.1) show a relatively clear pattern for the dry seasons, with the order and time-of-year of Midawarr, Dharrathamirri, and Rarrandharr closely matching participant descriptions and published sources. Dhuludur, the start of the wet season, is less clear, but this seems largely due to variation in timing between years rather than poor detection. If Barramirri and Mayaltha were treated as a single season, they would be detected reasonably well – but internally, the distinction is poor and their ordering is inconsistent. It is unclear whether this is an artifact of the skewed distribution of rainfall, or if it has a real basis in Yolngu definitions and perceptions of seasons.

Applying this approach tends to show seasons interrupting each other, which may seem strange to non-Indigenous analysts. To the degree that this accurately reflects Yolngu understanding of the seasons, it is a strength – but this is difficult to assess in the absence of validation data. Testing this aspect of the results would be a high priority for subsequent rounds of fieldwork, which were not possible within the time and resources available for this research.

If interruptions were detected too frequently, three solutions could be explored. Phenological data could provide a basis for ecological season definitions, which might constrain the periods in which seasons can be detected. This would be a fuller reflection of Yolngu knowledge, but faces serious practical challenges including that if historically typical timings are used (rather than live data) the results will fail to represent the 'strange changes' that participants reported in their environment. The second possibility is to apply a more complex algorithm to weather data, which preferentially detects longer runs of days for each season. The disdvantages of this approach include increased complexity, and either heightened sensitivity to initial conditions or a loss of locality – in either case, the result for a certain day could be affected by observations at a substantial temporal distance. Finally, a validation dataset could be created over one or more years of additional fieldwork or surveys, including data collection over SMS or web platforms. This dataset would be valuable in strengthening two-way learning, refining the methods, and supporting further study including the options above. Collecting participant observations on ecology as well as meterological season would be particularly useful.

5.1.4 Quantitative Analysis

In the best published sources, onset and timing of Indigneous seasons is typically presented by listing the months in which each season occurs. Dissatisfaction with this approach contributed significantly to the motivation for this research. While calculating seasonal onset dates each year and summarising these data is possible, such summaries are not meaningful when seasons can interrupt one another in any order. Identifying the first or last date on which a season occurred is not a suitable approach given the detail and complexity of Yolngu seasons.

How then, if at all, can the typical timing of Yolngu seasons be accurately characterised? The results in Section 4.4 suggest two basic possibilities: for each day of the year a mean over all years can be compared to either the mean normalised indices, or the observed occurence of each season. Comparing the indices has conceptual clarity; it suggests that the typical timing of a season is that period where conditions tend to fit the definition of that season better than any other. It can be estimated simply by reading off the topmost line in Figure 4.8 for any particular day. This aggregation gives a steady seasonal progression for most of the year, and while it 'jitters' a little in the Wet no two seasons ever co-occur.

Comparing modelled occurence rates of Yolngu seasons (see Figure 4.9) is somewhat further from the weather data, but closer to people's experience. If a similar result to the index-based characterisation is desired (i.e. non-overlapping occurence with interruptions) the same approach of taking the season with the highest value for each day of the year can be applied. Alternatively, for each season the shortest interval which contains some proportion of all days on which that season occured can be calculated – for example ninety percent for robust and overlapping intervals, or fifty percent for shorter but non-overlapping intervals. On balance, this last option appears the most robust way to characterise typical timing of Yolngu seasons while acknowledging inter-annual variability and remaining well-founded in Indigenous definitions of the seasons.

All three approaches are illustrated in Figure 5.1. The two rings in the center show the dominant season for each day, defined as that which was most often observed on that day (inner) and that with the greatest mean normalised index (outer). The arcs show intervals in which a specified proportion of days of that season fell, which is the preferred approach

