Gemma Louise Ives

The University of Sheffield

Department of Geography

A history of the monsoon in southern India between 1730 and 1920 and its impact on society: with a particular focus on Tamil Nadu.

PhD Thesis

A thesis submitted in partial fulfilment of the requirement for the degree of Doctor of Philosophy

March 2020

Abstract

The field of historical climatology has rapidly developed over the past two decades, driven by the understanding that improving the knowledge of the past can help make informed decisions about the future. Most studies currently focus on mid-latitude regions, whereas, this thesis is part of a growing body of work that seeks to expand the methodology into tropical and subtropical regions. Because of India's colonial past, there is a substantial amount of extant, English language documentation available to researchers and these documents can help to build an understanding of both historical monsoon magnitude and changes in the social-ecological systems of the past.

This thesis firstly explores the application of two types of documentary evidence for reconstructing the monsoon of Southern India, with a focus on the northeast monsoon of Tamil Nadu between 1730 and 1920. The first type is terrestrial documentation; this predominantly consists of government records, diaries, correspondence, historical accounts, newspapers and early instrumental records. The content of these documents was calibrated to modern instrumental rainfall, creating a five-point index of northeast monsoon magnitude, the first reconstruction of its length and resolution for the region, which had a strong correlation with modern instrumental data of 0.74, significant at the 0.05 threshold. The reconstruction was extended to present using degraded modern instrumental data: this new dataset showed that there is persistence in the cyclic pattern of increased and decreased monsoon rainfall, with approximately six epochs, each containing a period of above and below normal northeast monsoon rainfall between 1730 and 2017. The quality of this reconstruction was sufficient to investigate teleconnections between the northeast monsoon and the Indian Ocean Dipole and El Niño Southern Oscillation over nearly three centuries. This study demonstrated a non-stationary relationship between northeast monsoon rainfall and each of the two climate drivers, with good agreement between strong El Niño/La Niña and strong positive IOD events and normal-increased or normal-decreased northeast monsoon magnitude.

Secondly, this thesis explored the use of data from within ships' logbooks to reconstruct monsoon magnitude between 1750 and 1920, for both Kerala and Tamil Nadu and for each rainfall season. Two reconstruction methods were explored, composite plus scaling, and principal component regression. Interestingly, due to the unique monsoon climate and the need to adequately resolve it in both time and space, these reconstructions were less successful than their terrestrial counterpart.

This thesis goes on to use the information contained within the documentary sources to explore details of historical famine events in the region of modern day Tamil Nadu. These periods of famine were identified and characterised. The management strategies employed by government and their changes over time were identified, revealing a distinct and widespread transition to non-interventionist famine management on the part of the British government at the turn of the nineteenth century. Finally, this thesis uses the new northeast monsoon reconstruction to explore the interwoven relationship between political failure, rainfall and famine.

Acknowledgements

Firstly, I'd like to thank my supervisors, Dr. Julie Jones, Prof. Grant Bigg, Dr. George Adamson and Prof. David Nash for all the support, feedback and guidance they have given me throughout the process. Also, thanks to the University of Sheffield for funding the project and all the staff in the Geography building.

This thesis wouldn't have been possible without the love and support that I've received from my family and friends. Thanks to Joe and Fudge for making home the happiest place in the world. To my parents, Diane and Rob, for supporting me every step of the way and for being unfailingly proud of me, no matter how small my achievement. To my brother, Tiff, Poppy and Eden for believing in me and for always being there when I needed them. To Janet and Steve, for all the support and the snacks. Of course, my thanks to the cutlery draw, James, Rachel, Niall, Shauna, Hannah and James, who were all in this with me from start to finish and who never, even for one second, let me doubt myself.

Finally, thanks to everyone on A-floor for the tea breaks, the advice and for making each day as bright as can be!

Thanks everyone.

Contents

List of Figures

List of Tables

Chapter 1: Research context and aims

The Indian monsoon is the most eagerly anticipated weather phenomenon in India (Pai & Rajeevan, 2009). Its seasonal rains bring between 65-90% of a state's total annual precipitation (Guhathakurta *et al.*, 2015; Gupta, 2012; Nair *et al.*, 2014) which bolsters India's largest Gross Domestic Product (GDP) factor: agriculture (Krishna Kumar *et al.*, 2004; Nair *et al.*, 2018). Drought conditions in India have significant socio-economic impacts (Gadgil, 2003; Mallya *et al.*, 2015), including, a reduction in the country's GDP and the people's welfare, including food and water security (Niranjan Kumar *et al.*, 2013; Prabhakar & Shaw, 2008). Equally, heavy rainfall can lead to flash flooding, which takes lives, damages property and infrastructure, and reduces crop production (Auffhammer *et al.*, 2012; Guhathakurta *et al.*, 2015). However, despite its importance, monsoon dynamics are particularly challenging to capture in modern climate models, this lack of predictability can be challenging for those whose livelihoods and community depend on the timing and quantity of monsoon rainfall (Biasutti *et al.*, 2018; Rakesh *et al.*, 2015; Seth *et al.*, 2019).

Knowledge of how the monsoon changed in the past is vital to understanding modern variability and projecting future changes (Seth *et al.*, 2019; Veena *et al.*, 2014). Reliable modern instrumental records in India date back to 1871 (Dwivedi *et al.*, 2015; Krishnamurthy & Shukla, 2000), yet even with over a century of data in most regions, the variability of the southwest and northeast monsoons is poorly constrained. Previous efforts to extend the existing data sets have exploited proxy evidence. For example using ice cores from the Himalayas (Duan *et al.*, 2004), coral records from the Arabian Sea (Tudhope *et al.*, 1996), speleothem records from central India (Sinha *et al.*, 2007), sediment cores from lakes (Veena *et al.*, 2014), and tree-ring records from across India (Bhattacharyya *et al.*, 2007; Ram *et al.*, 2011).

The spatial variability in monsoon rainfall is high and many of proxy reconstructions capture all-India monsoon variability. There remains a dearth of studies that focus on long-term regional changes in the Indian monsoon as opposed to national changes (Borgaonkar *et al.*, 2010). Furthermore, the literature is dominated by annually resolved reconstructions, yet the variability of the southwest and northeast monsoons in relation global teleconnections are not symmetrical (Nair *et al.*, 2013). Of those reconstructions at a seasonal resolution, there is a substantial bias towards studies of the southwest monsoon as opposed to the northeast monsoon (Rajeevan *et al.* 2012), leaving those states whose rainfall regimen is dominated by the latter underrepresented in modern literature.

The Indian monsoon demonstrates periodicity on several scales (Zhisheng *et al.*, 2015) for example, millennial (Yancheva *et al.*, 2007), centennial (Sinha *et al.*, 2011a), decadal (Biasutti *et al.*, 2018), and interannual (Goswami & Ajaya Mohan, 2000). Currently the drivers of this variability are not yet fully understood and yet to characterise present and future changes, an understanding of these long term cycles is required (Seth *et al.,* 2019). Presently, the most prominent drivers of interannual monsoon variability are understood to be large-scale coupled ocean-atmosphere systems namely, the El Nino Southern Oscillation (Dwivedi *et al.*, 2015) and Indian Ocean Dipole (Lu *et al.*, 2018). However, recent studies have shown that the influence of these mechanisms are not stationary through time (Pokhrel *et al.*, 2012; Roy *et al.*, 2019), nor are there influences independent of one and other (Kriplani & Kumar, 2004), as a result, it is challenge to understand how they influence monsoon variability (Annamali & Slingo, 2001), more so to project future changes. Due to the complexity and lack of stationarity, it is understandable that the length of modern instrumental data is insufficient to adequately investigate these changes (Adamson & Nash, 2014; Sengupta *et al.*, 2018).

India's colonial past has left in its wake a wealth of historical, English language documents that are readily available to modern researchers. Such documents have previously demonstrated their ability to create regional, seasonally resolved, reconstructions of rainfall in tropical climates, with examples from Africa (Hannaford & Nash, 2016a; Nash *et al.*, 2016; Nash & Grab, 2010; Neukom *et al.*, 2009) and China (Ge *et al.*, 2005; Liu *et al.*, 2001). Fewer attempts have been made in India (Adamson & Nash, 2014; Walsh *et al.*, 1999), yet copious information remains locked in archives.

Understanding how the monsoons have changed is only a part of the story that historical documents can tell. Historical documents such as newspapers, letters and official government records all provide rich social information (Adamson *et al.*, 2018; Hall-Matthews, 2008; Mahony & Endfield, 2018), acting as a window into the past from which it is possible to record how societies were impacted by historical weather (Endfield, 2007) as well as their primary responses (Adamson, 2014). Even in a changing climate, this unique insight into the evolution of regionally specific human-environment relations (Daniels & Endfield, 2009) can often be overlooked in favour of purely quantitative reconstructions (Allan *et al.*, 2016; Carey, 2012). Social information is particularly rich during times of crisis, when significant political and social action is demanded, particularly during prolonged events, such as famine.

In light of this, this thesis aims to explore the information contained within historical documents, of both terrestrial and marine origin, and determine to what extent they can be used to develop the modern understanding of historical monsoon variability and the socio-political response to famine in southern India. In pursuit of this aim, the following research questions will be addressed:

i. Can qualitative and quantitative data, contained within documentary records be used to reconstruct historical monsoon magnitude and to identify prominent trends and/or teleconnections with large scale climate drivers, such as the IOD and ENSO?

ii. Can semi-quantitative wind data, contained within the logbooks of ships' captains be used to reconstruct historical monsoon rainfall and are the resulting reconstructions sufficient to explore trends and/or teleconnections with large scale climate drivers, such as the IOD and ENSO?

iii. What were the political and social responses to historical famines, as reported in the historical documents?

iv. Is there evidence, within the documentary sources, of a connection between historical famine events and northeast monsoon rainfall?

1.1 Structure of the thesis

Chapter 2 of this thesis outlines the study area, including a regionally specific discussion of the Indian monsoon and its present, past and predicted future variability. This discussion will detail both of the primary monsoon seasons, the southwest, or summer monsoon, and the northeast, or winter monsoon. It will also include a short description of the dry seasons. Chapter 2 then goes on to provide an overview of the origin of English language documents in India, specifically, the history of the origin and nature of English language documents in southern India, in respect to the colonial territory named the Madras Presidency. This chapter will detail the expansion of the colonial power in the region and introduce key places that feature prominently within the thesis.

Chapter 3 presents the terrestrial monsoon reconstruction. The chapter begins with a description of the present state of historical climatology applied to Indian climate; it presents previous examples and uses this review to frame the methods chosen for the reconstruction. Chapter 3 goes on to detail the collection and processing of historical data into a new reconstruction of the northeast monsoon over the land of modern-day Tamil Nadu and the union territory of Puducherry, hereafter, Tamil Nadu, before comparing the new reconstruction with existing reconstructions of regional monsoon rainfall and known drivers of northeast monsoon variability.