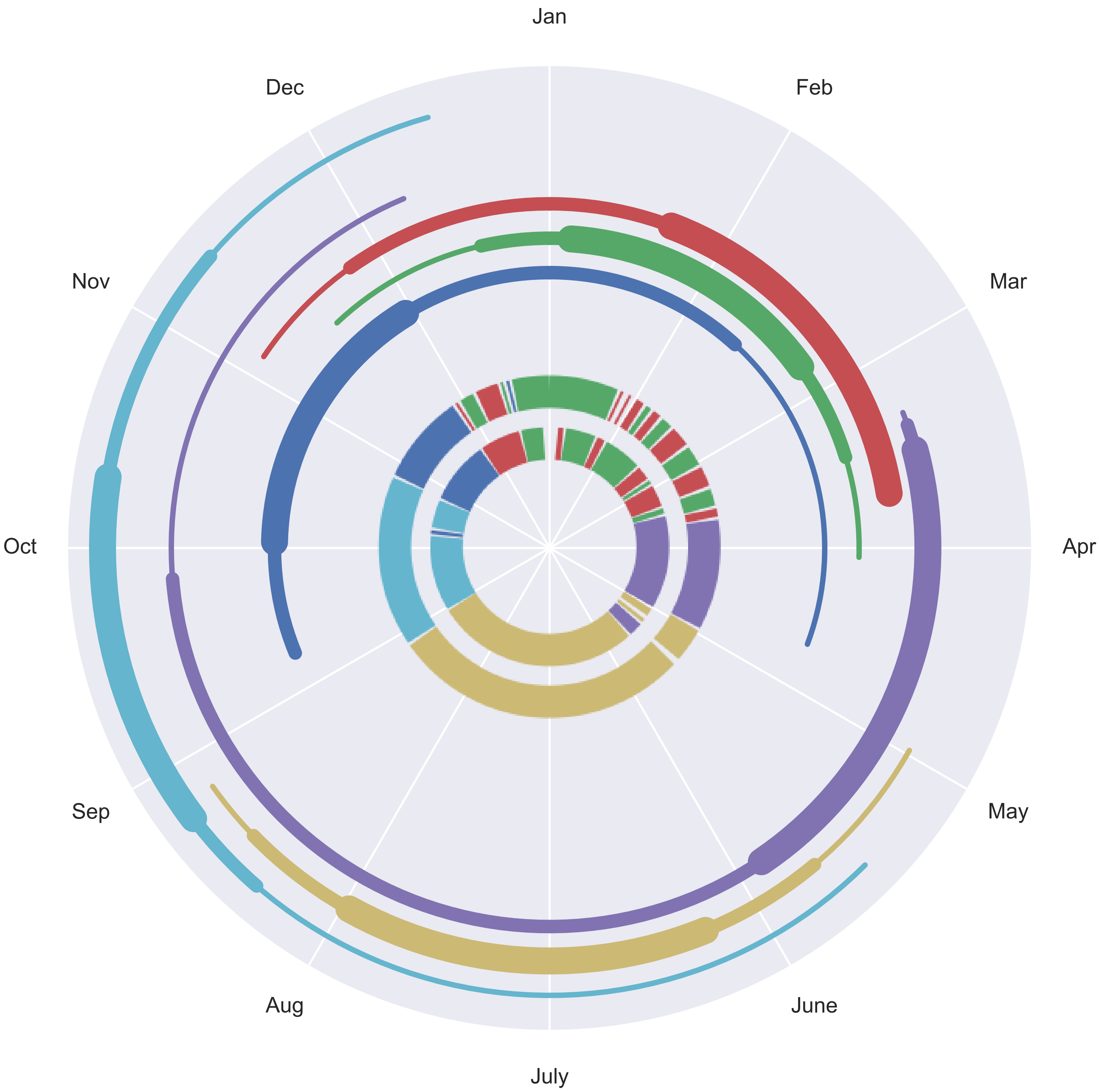

Figure 5.1: Three ways to characterise timing of seasons, Galiwinku. The two rings in the center show the dominant season for each day, defined as that which was most often observed on that day (inner) and that with the greatest mean normalised index (outer). The arcs show intervals in which a specified proportion of days of that season fell – thin line 90%, medium 75%, thick 50% – which is the preferred approach to characterising season timing. The colour scheme is given by Figure 4.7.

to characterising season timing. This avoids representing seasons as having a start or end date, which does not match Yolngu understanding, but instead represents them as phasing in and out over time. While this does not happen within a single year, it provides a summary of seasonal behavious over multiple years which can easily be understood by non-Indigenous people.

The value and novelty of this analysis can be understood by contrasting it with the CSIRO posters, for example the Tiwi Seasons Calendar (Figure 2.3) on page 10. The timing of these seasons is represented without showing variability or the potential for interruptions (which may not be a part of this calendar), where Figure 5.1 illustrates both. It is important to note that the CSIRO posters tend to focus on the ecological knowledge and customary actvities associated with seasons (as do other published sources, including eg. Barber 2005, BOM 2016, Davis 1989) rather than weather characteristics and timing. Just as this thesis covers substantially less ecological knowledge than previous studies, it shows substantially more about the timing and variability of Yolngu seasons than any other source – different information, for a different purpose.

5.2 Reflection – Methodology and Limitations

While the detail of specific methods is assessed above, reflections on the methodology and scope are also important in exploratory research.

The flexibility of the multi-stage approach and coupling between stages allowed the study to be adapted to unexpected qualitative results that were identified during the interviews. I consider that participant-led conversations and this flexibility were the primary factors that led to the emergent focus on the complex structure of Yolngu seasons, an aspect of Indigenous seasonal knowledge that is neglected in most of the available literature. A close reading of Barber (2005, eg. p89) does suggest a multi-level seasonal cycle between monsoonal Wet/Dry and “short Yolngu seasons”, but this is not explored in depth.

I consider that the aim of this research – to develop an approach to integrating traditional and quantitative/analytical knowledge – was well served by the chosen methodology and methods. Multi-stage and iterative methods are well suited to exploratory research, and would provide a robust basis for further research. Suggested improvements to the methods within each stage, for investigation of Indigenous seasons specifically, are given in the section above. The scope of this thesis transitioned from broad synthesis to focussed inquiry as the depth and complexity of Yolngu seasonal knowledge became clear. The final scope focusses on well-grounded analysis of the data available, while identifying many tangents and extensions as potential directions for future research.

The main limitations are that the results represent a valuable but tiny fraction of relevant Indigenous Knowledge, it is difficult to assess the robustness of the findings, and only limited generalisation is possible. These limitations imply interpretation should be cautious. It is possible that critical parts of Yolngu seasonal knowledge are missing from the results above due to the small sample size and other limits. Difficulty in assessing the results is more concerning, and derived from uncertainty as to what the results *should* be. Properly resourcing follow-up fieldwork should be a priority for any future study (see eg. Jackson & Douglas 2015, on engagement plans). A second round of interviews or other appropriate data collection would allow engagement with and correction of any shortcomings in the qualitative results. It could also validate or guide refinement of the thresholds chosen in the numerical definitions of seasons. Most importantly it would ensure that the research is a partnership between equals by making follow-up fieldwork an integral part of the research rather than a seperate undertaking.

The same detail and locality that embeds ecological and climate knowledge in Indigenous calendars makes generalisation highly challenging (Barber 2005 and Davis 1989 came to similar conclusions). Specific findings of this study may not even be true for Yolngu calendars generally, due to the focus on Galiwinku and Milingimbi. More general findings, such as the three-level typology of 'kinds of seasons' may be more robust; for example that pattern is recognisable in the Tiwi Seasons (Figure 2.3) but would not be expected in temperate latitude calendars. Many of the general premises, notably including links between seasonal and ecological knowledge, are drawn from the literature and appear to be reliable across a range of Indigenous groups.

5.3 Applications and Benefits of the Research

This thesis makes a novel contribution to academic knowledge: it is the first study to quantitatively assess Australian Indigenous seasons, and develops techniques for further novel analysis including characterisation of seasonal timing. It supports concrete applications of interest to both Yolngu and non-Indigenous people, particularly through the methods pioneered above rather than the specific results of the calendar. Intangible benefits are more difficult to identify, but no less important.

Considering what activities in Northern Australia might benefit from the insights of this research reveals several potential applications (see eg. Dept. of Industry 2015). A local, experience-based, and tested seasonal calendar has real advantages for land, environmental, and natural resource management compared to an imported temperate-zone calendar assuming low spatial and inter-annual variability. Due to the exploratory approach taken in this study, and the context-specific nature of Indigenous seasons, it is anticipated that the most concrete applications would involve stakeholder groups conducting their own research based on the methods developed in this thesis rather than applying specific results of this research.