Chapter 4 deals with reconstructing the monsoon using wind data contained within ships' logbooks. As in Chapter 3, it begins by providing a context for the reconstruction with an introduction to the data within ships' logbooks and their use within previous studies. It goes on to detail the methods used in this research before presenting the first attempt to reconstruct Indian monsoon rainfall in South India using this unique data source.

Chapter 5 moves away from rainfall reconstructions by presenting famine history of Tamil Nadu, as described by the documentary data. Due to the colonial origin of the documents, this chapter focuses on describing the evolution of the primary political responses and it goes on to discuss the famine discourse preserved in the archives and the evolution of the colonial voice.

Chapter 6 summarises the relative strengths and weaknesses of both the terrestrial monsoon magnitude and the marine monsoon rainfall reconstructions detailed in Chapters 3 and 4. It goes on to summarise the social and political impacts and responses that were recorded during famine events. Finally, this chapter draws together both the reconstruction and the famine history by analysing the linearity of the drought-famine relationship that was so often reported in Chapter 5.

Chapter 7 summarises the key findings of this thesis before presenting opportunities for further study that have arisen from this research.

Chapter 2: Scientific background and historical context

This chapter outlines the physical and historical context for the thesis. It begins with an introduction to the study area, before discussing India's average monsoon and the current scientific theory for its manifestation and progression. It then outlines the forces acting both within and upon the system causing variability on both short and long time scales. Finally, it provides an abridged history of the British rule over India. With a focus on South India, it describes the origin and expansion of the East India Company's political influence throughout the region, the Company's eventual dissolution, the transition to British Crown rule and later, Indian Independence. With the exception of modern states, historical place names are used in order to remain consistent with quotations supplied in later Chapters. Unless otherwise stated, this is true for remainder of the thesis.

2.1 Study area

This study will focus upon the southernmost region of the Indian peninsula, the present day states of Kerala and Tamil Nadu. Despite their proximity (Figure 2.1), the two states have different cultures and climate.

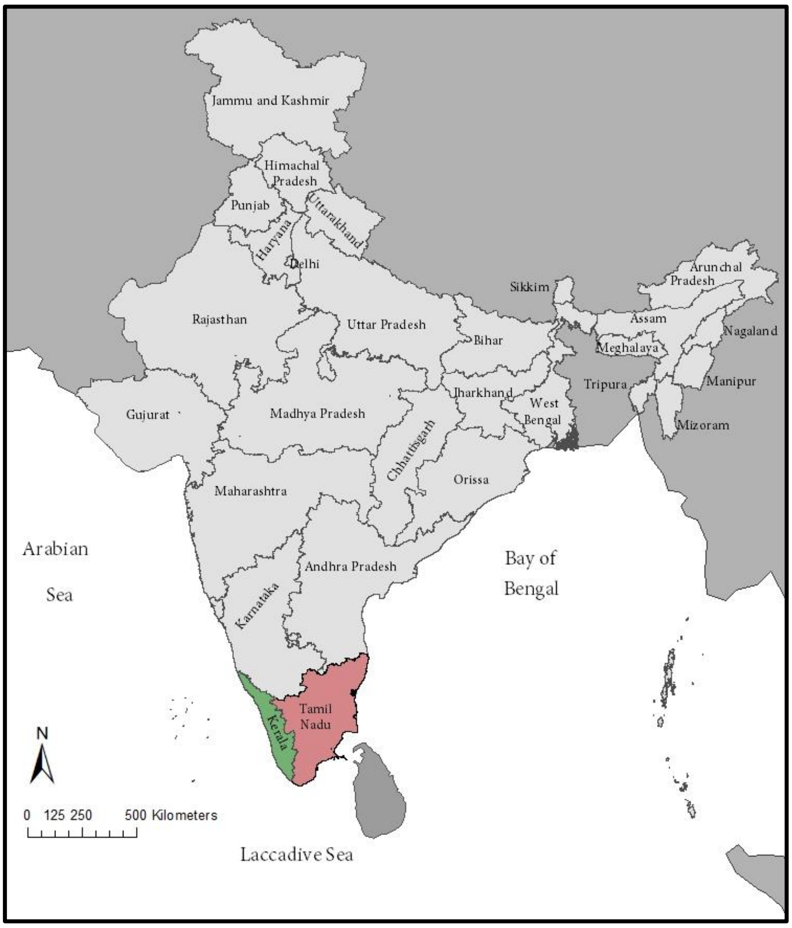

Figure 2.1 - Modern states of India, with Tamil Nadu shown in red and Kerala shown in green

2.1.1 *Kerala*

The state of Kerala covers 38,863 sq. km. The most significant rainfall event is the southwest monsoon between June and September (Figure 2.2) however, due to its tropical maritime position and orography, it also receives rain during the pre-monsoon season and in the northeast monsoon (Rajeevan *et al.*, 2012). As a result, Kerala obtains three times as much rainfall as the national average, amounting to over 2825mm per year, calculated from regionally averaged rainfall data between 1871-2014 (Mooley *et al.*, 2016). Some 68% of Kerala's landmass is cropped, and a further 29% is forested. The most commonly cultivated crop is coconut, followed by other high value cash crops such as rubber, pepper and cashew (Government of Kerala, 2011). Kerala experiences a lower inter-annual variability in its monsoon rainfall (Nair *et al.*, 2013, 2014) and is one of two states – West Bengal being the second- where *kharif*[1] grain production is not strongly correlated with all-India monsoon rainfall due to significant excess (Bhanu Kumar *et al.*, 2004).

2.1.2 *Tamil Nadu*

Tamil Nadu is larger in area covering 130,058 sq. km. Like much of India it has a strongly varying topography, including coastal plains to the east and mountainous regions to the west. The state receives an average of over 928mm of rainfall annually (1871-2014). It is partially shielded from the southwest monsoon by the Western Ghats. As a result, it receives only 38% of its rainfall from this season. The majority of its rainfall (48%) is received during the northeast monsoon (Government of Tamil Nadu, 2013). Figure 2.2 shows the annual distribution of rainfall over Tamil Nadu. The state can be divided into seven agro-climatic zones, creating significant agricultural diversity and contributing to the richness of the state's output (Varadan & Kumar, 2015). Tamil Nadu produces both subsistence crops such as *kharif* and *rabi*[2] rice, cereals and pulses, along with commercial crops, namely oilseeds, spices and sugarcane. Agriculture provides the livelihoods of ~45% of people in Tamil Nadu, despite the inter-annual variability (28%) of the northeast monsoon being far higher than that of the southwest (11%) (Rao, 1998; Sreekala *et al.*, 2012), which leaves harvests of non-irrigated crops more vulnerable to climatic variability (Varadan & Kumar, 2015).

---

[1] *Kharif* refers to the cropping season under the summer monsoon, typically July-October.

[2] *Rabi* refers to the cropping season under the northeast monsoon, typically October-March.

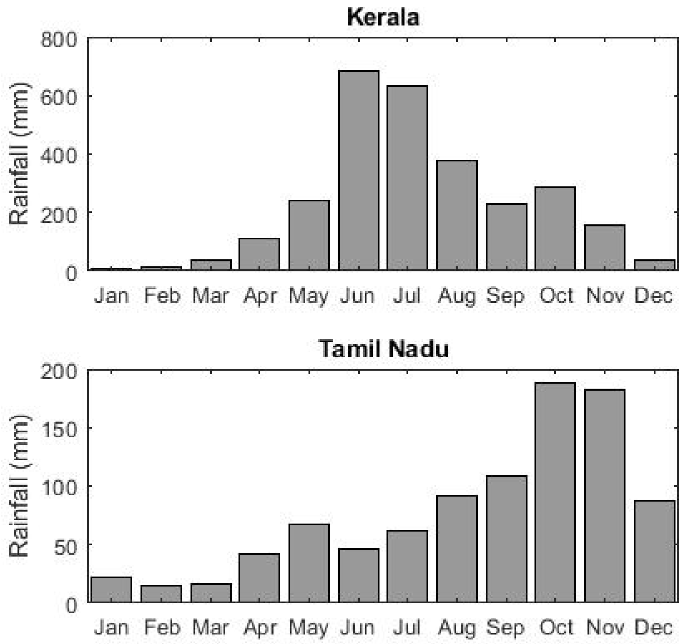

Figure 2.2 –Average monthly rainfall over Kerala and Tamil Nadu. Calculated for the period 1871-2014 using data from the Indian Institute of Tropical Meteorology (Mooley et al. 2016). Note the different scales on the top and bottom plots.

2.2 India's mean monsoon

India's geographical range is approximately 8°4' N to 37°6' N and 68°8' E to 97°25' E; it possesses a tropical and sub-tropical climate in its southern and northern regions respectively. The country's rainfall regime is dominated by the Indian monsoon. On average, monsoon conditions prevail between June and December and is characterised by the seasonal reversal in the prevailing surface winds and a substantial increase in precipitation. The monsoon is separated into two seasons, the southwest monsoon, otherwise referred to as the summer monsoon, which typically prevails between June and September, and the northeast, or winter monsoon, which on average occurs between October to December. For most of the sub-continent the southwest monsoon is the primary rainy season, with the notable exception of the southeastern states where the northeast monsoon contributes the most to annual rainfall (Balachandran *et al.*, 2006; Rajeevan *et al.*, 2012).

Onset of the southwest monsoon typically occurs over Kerala on the 1st of June with a standard deviation of approximately eight days (Pai & Rajeevan, 2009; Tyagi *et al.*, 2011). The monsoon gradually spreads northeast and encompasses the entire Indian subcontinent by mid-July. Withdrawal of the southwest monsoon typically commences on the 13th of September, with a standard deviation of seven days (Raju & Bhatla, 2014). It withdraws rapidly from the north-western states, slowing around mid-October over southeast India. Withdrawal of the monsoon from the continent is, on average, complete by mid-December. The average dates for onset and withdrawal are shown in Figure 2.3.

The characteristic monsoon conditions develop as the location of the solar maximum migrates northwards, from its winter position at approximately 22° south of the equator, to its summer position at the same latitude north of the equator. Classically, this migration of the solar maximum, led to the theory that the monsoon was a large-scale sea breeze, whose meridional flow was generated by the differential solar heating of land compared to the neighbouring oceans (Halley, 1686). However, this theory failed to capture unique aspects of the monsoon's manifestation and its internal variability, in addition to its place within the wider global monsoon system (Privé & Plumb, 2007b; Turner & Annamalai, 2012). Significant improvements on this theory have been made in recent decades; the most popular concept within current monsoon theory is that global monsoon circulations are a manifestation of the seasonal migration of the intertropical convergence zone (ITCZ) (Gadgil, 2018; Hill, 2019; Seth *et al.*, 2019; Yancheva *et al.*, 2007). Unlike Halley's model, the ITCZ theory grounds the Indian monsoon within the global atmospheric meridional circulation (Seth *et al.*, 2019), where, like the Hadley cell, these regional monsoon systems develop to transport net incoming energy poleward. The ascending limb, and associated rainfall belts are located at this zone of maximum energy input (Hill, 2019; Seth *et al.*, 2019; Shekhar & Boos, 2016). The northeast monsoon is often characterised as the retreat of the ITCZ as it follows the sun towards the equator (Acharya *et al.*, 2011; Nair *et al.*, 2013; Yadav, 2013).

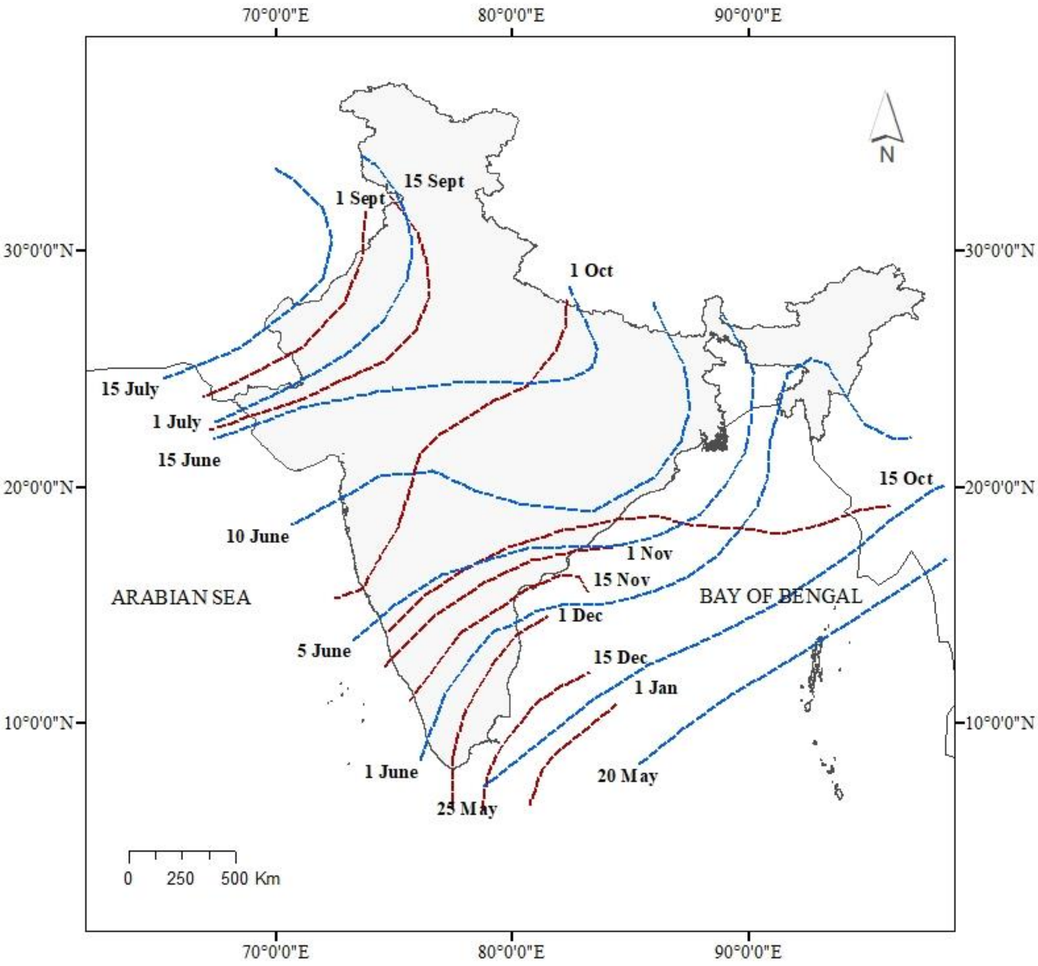

Figure 2.3 – Typical progression of monsoon onset and withdrawal. Monsoon onset is shown in blue, with accompanying dates on the left. Monsoon withdrawal is shown in red, with accompanying dates on the right. (Adapted from: Indian Meteorological Department, 2015)

2.2.1 ***Winter***

Before discussing the prevailing conditions during active monsoon seasons, it is first convenient to discuss the typical conditions between January and March while the monsoon is inactive. During the winter season which is typically considered to be the months of January and February, little rainfall occurs across the continent, and the surface conditions generally consist of prevailing northwesterly winds over northern India and easterly winds over the central and southern reaches. The upper atmospheric flow is characterised by a twin westerly jet stream whose branches diverge around the Tibetan plateau; its southern branch travels below the Himalayas, passing over Pakistan, Northern India, Bangladesh and Myanmar (Barry and Chorley 2010). During winter, the Himalayas and the Tibetan plateau act as a heat sink (Dimri *et al.*, 2015), above which anticyclonic conditions prevail, causing net continent – ocean air flow from the colder drier northern regions to the lower pressure oceanic regions (Figure 2.4) (Barry and Chorley 2010; Dimri *et al.*, 2015).

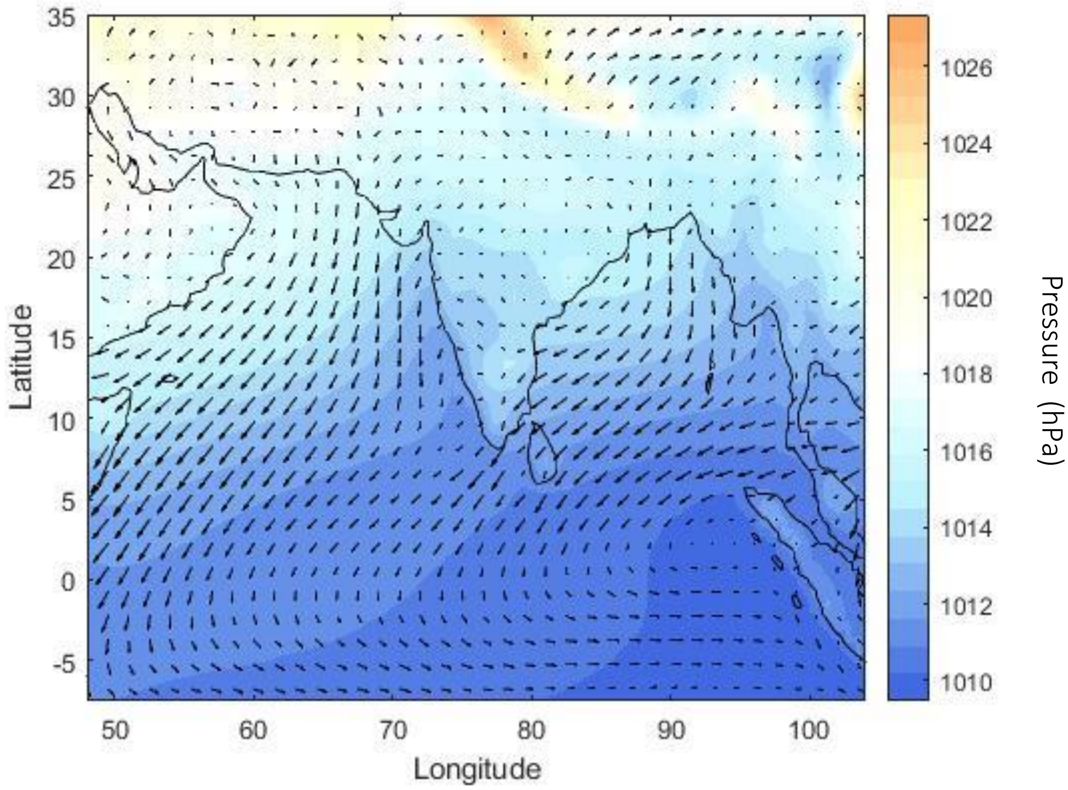

Figure 2.4 - Mean 10m wind flow and surface pressure (hPa) during January. Data from ERA-Interim reanalysis, 1979-2017.

2.2.2 ***Pre-monsoon***

The pre-monsoon season between March and May is characteristically very hot and dry. During this period India is susceptible to extreme temperatures and heat waves (Kothawale *et al.*, 2010). The March equinox sees the zone of maximum surface heating reach the equator and the low latitude tropical regions begin to warm (McGregor & Nieuwold, 1998). There is weak convection over the continent although it has a limited vertical extent as flow is dominated by subsidence from the ITCZ (Barry and Chorley, 2010). The zonal mean ITCZ is a band of deep convection that forms at the convergence of the tropical trade winds (Mehta *et al.*, 2017), otherwise described as the boundary between the two Hadley cells (Berry & Reeder, 2014; Biasutti *et al.*, 2018). This band of low pressure typically shifts meridionally with the annual migration of maximum solar heating, between approximately 25° north and south of the equator. During the pre-monsoon, small amounts of rainfall are delivered to the northern reaches of the continent via westerly disturbances. These disturbances are low-pressure systems embedded in the subtropical westerly jet stream that bring moist air from regions to the west, such as the Mediterranean Sea and the Persian gulf (Hunt *et al.*, 2018; Ridley *et al.*, 2013).

As the pre-monsoon season progresses, solar heating of the continental landmass accelerates. During May a deep low pressure forms over Northern India and Pakistan, where solar heating is exacerbated by clear skies and low evaporation (Bollasina & Nigam, 2011). This low pressure causes net ocean-continent wind flow at the surface (Figure 2.5) however, it typically forms a month before monsoon onset and while the northeast and coastal regions are susceptible to rainfall, the continent remains largely dry (Roy Bhowmik *et al.*, 2008).

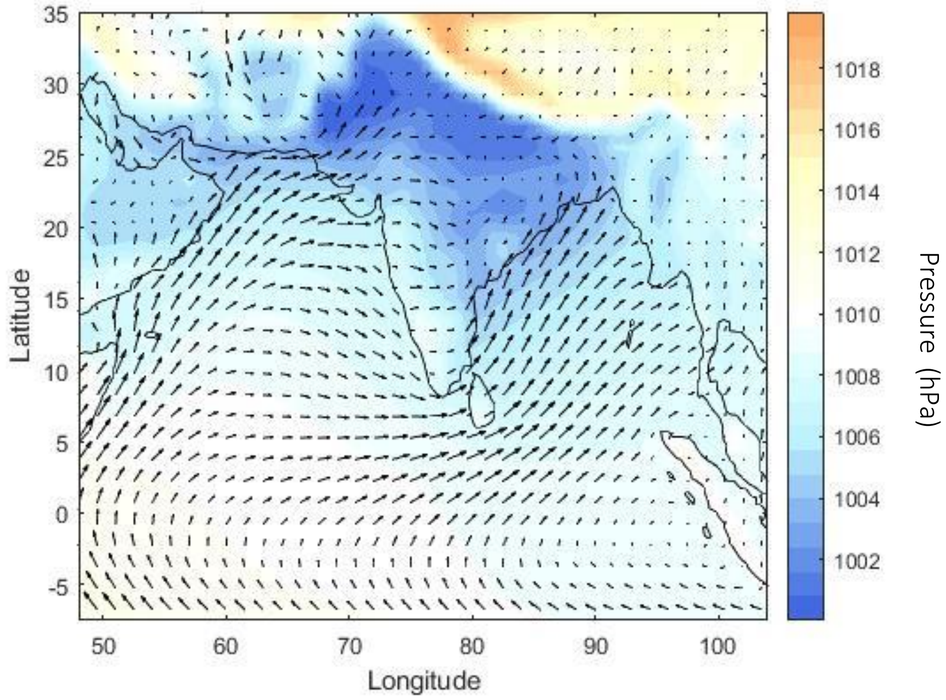

Figure 2.5 - Mean 10m wind flow and surface pressure (hPa) during May. Data from ERA-Interim reanalysis, 1979-2017.