Four industries are identified which might benefit substantially from follow-on research, using seasons as powerful heuristics for the expected range and variability in weather, or to provide insights into patterns of change. Land or natural resource management is deeply affected by seasons; while specific applications are difficult to predict there are clear advantages to understanding and predicting local conditions. Second, these methods for integrating Indigenous Knowledge with numerical – and forecastable – weather data have clear applications in fire management where seasonality is a key determinant of fire impacts (Driscoll et al. 2010). In joint-management areas, internal research could produce predictive tools for fire risk or to recommend prescribed burning, based on both Indigenous Knowledge and cutting-edge fire science (see eg. Bowman 2003, Yibarbuk et al. 2001).

Northern agriculture, especially for native or other non-traditional crops, could benefit from a clear understanding of local seasonality. Research in this field should pay close attention to the relationships between vegetation dynamics and weather, and might improve the profitability and viability of Indigenous enterprises. This would extend recent work (eg. Jackson & Douglas 2015, Jackson et al. 2012) with Indigenous participation in water and river system management plans. Finally, Indigenous Knowledge and culture drives a substantial part of the tourism industry in Arnhem Land and across northern Australia, with some operators already employing Indigneous ecologists guides. The depth and richness of Indigenous Knowledge may be better appreciated by non-Indigenous visitors if it is presented alongside and integrated with scientific knowledge, which may be more widely recognised or respected. This integration could also encourage the application of Indigenous knowledge to improve management outcomes.

The applications and benefits of this research for Yolngu people also deserve consideration. Yolngu participants spoke about the need for reciprocity in research and expressed strong interest in scientific records of and perspectives on environmental change – and their desire for non-Indigenous Australians to learn about Indigenous ways of living, just as they have had to learn to live in a non-Indigenous system.

> *I would like to see benefit for both of us from this project, because I am sharing and my help should be acknowledged. You need to share what you learn. ... [The] wet season and the dry season changes, it's getting harder to read because there's more foreign stuff in Australia. But we have to learn! We have to try catching up to the changes, generation to generation.* —*Yolngu man*

Reflection on Petheram et al. (2010) suggests the approach to seasonal knowledge in this thesis may assist communities to engage with climate change science, to make adaptation choices and as a platform to advocate mitigation of climate change impacts – both important for coastal communities living off the land. There may be other ways for Yolngu to apply this research, the specifics of which are a matter for community discussion and further research.

Further research is recommended on Indigenous seasonal calendars, or integrating Indigenous and non-Indigenous knowledge about other topics. Such research would be applicable to many of the challenges facing Australia in the twenty-first century, helping Indigenous and non-Indigenous people to understand and adapt to global change, and perhaps for non-Indigenous Australians to reach a genuinely Australian understanding of what it means to live on this continent, our home.

6 Conclusion

This research investigated Yolngu seasons in North-East Arnhem Land, and developed an approach for integrating traditional seasonal knowledge with quantitative analysis. It contributes to academic knowledge by the publication of novel findings, development of methods to quantify Yolngu seasons, and demonstration of a research approach which integrates Indigenous and scientific perspectives. The findings and developed methods have concrete applications and suggest further research, and have implications for environmental management and for understanding global change at local scales.

6.1 Questions, Aims, Findings

The specific research questions proposed in Chapter 1 were addressed, and resulted in the following distinctive contributions to scientific understanding of Indigenous and Yolngu seasonal knowledge:

Calendar structure

Research participants describe seasons on three timescales with distinct monsoonal, meteorological, and ecological indicators for each. Yolngu seasons can occur in any order, even 'interrupting' one another depending on indicator conditions such as wind direction. This structure and detail is not explicitly evident in previous published research, and may generate new insights into the relationship between climate and ecology in Arnhem Land.

Characterisation and definition of seasons

Yolngu seasons are defined by environmental observations rather than the passage of time or astronomical indicatiors. Definitions may be in terms of weather, plant or animal dynamics, or a combination thereof. This finding builds on and extends the best previously published research. Yolngu participants agreed that weather indicators would be sufficient to determine which meteorological season occured on any given day. The definitions of Yolngu seasons vary between locations – as do the names and even number of seasons.