In the upper atmosphere, the southern branch of the southwesterly jet stream weakens and is typically forced northward of the Tibetan Plateau by the end of May (Barry and Chorley, 2010). As this upper westerly flow breaks down, the low surface pressure associated with the ITCZ propagates to the north of the Indian continent. This low pressure encourages the westerly flow of humid air over the Arabian Sea to the continent, which strengthens as the monsoon becomes established forming the low level westerly jet, or the Somali jet (Fletcher *et al.*, 2019; Parker *et al.*, 2016). By mid-late May the vertical motion of air over the continent increases (McGregor and Nieuwolt, 1982; Parker *et al.*, 2016) and easterly winds become established in the upper troposphere, strengthening to form the upper tropical easterly jet (TEJ) (Galvin & Jones, 2009; Raju *et al.*, 2005) . During this period of transition between winter and summer circulation, the phenomenon of double onset can occur. Typically occurring in early to mid-May, Flatau *et al.* (2001) found that double monsoon onsets are caused by convective perturbations that cause the equatorial convection to spilt, with one cell migrating to the Western Pacific and the second into the Bay of Bengal. As the latter propagates northward it produces monsoonal conditions over continental India. As this system is exhausted, hot dry weather typically resumes over the continent and the onset of the monsoon is usually delayed.

2.2.3 *The southwest monsoon*

The southwest monsoon season is active between June and September. It delivers the largest proportion of the total annual rainfall to the continent, with the notable exception of the southeastern states. By mid-July, the monsoon typically encompasses the entire Indian sub-continent (Figure 2.3). The zone of solar maximum heating is between 22-25˚N of the equator and the rainfall band associated with the ITCZ lies over the north of India. Low pressure is well established over this region and deep convection of moist air into the upper troposphere prevails (Gadgil, 2018), with the vertical motion of air being supplied by low level cross-equatorial southeasterly winds. As these surface winds pass over the equator, they are deflected by the Coriolis force, which creates the characteristic c-shaped wind pattern over the Indian Ocean and Arabian Sea (Figure 2.6). In the upper atmosphere, strong easterly winds prevail over the continent and upper atmospheric divergence sustains convection in the monsoon cell (Bordoni & Schneider, 2008). The characteristic intensity of the Indian Monsoon is bolstered by the presence of the Himalayas and the Tibetan Plateau (Parker *et al.*, 2016). Historically, this region was thought to anchor the poleward extent of the monsoon by ensuring that sensible heat was transferred aloft. However, modern studies show that the orographic barrier actually acts as in insulator, preventing the incursion of cooler drier, extra-tropical air at the base of the monsoon circulation which can ventilate the flow by displacing hot, moist air (Boos & Kuang, 2010; Privé & Plumb, 2007a)

A large proportion of the total precipitation is delivered to the continent via monsoon depressions. As such, rainfall over the continent exhibits considerable intraseasonal variability demonstrating characteristic periods of active monsoon rainfall followed by break periods with little to no rainfall. Active periods are characterised by heavy rainfall from atmospheric disturbances and cyclonic activity over the Indian continent, with a variability of approximately 10-20 days for westward propagating disturbances and approximately 30-60 days for northward propagating disturbances (Annamalai & Slingo, 2001; Rajeevan, M., Gadgil, S., Bhate, 2010). These active and break cycles have a significant impact on the Indian population; long break periods can lower cumulative annual rainfall, and even in years with mean rainfall quantities, poorly timed or frequent break periods can negatively impact on agricultural production (Dwivedi *et al.*, 2006; Gadgil & Joseph, 2003).

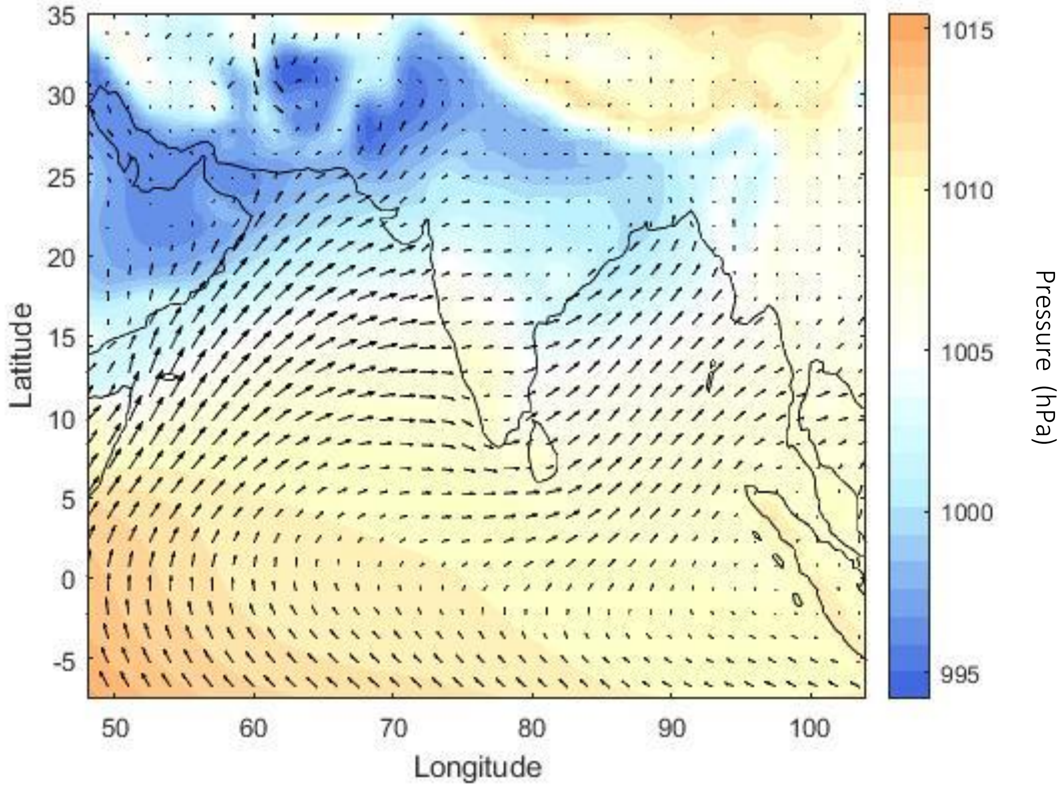

Figure 2.6 - Mean 10m wind flow and surface pressure (hPa) during July. Data from ERA-Interim reanalysis, 1979-2017.

The ITCZ theory, when applied to the manifestation and magnitude of the southwest monsoon, is alone, insufficient to capture some key aspects of the inter-annual variability of the monsoon. This includes how changes in the width, strength and location of the ITCZ relate to the monsoon circulation (Hill, 2019), particularly, the zonal and meridional extent of monsoon rainfall and its response to external forcings (Biasutti *et al.*, 2018; Gadgil, 2018; Seth *et al.*, 2019). However, Sinha, *et al.* (2011) suggest that the relationship between monsoon rainfall and ITCZ migration is best demonstrated over longer timescales. Similarly, in their study of past changes in the East Asian monsoon, Yancheva *et al*. (2007: 76) find the *"migration of the annual mean position of the ITCZ provides a single coherent explanation for the observed trends in both winter and summer monsoons over the past 16kyr… "*, where northward (southward) displacement of the mean position of the ITCZ resulted in increased (decreased) summer monsoon rainfall and decreased (increased) winter monsoon rainfall.

2.2.4 *The northeast monsoon*

The northeast monsoon sets in as the southwest monsoon cell withdraws from the continent and it is active between October and December. The northeast monsoon manifests as the zone of maximum solar heating, and the rain belts associated with the ITCZ, return equatorward (Sanap *et al.*, 2019). It is characterised by the reversal of the prevailing southwesterly summer monsoon winds to the northeasterly winter configuration. Low pressure establishes itself over the south of the Bay of Bengal and the average surface flow is from the continent to the ocean (Acharya *et al.*, 2011; Nair *et al.*, 2018) (Figure 2.7). In the upper atmosphere the Southern branch of the westerly jet stream re-establishes itself south of the Tibetan Plateau, and cooler winter conditions rapidly return to the North of India (Barry and Chorely, 2011). The northeast monsoon is characteristically drier and provides an average of 11% of India's total rainfall. The notable exceptions to this figure are the southern states which receive 30-60% of total annual rainfall (Rajeevan *et al.*, 2012). Studies of the northeast monsoon are substantially less prominent than for the southwest monsoon, despite it being the dominant source of annual precipitation for south east India and Sri Lanka (Gadgil, 2018; Rajeevan *et al.*, 2012).

Easterly low pressure waves are a characteristic feature of the northeast monsoon circulation, typically developing over the Pacific Ocean and propagating to the west (Acharya *et al.*, 2011; Nair *et al.*, 2013; Sanap *et al.*, 2019). Depressions and cyclonic storms form in this trough and propagate zonally (Yadav, 2013), delivering widespread rainfall to southern India (Sreekala *et al.* 2012; Kumar *et al.* 2004).

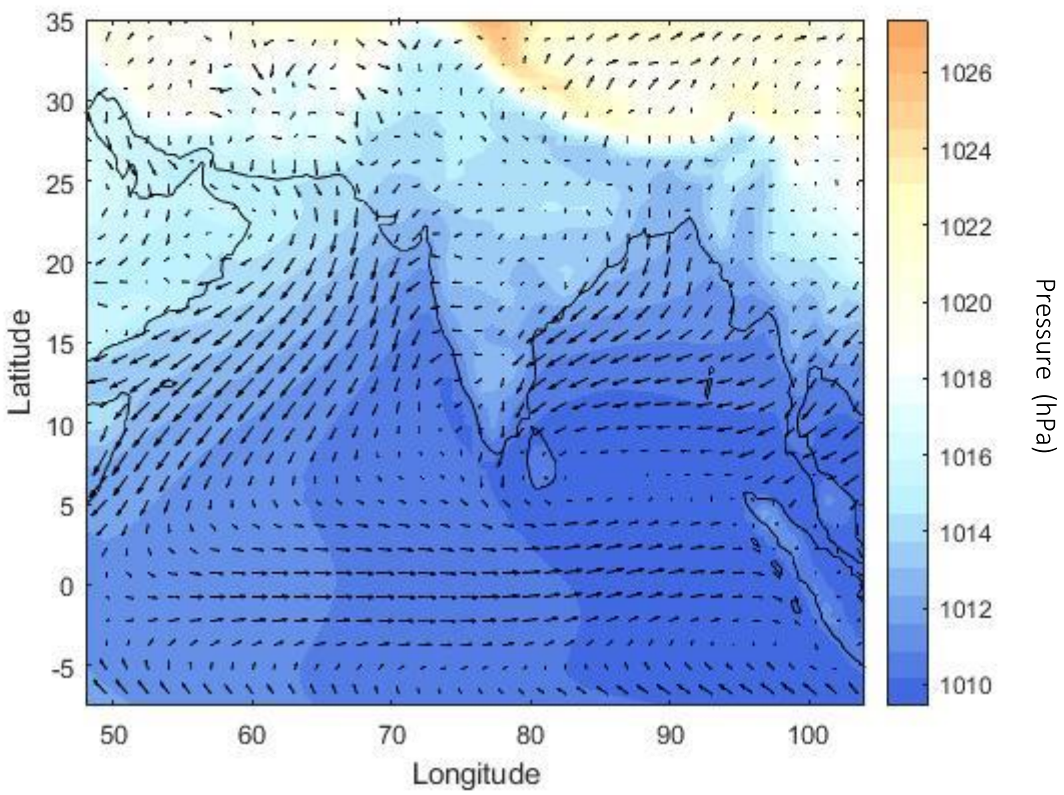

Figure 2.7 - Mean 10m wind flow and surface pressure (hPa) during November. Data from ERA-Interim reanalysis, 1979-2017.

2.3 Changes in the monsoon

The mean monsoon described above is subject to considerable variability, which influences the quantity and timing of monsoon rainfall. Understanding inter-annual variability of the monsoon is essential to allow for accurate monsoon prediction, numerous teleconnections have been proposed, including, but not limited to, sea surface temperatures (Huang *et al.*, 2012), Eurasian snow cover (Liu *et al.*, 2012), soil moisture (Webster *et al.*, 1998), and tropospheric aerosols (Singh & Patwardhan, 2012). However, the most prominent drivers of inter-annual monsoon variability are thought to be El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD), both are detailed below. Finally, the long-term trends in seasonal northeast and southwest monsoon rainfall are described in Section 2.3.2.

2.3.1 *El Niño-Southern Oscillation (ENSO)*

ENSO is a major driver of climate variability in the tropical Pacific (Roy *et al.*, 2019; Yun & Timmermann, 2018) and is known to interact with the Indian monsoon system (Dwivedi *et al.*, 2015; Ihara *et al.*, 2007b). Broadly, it is understood that during El Niño years, the zonal displacement of the Walker Circulation, which aligns with equatorial Pacific heat sources, results in subsidence over the Indian region, suppressing convection and consequently reducing rainfall; the reverse is true for La Niña (Gadgil & Joseph, 2003; Krishnamurthy & Goswami, 2000). The relationship is not consistent; strong El Niño events can manifest with little influence on monsoon rainfall (Ihara *et al.*, 2007b). However, recent literature has demonstrated that the type of ENSO may cause these anomalies (Roy *et al.*, 2019; Wang *et al.*, 2015). ENSO, whose Sea Surface Temperature (SST) anomaly is located in the Eastern Pacific (EP ENSO), is shown to exert greater influence on the suppression of monsoon convection, while ENSO whose SST anomaly is located in the Central Pacific (CP ENSO) shows no consistent relationship with monsoon rainfall.

ENSO exhibits the strongest relationship with the southwest monsoon and in comparison with the northeast monsoon its link with the former is the subject of the greatest study. However, recent studies have identified a potential relationship between ENSO and the northeast monsoon, which has strengthened from the 1980s (Kumar *et al.*, 2007; Zubair & Ropelewski, 2006). Where ENSO and the southeast monsoon are inversely related, the opposite is true for the northeast monsoon. During the northeast monsoon, boreal winter (December-February) Nino 3.4 SSTs are shown to directly influence rainfall, where El Niño events largely correspond with increased rainfall over southern India and Sri Lanka and reduced rainfall in Thailand, Vietnam and the Philippines (Sengupta & Nigam, 2019). This regional increase in precipitation has been linked to warm SST anomalies over the Indian Ocean at the lower latitudes during positive ENSO, coupled with an easterly wind anomaly due to the displacement of the Walker Circulation (Kumar *et al.*, 2007; Singh *et al.*, 2017; Yadav, 2012).

2.3.2 *The Indian Ocean Dipole*

The IOD refers to SST anomalies in the Indian Ocean. Typically, warm SSTs prevail in the east, off the coast of Sumatra, and cooler SSTs prevail in the western Indian Ocean. A positive IOD indicates a cooling in the former and a warming of the latter and vice versa for the negative phase (Lu *et al.*, 2018). The IOD is positively correlated with both the southwest and the northeast monsoon (Ashok & Saji, 2007; Cherchi *et al.*, 2007). In both cases, the positive phase enhances the monsoon flow. During the southwest monsoon season, easterly wind anomalies from the equatorial west travel below the equator, and are deflected west with the characteristic monsoon winds (Ashok *et al.*, 2004; Nair *et al.*, 2013). Similarly, the northeast monsoon circulation is enhanced, with easterly wind anomalies driving greater airflow from the moist equatorial ocean to south peninsular India (Figure 2.8). During the negative IOD phase, anomalous winds drive airflow away from the continent. Neither ENSO nor IOD act in isolation (Kripalani & Kumar, 2004), for example, the increased convection associated with a strong positive IOD has the potential to dampen the suppressive effects of El Niño on the southwest monsoon (Ashok & Saji, 2007).

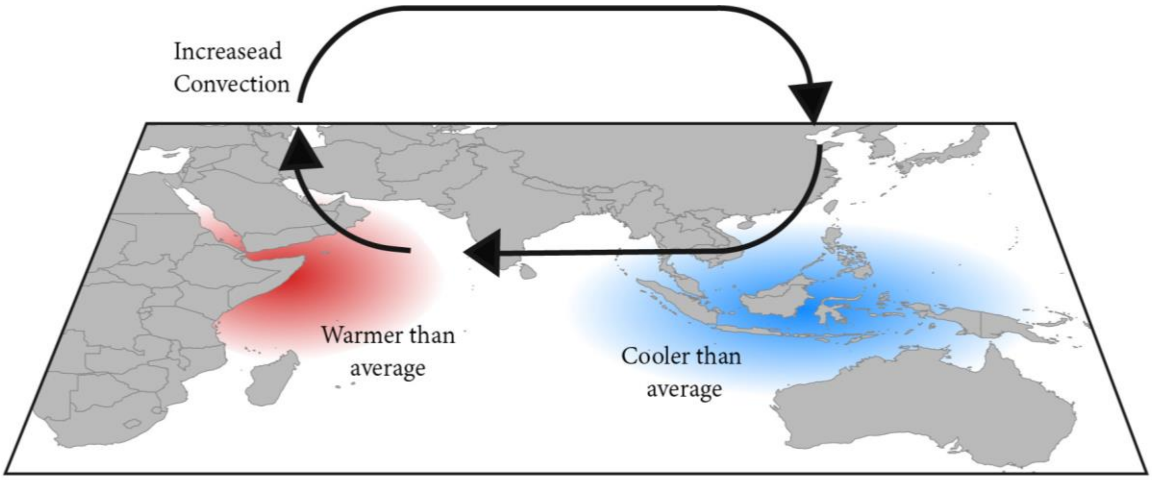

Figure 2.8 – A schematic showing a simplified positive phase of the IOD. Adapted from Commonwealth of Australia (2013). Map not to scale.

2.3.3 *Trends in monsoon rainfall*

Both ENSO and the IOD play prominent roles in driving inter-annual variability in the modern period (Bhanu Kumar *et al.*, 2004; Gadgil, 2003; Rajeevan *et al.*, 2012; Sreekala *et al.*, 2012), however, the strength of their relationship with both the southwest and the northeast monsoon is not consistent over time. Both the IOD and ENSO have demonstrated a strengthening relationship with northeast monsoon rainfall over recent decades (Kumar *et al.*, 2007; Yadav, 2012; Zubair & Ropelewski, 2006). In contrast, it has been suggested that the relationship between ENSO and the southwest monsoon is weakening (Kumar *et al.*, 1999), however this remains uncertain (Ashok *et al.*, 2019). Non-stationary teleconnections such as these compound with the decadal scale variability within the monsoon system making both long term trend identification and shorter term seasonal forecasting challenging (Goswami, 2006; Suokhrie *et al.*, 2018), as a result, forecasting monsoon rainfall remains challenging (Ihara *et al.*, 2007a; Rajeevan *et al.*, 2007; Wu & Yu, 2016) and model uncertainty is high (Turner & Annamalai, 2012).

There is a remarkable amount of variability in the results of modern empirical studies that investigate observed trends in monsoon rainfall, this is largely due to the decadal scale variability (Krishnamurthy & Goswami, 2000; Turner & Annamalai, 2012; Zubair & Ropelewski, 2006). Asymmetric cyclic patterns in rainfall are known to skew results. Guhathakurta *et al.*, (2015) and Sontakke *et al.* (2008) find five epochs of increasing and decreasing southwest monsoon rainfall between 1813 and 2005. Ramanathan *et al.* (2005) show that all-India monsoon rainfall decreased by 5% between 1961 and 1998 based on a thirty-year reference period yet an earlier study by Parthasarathy et al. (1994) shows that the strength of this negative trend may have been enhanced as result of a strong positive trend prior to this from 1910 to 1950. Despite this challenge, many have identified a negative trend in southwest monsoon rainfall, although this is shown to vary on spatial scale (Dash *et al.*, 2013; Kumar *et al.*, 2010; Singh *et al.*, 2014; Thomas & Prasannakumar, 2016). Finally, using over a century of data (1875-2005), Kumar *et al.* (2010) and Krishnakumar *et al.* (2009) demonstrate a negative trend in southwest monsoon rainfall over Kerala and Kumar et al. (2010) also find weaker negative trend for the same season over Tamil Nadu.

Studies of long term changes in the northeast monsoon are fewer than their southwestern counterpart (Bhanu Kumar *et al.*, 2004; Nair *et al.*, 2013; Turner & Slingo, 2009). Kripalani & Kumar (2004) have demonstrated similar epochs of above and below average rainfall, however, in contrast to the longer sustained epochs of it southwest monsoon, those during the northeast monsoon are approximately 10-20 years and appear to be controlled predominantly by the Indian Ocean Dipole (Bhanu Kumar *et al.*, 2004; Rajeevan *et al.*, 2012; Sreekala *et al.*, 2012). Kumar *et al.* (2010) note a weak negative trend in northeast monsoon rainfall between 1875 and 2005. However, recent studies by Naidu *et al.* (2010) and Sengupta and Nigam (2019), both find that more recently (1970-2006 and 1958-2013 respectively) northeast monsoon rainfall over southeastern India demonstrates a stronger positive trend. Sontakke *et al.* (2008) find a similar transition in their extended 1813-2005 rainfall data set, where they note that the trend in northeast monsoon rainfall over southeast India increases from approximately 1910.