Quantified seasons

A Yolngu seasonal calendar was constructed based on literature and interview data. Seasons were defined in terms of daily weather observations, and substantial analysis was undertaken – including production of the first known timeseries identifying which season occured on each day, covering more than a decade of data at each of five weather stations.

Characterising timing

Based on the ground-breaking quantification of seasons, this study is the first to precisely describe the timing of Australian Indigenous seasons (in this study for Yolngu seasons at Galiwinku and Milingimbi) rather than simply reporting which months are generally associated with a season. This enables meaningful discussion of how to characterise the timing of such flexible seasons, and sets the stage for future work investigating relationships between Indigenous seaons and other climate or ecological data.

Uncertainty remains in the characterisation of seasonal instability or 'jitter', and the extent to which rapid changes in seasons (i.e. interruptions) in the constructed record reflect Yolngu understanding is not clear. In order to test whether the quantitative analysis of this study accurately represents Indigenous knowledge, further data gathering through fieldwork or remote surveys over one or more years would allow verification of the record going forward.

The pursuit of these findings was motivated by the wider aim of developing an approach to integrating traditional seasonal knowledge with a quantitative analytical approach. The research acheived this aim.

The specific methods developed to quantify Yolngu seasons appear robust, but difficult to generalise. While it is in principle possible to so quantify any calendar defined in terms of weather conditions, qualitative investigation into the structure and definitions of the calendar is unavoidable for well-grounded studies in this area. These methods provide an avenue for further research, especially as part of a larger programme investigating Indigenous seasonal calendars.

This thesis demonstrates a flexible methodology for integration of Indigenous and quantitative scientific knowledge and knowledge systems, which could be applied in domains beyond seasonal or ecological knowledge. It finds the general approach – participant-led conversations followed quantitative application of insights – surfaces novel and unexpected information, and makes it useful across cultural boundaries.

6.2 Directions for Further Study

Having demonstrated the viability of quantitative analysis of Indigenous seasons, and discussed the value of such research, there are three distinct directions for further study: expanding one or more of the depth, breadth, or topic of the research. Alternative research questions could also address the aim of this research – *"developing an approach to integrating traditional knowledge with a quantitative analytical approach"* – but are not suggested here.

6.2.1 Depth of Study

Deeper studies would likely focus on Indigenous Knowledge as it relates to seasonal patterns, and work to integrate IK with Western-style scientific knowledge. Researchers must ensure that both Indigenous and non-Indigenous people benefit from such work, and not continue the history of exploitative 'sharing' condemed by Smith (1999) and others. Further analysis of monsoon- or weather-based seasons would also fit in this category.

Attention to Yolngu benefits
Drawing on two-ways research, future studies should ensure that Indigenous people are involved in setting goals and implementing outcomes that are important to them, as well as benefiting non-Indigenous researchers.

Kinds of seasons
Section 4.1 describes a typology of seasons – monsoonal, meteorological, and ecological – that can be identified as part of a single Yolngu calendar (to the degree that 'single Yolngu calendar' is a coherent idea). Further investigation of the conceptual basis of this typology would be enlightening, as would gaining a stronger understanding of how seasonal indicators interact.

Ecological knowledge
Investigating Indigenous ecological seasons could provide deep insights into local ecology and traditional natural resource management. This would involve substantial logistical challenges: such study would require real investment in relationship-building, and collecting the data required to 'translate' Indigenous Knowledge to Western science would be expensive.

Per-year patterns
There is clearly a degree of variation in the ways in which Indigenous seasons occur between different years; studying these variations may reveal patterns. Are there distinct regimes that describe seasonal onset, timing, or interruption? If so, what data are required to categorise different years by regime and to make useful predictions?

6.2.2 Breadth of Study

Expanding the breadth of study would result in similar but less exploratory research; reducing novelty but increasing rigor. The clearest avenue for this is to collect and analyse more data from an increased number of sites.

Multiple Indigenous calendars
Replication of this study in other areas to document other Indigenous calendars would be valuable in each case, and the ability to compare calendars and investigate possible correlations between local climate and how seasons are defined could yield fascinating insights.

Single calendar, multiple sites
Similarly, comparing the calendar of a single language group across multiple sites and subtly different climates could be very interesting. An 'objective' weather record could really help researchers to draw out the differences between calendars, and perhaps see some of the subtleties. While this study had participants and weather observations from multiple sites, it did not analyse them as qualitatively distinct records or attempt any comparisons.