2.4 Political history of India 1730-1947

India's colonial past has left in its wake a wealth of historical English language documents, many of them are preserved in archives around the world and are readily available to modern researchers. Chapters 3 and 5 will use the qualitative transcriptions from these documents to explore historic weather conditions and socio-political activity in Tamil Nadu. This section will provide a brief history of the rise and fall of British governance of India, with a focus on southern India between the years 1730 and 1920, 130 years after the establishment of the East India Company and 27 years before Indian independence from Britain. Understanding the broad history of the region gives context to the origin of the documents and their contents. The region of modern day Tamil Nadu falls within the historic district of the Madras Presidency, which, at its greatest extent encompassed Kerala, Tamil Nadu, Karnataka and Andhra Pradesh (

Figure 2.1). The seat of this presidency was Fort St. George, whose surrounding town later became known as Madras Town. This and other prominent administrative regions that feature in this section and throughout the thesis are shown in Figure 2.9. Prominent towns and cities that are mentioned in this Chapter and later throughout the thesis are shown in the Supplementary Information, Figure S.1.

The rich socio-political history of India is too large for a full account of the colonial campaign, or its lasting impact in both Asia and Europe. However, this section will outline key events that occurred within the study period, focusing particularly on those that affected the spread of British political influence in the south of India and consequently, the volume and spatial content of English language documentation. This includes prominent legislative changes, military campaigns and sources of revenue. For ease of the following narrative, the timeline is broken down into three sections, the first describes the early arrival of the British in the region as a trading entity and the subsequent struggle for power with other European trading companies and later, with Indian rulers. The second section, introduces the transition of the East India Company from a trading entity to a militarised political power. The final section describes the increasing legislative control placed upon the Company by the British government, the decline and eventual collapse of Company and the transfer of former company territory to Crown rule. This section ends in 1947 with the Indian Independence from British rule.

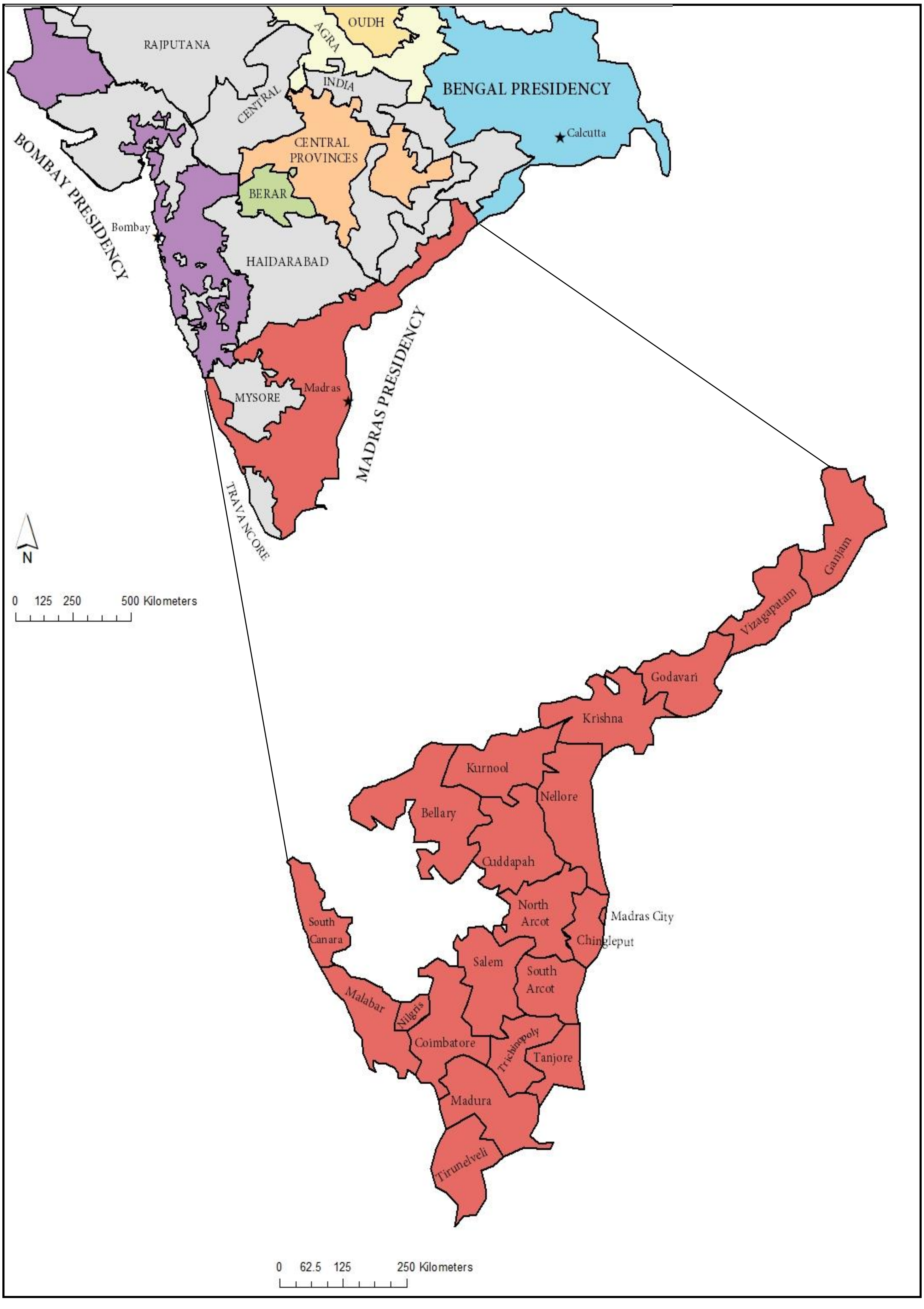

*Figure 2.9 - The political boundaries of India in 1875, with a focus on the central and southern states. British territory is shown in colour; those regions with Indian governments are shown in grey. The principal administrative towns of Madras, Bombay and Calcutta are labelled. The boundaries of the districts of the Madras Presidency are shown in the larger map of the Madras Presidency. Both maps are adapted from Stieler's hand-*Atlas *(Stieler, 1875)*

2.4.1 *Trading and war making. Early exploits of the East India Company*

The East India Company received its royal charter from Queen Elizabeth the 1st in 1600, it was to be a long distance, joint stock trading company with exclusive rights as the only legitimate English (later British) traders with the East (Lawson, 1993; Robins, 2012). Two years later, its first ships arrived in Asia (Farrington, 2002). Early trade largely comprised of pepper, however, as this trade collapsed in the early 1600s, the Company successfully identified new avenues of commerce (Robins, 2012; Lawson, 1993). Large financial returns were made in the trade of arrack, betel leaf, tobacco and cannabis (Love, 1913), along with its more famous exports of tea, cotton fabrics, saltpetre and opium. British imports to India consisted of silver, iron and broadcloth (Farrington, 2002; Robins, 2012). Prior to the 1700s, the demand for Indian cotton fabrics, specifically, calico and hand painted chintz was exceptional. However, the heavy importation of Indian fabric led to riots by the woollen and silk producers in England which culminated in the ban of the importation of these fabrics in the Calico Acts of 1700 and 1721 (Eacott, 2012). Madras was a centre for the weaving and painting of calico, and the Madras government blamed the reduction in European demand, as a result of the Acts, for an increase in unemployment in the town (Love, 1913). The Act was repealed in 1774, however, by this time substantial efforts had been made in England to replicate the Indian method of producing printed fabrics and the demand for Indian fabrics was reduced (Thomas, 1924).

To streamline trade in the east, the Company established warehouses and trading markets in the popular trading regions. These warehouses were dubbed factories, after the high concentrations of 'factors' (merchants) who traded within them. In 1639, the East India Company was given permission to *"construct a fort and castle in or about Medraspatam"* (Love, 1913: 17). The construction of Fort St. George, began the same year and in just two years, the Fort became the principal factory in South India (Love, 1913), the surrounding regions later became known as Madras Town (Figure 2.9). The land was granted to the Company by Naik Damarla Venkatadri who governed a region of southern India from Pulicat (Supplementary Information, Figure S.1) to the Mount St Thomas, approximately 17km southwest of Fort St. George, which was the northern border of the Portuguese settlement. The ruling Naiks were princes of southern India, who became largely independent following the destruction of the South Indian Hindu kingdom of Vijayanagara after the battle of Talicot in 1565 (Joppen, 1907). The Company holdings remained small throughout the seventeenth century; by 1690 the British East India company held three primary settlements shown in Figure 2.9 (Lawson, 1993; Wheeler, 1861). The earliest was Madras, established in 1639, the second acquisition was Bombay, transferred to the Company from the Portuguese counterpart in 1668, on the marriage of Catherine of Braganza and King Charles the 2nd (Joppen, 1907), the third was Calcutta, in Bengal which was established in 1690 (Robins, 2012).

It is in this early period that the military power of the East India Company increased and with it, its political interference. The motivation for, and the consequences of, this transition from trading entity to political and military power in India is too large to consider in this thesis, however, the substantial changes in territory and political influence of the British in southern India as a result should be summarised. Two protracted periods of warfare occurred within this period, the Carnatic wars (1746- 1763), fought primarily between the British and the French East India Companies and their Indian allies, and the Mysore Wars (1767-1799), fought between the Sultanate of Mysore (shown in its reduced size in Figure 2.9) and the British East India Company and its native allies. Each are discussed in greater detail below. These conflicts are pivotal to British ascent to power in southern India.

The Carnatic Wars

The British East India company in South India was in competition with other colonial powers, including, the Portuguese, the French and the Dutch. The East India companies of each respective country became auxiliaries in European politics. Hostilities between the French and the British were commonplace throughout this early period. Prior to 1746, the French were prohibited from attacking European forces by the local Mughal Governor (Bryant, 2004). Therefore, with the exception of a naval battle which took place off the coast of Madras in 1690 (Love, 1913), the first campaign between the French and British for control of Indian trade was a succession of three wars, known as the Carnatic Wars between 1746 and 1763. The first Carnatic War, commenced with the capture of Fort St. George by the French in 1746, the British responded with a failed attack on the French settlement, Pondicherry. Warfare between the French and the British in Europe ceased in 1748 and as part of the wider Treaty of Aix-la-Chapelle, Fort St. George was returned to the British. However, the Second Carnatic war, which was fought between 1749 and 1754, saw fighting recommence as a proxy war, using two powerful Indian rulers. The French supported Muzaffar Jang and Chanda Shaib, while the British favoured their opponents Nasir Jang and Muhammed Ali (Johnson, 2013). There was no clear victor; in 1754, Muhammed Ali was established as the Nawab of the Carnatic region and the treaty of Pondicherry was signed. The treaty recognised the financial exhaustion of both sides (Bryant, 2012). During the war, several battles, and their generals, were celebrated, the most notable being the capture of Chanda Sahib's capital, Arcot, by Robert Clive. Clive would later go on to achieve a pivotal victory at the Battle of Plassey in 1757 and re-establish British political control of Bengal, after which the balance of power in India began to favour the British (Bryant, 2004).