Iterative fieldwork

Future work should if at all possible invest the time and resources neccessary for multiple visits to the study area. Second opinions, feedback on quantitative results, and strong relationships supported by long-term engagement can all be valuable.

6.2.3 Topic of Study

Expanding the topic of the study might involve considering links to the wider context, for example climate indices and long-term change, or non-Indigenous calendars.

Non-Indigenous calendars

A comparative study of many kinds of calendars could be fascinating – Indigenous, agricultural, solar, lunar, or harvest seasons – unlocking the knowledge embedded in each.

Climatology

With seasons defined by weather observations, a climatological study of the Yolngu calendar could suggest links between forecastable climate indices and Arnhem Land ecology. Research could begin by investigating correlations between seasonal occurance and non-surface weather, or look at cycles with timescales on the order of months (eg. the Madden-Julian Oscillation), years (ENSO, the Indian Ocean Dipole), or even decades (the Pacific Decadal Oscillation).

Climate Change

The methods used in this study can be applied to any dataset which includes a daily record of the relevant variables. This enables investigation of observed, estimated, or projected past and future changes across scenarios including a wider range of conditions than exist in the historical record. One obvious application of this is to investigate how Yolngu seasons have changed over the past century, and how they may change under future climate change scenarios in model forecast and backcasts. Yolngu participants indicated substantial interest in such studies.

6.3 Implications

Beyond specific applications, this research has benefits which are less tangible or more difficult to predict. It demonstrates more nuanced ways of thinking about tropical seasons than the simplistic Wet/Dry dichotomy (Willmett 2009), and builds the foundation for new framing around climate change – everyone has lived experience with weather and seasons, while changing global mean temperature is an abstract and distant concept. In the long term, it may contribute to the drawn out but ultimately rewarding process of non-Indigenous Australians learning to understand, live in, and nurture Australia through a fully Australian world-view. This would require setting aside our 'maladaptive traditions' grounded in non-Australian contexts (Flannery 1994) to celebrate the unique challenges presented by our variable and extreme environments. Imagine a future where local radio discusses not the timing of European flowers, but local seasons – with a guest panel of Indigenous elders and climate scientists.

If this research can inspire the building of bridges or the breaking down of walls between our many separate forms of knowledge, Australia may be better placed to meet the challenges and opportunities of the coming century than the last.

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A Appendices

The printed appendices for this thesis are intentionally minimal. All the data I used are included in the electronic appendices, along with the custom-written analysis and plotting code. Any interested reader who has not received the DVD with this material is invited to contact me at `zac.hatfield.dodds@gmail.com` for a copy.

Additional Figures

This section contains figures which would unnecessarily disrupt the flow of the thesis, but are directly referenced in the text and therefore should not be left to the electronic appendices.

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Zac Hatfield Dodds,
ANU Honours Student

Dear Zac,

You has approached me about your research on the Yolngu Seasonal Calendar: Past, Present and Future (under climate change) as your Honours Thesis at ANU.

Thank you for our phone conversation in which we discussed how we can talk together properly and in a way that is respectful of Indigenous Knowledge. For Yolngu (the people of North Eastern Arnhem Land) it is the Liyagadhaman who carry within them the wisdom and knowledge of these matters. It is right that in this research you have approached me to talk about these things. I can also introduce you to others who have this knowledge.

We have talked about the value of this research for Yolngu as well as for the wider community and we agreed to discuss the results of this research so that we can learn together. I do not want you to take away our knowledge and not share any of your own work and the knowledge of other people about this matter.

Yolngu have made careful observation of the ways of nature and the seasons over the millennia and have passed on that knowledge down the generations. We know the changes that are taking place in the seasons and I am willing to talk with you about what I have seen happening around me.

Thank you for showing respect for Indigenous Knowledge. I am willing to work with you on this research.

Rev Jeffrey Rronang Garrawurra

Liyagawumirr Clan

4th September 2015

1

Figure A.1: The formal invitation to study Yolngu seasons, and share results with both first and second peoples. Pre-existing relationships, with Yolngu and non-indigenous people, were essential in arranging this collaboration.