The third Carnatic war was linked to the outbreak of the Seven Years War (1756-1763), between European powers. On this occasion, open warfare was resumed between the French and the British as each continued the struggle for supremacy. The French besieged both Fort St. George and Fort St. David in the period between 1758 and 1759. They failed to capture the former, but succeeded in the latter, which was surrendered to the French in 1758[3] (Love, 1913). The French suffered a major defeat at the Battle of Wandiwash in 1760, which led to the surrender to the British, in the following year, of the French administrative capital in South India, Pondicherry. This all but decided the Anglo-French conflict in India, leaving the British as the primary European power in South India (Bryant, 2004; Bryant 2012).

[3] IOR/G/18: Fort St David: Letters to government 24 Jan 1751 to 31 July 1759. *List of particulars relating to the attack, siege and surrender to the French of Fort St. David 1758.*

The Anglo Mysore wars

The Anglo-Mysore wars were a series of four wars between the British East India Company and the Kingdom of Mysore. Mysore, like the lands of the Naik's gained independence with the fall of the Vijayangara Empire. It was ruled by Hyder Ali, who usurped leadership from the native Wodeyar dynasty in 1761 (Barua, 2011; Dowdwell, 1923); the region was later ruled by his son, Tipu Sultan. The First Anglo-Mysore war broke out after the fragile political relationship between Mysore and the Company broke down. Prior to open hostilities, the British held a weak allegiance with Mysore, which ceased when the Company failed to assist Hyder Ali in a battle against the Maratha Confederacy in central India. Hyder Ali invaded the Carnatic in 1767. By this time, the Nawab of the Carnatic, Muhammed Ali, was largely under British political control, and dependent on the British armies for defence of the region (Bryant, 2004). Following a series of defeats, Hyder Ali began a campaign of scorched-earth tactics. In 1768 he razed the agricultural lands and cut off supplies to Madras town and focused on carrying out continual raids on supply houses (Ahuja, 2002a; Barua, 2011). His tactics were effective, as a largely desolated Carnatic region (Love, 1913) deprived the British of a large income (Hayavadana Rao, 1948), and they were forced into a peace treaty in 1769.

The second Anglo-Mysore war was fought between 1780 and 1784. The American revolution reignited tensions between the British and the French, with whom Hyder Ali was allied (Robins, 2012). Following a British attack on French holdings in South India, Hyder Ali began a second invasion of the Carnatic. The British force was defeated in the first battle causing a large-scale military retreat to Fort St. George and the emigration of large number of civilian residents (Love, 1913). Reinforcements were sent from Bengal, however, Hyder Ali employed the same scorched-earth tactics that were so successful in the previous war, destroying agricultural land and settlements, blocking supply chains, and carrying out numerous raids that isolated and eliminated smaller bands of British troops. Rao (1943) records that Hyder Ali's forces destroyed a 50-mile swathe of land around Madras, although the origin of this figure is unclear. A French squadron assisted the blockade of supplies from sea temporarily, and the lack of food supplies in Fort St. George and Madras town became critical. The French sea blockade withdrew early in 1781 (Barua, 2011), which allowed supplies to increase to a sufficient level for an offensive stance from the British. However, the hungry British army suffered several defeats (Vartavarian, 2014) and eventually a peace treaty was signed by the British in 1784. Hyder Ali died of natural causes in December, 1782 and he was succeed by his son Tipu Sultan (Barua, 2011) who led Mysore through the subsequent two wars with the British.

The British, in violation of the peace treaty, attacked Tellicherry in 1790 and initiated the third war. An attempt to lay siege to the Mysore stronghold, Seringapatam, failed as the British supply lines were once again cut off by Tipu's cavalry. Prior to the third war, the British had allied themselves to the Central Indian Maratha confederacy. Following the failure to take Seringapatam, the Maratha cavalry not only reinforced the British troops, but also provided supplies (Barua, 2011). As a united force, the British, the Marathas and the troops of Hyderabad (Figure 2.9), whose Indian ruler was under British political control, were able to force Tipu into a peace treaty in which half of the Sultans lands were turned over and distributed to the three powers. The British took control of Western coastal districts and inland districts such as Salem (Figure 2.9) (Barua, 2011; Robins, 2012; Dowdwell, 1929). The fourth and final Anglo-Mysore war began in 1798 and ended with the siege and invasion of Seringapatam where Tipu Sultan was killed fighting on the walls in 1799 (Dowdwell, 1923).

The Anglo-Mysore wars, and to a lesser extent, the Carnatic wars represent a period of substantial territorial acquisition for the Madras Presidency in South India. In addition to those lands acquired after the defeat of Tipu, the Nizam of Hyderabad ceded his southern districts to the British in 1800 as payment for the maintenance of the subsidiary force of British troops (Joppen, 1907). The Wodeyar rule of Mysore was re-established, but largely fell under British political control. Figure 2.10a, shows the political boundaries in 1751, in the midst of the second Carnatic War. During this period, the Kingdom of Mysore and the Nizam's Dominions, allies of the French, dominated southern India. Figure 2.10b, shows the political boundaries in 1805, where control largely lies with the East India Company, and the reduced state of Mysore. As is evident from these figures, British territory in southern India increases substantially between 1751 and 1805.

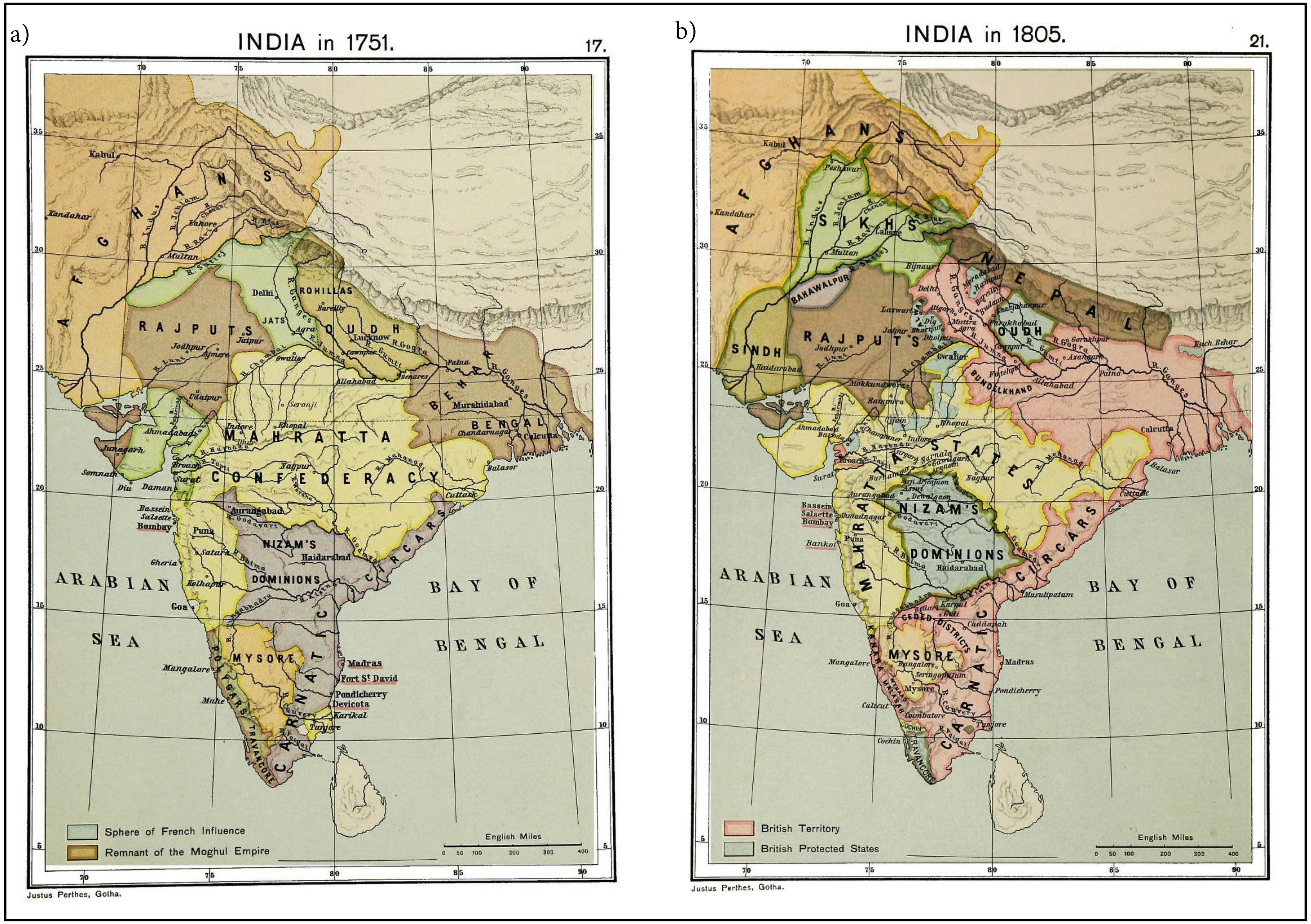

Figure 2.10 – a) The political boundaries in India in 1751 and b) the political boundaries of southern India in 1805. Joppen (1907)

2.4.2 *East India Company as Landholders in Madras*

While the collection of taxes by the East India Company was permitted by the native rulers within the immediate bounds of company settlements, the Battle of Plassey in 1757 plunged the East India Company into a new era. After his victory, Robert Clive and the Company were given *diwani* rights, imbuing this corporate enterprise with the right to tax the 10 million residents of Bengal (Robins, 2012). Similarly, in Madras, the Company declared themselves owners of the lands they had conquered by overthrowing Tipu Sultan in addition to those regions that were obtained through payments of debt. With ownership of the land, the Company claimed the right to the taxation of the residents (Mustafa, 2007). The consequences of a private foreign company obtaining the rights to collect and spend public funds are beyond this summary; however, the new stream of income significantly expanded the Company's original trading remit. The landscape of Company power was divided into three presidencies, Madras, Bombay and Bengal (Figure 2.9) with the overarching control of the Company administrators based at East India House in London.

In the Madras Presidency, the Company began a series of experiments with taxation reforms (Mustafa, 2007; Wilson, 2011). With the appointment of Thomas Munro as governor of Madras, the ryotwari system, which he and Alexander Read had developed, was established across the presidency. This system operated a scheme of 'peasant taxation', where cultivators leased land directly from the government. The cost of the lease was fixed for all plots of agricultural land following a survey, performed by Company officials of the productive capacity of the soil (Hussain and Sarwar, 2012; Ambirajan, 1978). These surveys were carried out in each village for all plots of agricultural land. The rents were intended to take into account the condition of the cultivators, the soils, the potential crop types and the access to water (Reddy, 1988). Under the ryotwari system, collectors were assigned to each province; it was the responsibility of these collectors to extract rent from the cultivators and to inform the government of the condition of the people in their district (Wilson, 2011). Remissions or partial remissions of rents could be petitioned for, however these were only granted in extreme circumstances. The East India Company set the rates famously high (Adamson, 2014; Mustafa, 2007; Reddy, 1988) and the oppressive system often left only a bare subsistence for many farmers (Hussain & Sarwar, 2012).