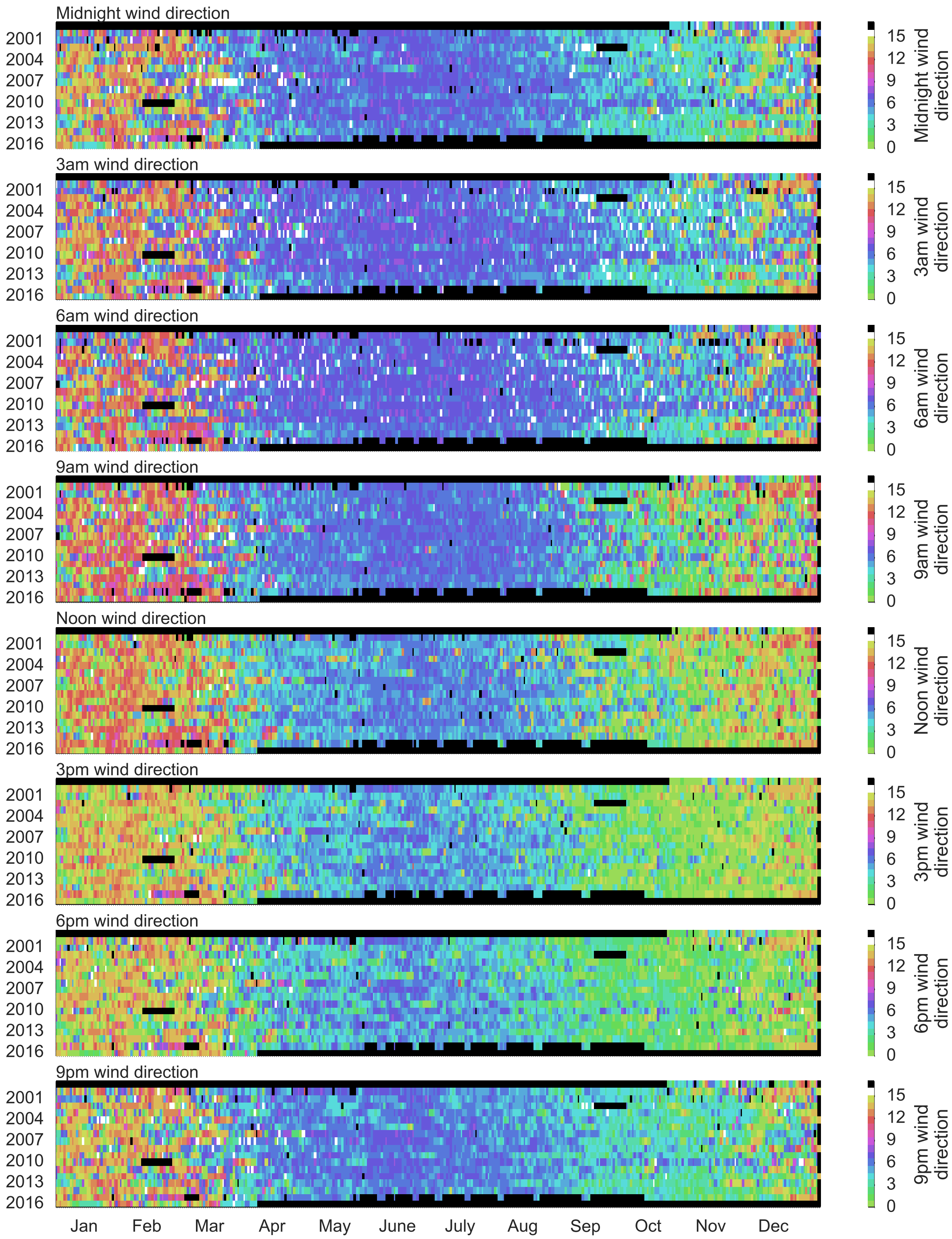

Figure A.2: 3-hourly wind direction heatmaps for Galiwinku, showing the northerly sea-breeze in the afternoon. Based on this figure, I judged that the difference between 3pm and 6pm wind for season detection is small enough that I prefer the meteorological standard (3pm) over Yolngu advice (6pm).