This transition to British land rule did not occur without resistance. Those chiefs which gained independence upon the fall of the Vijayangara Empire ruled over smaller settlements; collectively, these 'little kings' were known as the poligars. Poligar landholdings largely fell in the western extent of the Madras Presidency (Figure 2.10), but were also distributed throughout the southern districts such as Madura and Tirunelveli (Figure 2.9) (Gilady & Mackay, 2015; Yang, 2007). Many of these kings did not accept British sovereignty, and the proposed tax reforms encroached on their own rights to collect taxes within the bounds of their smaller kingdoms. An organised rebellion against British rule led to a period known as the Poligar wars between 1799 and 1801. The British sought to eliminate the Poligar's claim to power, however, they were unprepared for, and inexperienced at jungle warfare and incurred heavier losses than anticipated (Gilady & Mackay, 2015). The rebellion ended in 1801 when several prominent Poligar kings were publicly hanged, their conquered forts razed and the agricultural lands around them salted to prevent inheritance (Yang, 2007).

2.4.3 *The fall of the East India Company*

By the late eighteenth century, following numerous corruption scandals and reports of tyranny and abuse (Hussain & Sarwar, 2012; Mustafa, 2007; Raman, 2012; Washbrook, 2004), considerable pressure was placed upon the British government to bring the Company and its actions in India under political control. The Regulating Act of 1773 and later, the India Act of 1784 sought to make the Company responsible to parliament. The Board of Control was established which assigned the political, diplomatic and legal aspects of company rule to the British parliament with the Company responsible for its administration and trade (Lawson, 1993; Robins, 2002). The position of governor-general, based in Calcutta, Bengal, was also established, which devolved the powers of the Madras and Bombay presidencies (Robins, 2012).

The Company became increasingly embroiled in political and financial turmoil (Wilson, 2011). Internally, the company suffered from a high turnover of governors (Lawson, 1993) and externally, free-trade activists actively campaigned against the company and its monopoly rights on trade with the East (Ambirajan, 1978). Furthermore, the company continued to spend vast amounts of money on military exploits (Lawson, 1993) and as a result, when the time came to renew its charter in 1813, the company possessed considerable debts and a poor trading return. As a result, it was stripped of all its monopoly trading rights, with the exception of the tea trade with China, meaning that in the years following 1813, the Company had no control over trade with India. Following the introduction of free trade principles in India, campaigns for freedom of movement were looked upon more favourably by the British government and by 1824 there are early examples of British citizens legally obtaining leases on land for agricultural purposes in India (Ambirajan, 1978).

Further political reforms under the India Act of 1833 stripped the Company of its final monopoly privilege (Webster, 1990). By the time of the Great Rebellion in Bengal, 1857, control of the military and political affairs of the East India Company had been largely divested to parliament and revenue returns were focused on taxation as opposed to trading enterprise (Lawson, 1993; Ram, 1972). However, in 1858, following the brutal suppression of the rebellion (Robins, 2012), all Company lands and military assets were formally transferred to the British Crown and the East India Company's remaining administrative powers were revoked. Under Crown Rule, the position of governor-general mutated into the Viceroy and governor-general of India. This position was chosen by the Crown; the Viceroy was permitted to act on behalf of the British government and was responsible for carrying out orders of the secretaries of state (Muir, 1917). The study period for this research ends during Crown Rule in 1920. However, it should be noted that the Indian nationalist movement gained significant traction during the late 19^{th} and early 20^{th} centuries, particularly following the two world wars, during which, millions of soldiers were recruited from British India (Schulze-Engler, 2018). Numerous campaigns and peaceful protesting against British governance led to Indian independence in 1947.

2.5 Chapter Summary

This chapter has introduced the scientific and historical setting of this this research. It began by introducing the modern states of Kerala and Tamil Nadu, which comprise the study areas for this thesis. It went on to detail India’s typical monsoon and the dominant monsoon circulation during each of the four seasons, winter, the pre-monsoon, the southwest monsoon and the northeast monsoon. This section concluded by introducing two prominent teleconnections, ENSO and the IOD, which are known to influence inter-annual variability, followed by a discussion of the long-term trends in monsoon rainfall. Finally, this Chapter presented the expansion East India Company and British Territories throughout southern India, and the role British Indian Governance.

Chapter 3: Terrestrial documentary monsoon reconstruction

3.1 Introduction

This chapter details the new reconstruction of the northeast monsoon magnitude between 1730 and 1920 over the region of modern-day Tamil Nadu. It begins by introducing the field of historical climatology, with a focus on studies performed in tropical and monsoonal climates. This chapter then discusses the process of archival data collection, with details of the types of documents employed in this study before describing and justifying the methods used to reconstruct northeast monsoon magnitude using this data. Finally, it explores long-term trends and tropical climate teleconnections between 1730 and 2014 by extending this new reconstruction to present using modern instrumental data.

3.1.1 Historical climatology

Historical climatology is an interdisciplinary field formed of both the social and physical sciences (Pfister, 2010; Pfister *et al.*, 1999). It is a comparatively new field of study whose origins can be traced back as recently as 1950-1970 (de Kraker, 2006; Ogilvie, 2010). The field explores the use of historical texts to extend the knowledge of pre-instrumental climate and its impact on societies. Texts include diaries, government records, memoirs, letters of personal or professional correspondence, newspapers, and early meteorological records. This list is by no means exhaustive and historical climatologists are constantly seeking out new and novel approaches across the globe (Cornes, 2014). Early studies within historical climatology favoured the physical capacity of documentary data using it to improve the scientific knowledge of weather and climate in the years prior to the introduction of a widespread, reliable meteorological data collection (Brázdil *et al.*, 2005; Carey, 2012). However, in recent decades, the field has placed a similar emphasis on the ability of documentary data to provide valuable insights into past societies and their interaction with local weather and climate. This element is addressed later in the thesis in Chapters 5 and 6.

Documentary data are versatile, for example, they have been used to reconstruct pre-instrumental temperatures (Brázdil *et al.*, 2016; Camuffo *et al.*, 2010; Dobrovolný *et al.*, 2010; Fernández-Fernández *et al.*, 2017; Leijonhufvud *et al.*, 2010; Mudelsee, 2012), rainfall (Berland *et al.*, 2013; Fenby & Gergis, 2013; Gergis & Ashcroft, 2013; Rodrigo & Barriendos, 2008) and extreme weather such as droughts, floods and storms (Brázdil *et al.*, 2016; Liu *et al.*, 2001; Llasat *et al.*, 2005; Machado *et al.*, 2011; Retsö, 2015). These climate reconstructions allow modern climatic trends to be examined on longer temporal scales, providing a greater understanding of the extent of natural variability or multi-decadal mechanisms (Ge *et al.*, 2005; Nicholson *et al.*, 2012). Furthermore, they are a valuable tool for the validation of climate models and statistical reanalysis datasets (Zhou *et al.*, 2010). However, despite their value, the application of historical climate practices to terrestrial tropical and subtropical regions is a relatively new endeavour (Nash & Adamson, 2014). Previous studies within the field have concentrated upon European and North Atlantic regions (Brázdil *et al.*, 2010; de Kraker, 2006; Luterbacher *et al.*, 2002), the Americas and Canada (Druckenbrod *et al.*, 2003; Wood & Overland, 2003), and East Asia (Liu *et al.*, 2001; Mikami, 2008; Zhang & Crowley, 1989); regions with a long history of written traditions (Jones, 2008). More recently the employment of colonial documents, English language newspapers and missionary correspondence has encouraged a focus upon tropical and subtropical regions such as Africa (Grab & Nash, 2010; Hannaford *et al.*, 2015a; Nash *et al.*, 2016, 2018, 2019; Nicholson *et al.*, 2012) and India (Adamson & Nash, 2013, 2014; Allan *et al.*, 2002).

Currently only two studies have used documentary data to reconstruct Indian monsoon rainfall. The first was by Adamson and Nash (2014) who reconstructed the southwest monsoon variability as manifest over the Gulf of Khambat using British colonial records (Adamson & Nash, 2014). The reconstruction is presented on a five-point scale of monsoon magnitude. The second study, performed by Walsh *et al.* (1999), focuses on monsoon variability in Tamil Nadu. The data are presented as a chronology of prominent weather conditions and meteorological events as reported in European colonial discourse, chiefly that from a German/Danish mission located in Tranquebar (Supplementary Information, Figure S.1). In response to this dearth of information concerning historical Indian monsoon variability, this chapter aims to answer the first of the research questions by investigating the potential to extend the understanding of historical northeast monsoon variability over Tamil Nadu using British colonial documents.

3.2 Data collection

3.1.2 Indian Institute of Tropical Meteorology rainfall data

Instrumental rainfall data for this research is taken from the Indian Institute of Tropical Meteorology (IITM) http://www.tropmet.res.in/. The monthly sub-divisional series uses Tamil Nadu as a single sub-division whose rainfall figures are derived from 15 weather stations active between 1871 and 2014. The data from each station were quality controlled, initially by using a threshold exceedance of four times the normal to detect outliers, followed by a comparison with surrounding stations and an analysis of each data point's percentage departure from the sub-divisional mean (Kothawale & Rajeevan, 2017).

3.1.3 Archival exploration and documentary data

The principal archive collections consulted for relevant climate-related information are listed in Table 3.1. Both digital and physical data archives were given equal consideration; 51% of the documentary data were extracted from the former, and the remaining 49% from the latter. The principal physical archive consulted was the British Library, St. Pancras, London, which holds a substantial collection of East India Company records. These include over 3000 deposits in the private papers collection, consisting of diaries, journals and letters and over 300 collections relating to administrative matters of the India Office, including the management of military personnel, factory records, resources and trade (British Library, no date). In addition, the British Library maintains an offsite reading room at Boston Spa, Yorkshire, where the historical newspaper collection is preserved. The National Records of Scotland store personal papers of Scottish civil servants in India and Scottish/India trade records. Digital archives included the Hathi Trust, the Internet Archive and ProQuest, each of which were invaluable as they offered the ability to analyse many documents quickly.

Table 3.1 - Principal collections of English language documents and the archives in which they are held.

Collection name	Location	Catalogue prefix
India Office Private papers	British Library, London, UK	Mss.Eur and Photo.Eur
India Office Records	British Library, London, UK	IOR
British Library Newspaper Collection	British Library, Boston Spa, UK	NEWS
National Records of Scotland Archives	National Library of Scotland, Edinburgh, UK	GD
Meteorological Archives	The Royal Society, London, UK	MA
India Raj and Empire	Digital – Adam Matthew Digital	NLS MS.
East India Company	Digital – Adam Matthew Digital	N/A
The times of India	Digital – ProQuest	N/A
British periodicals	Digital – ProQuest	N/A
Various	Digital – Internet Archive	N/A
Various	Digital – Hathi Trust	N/A

Meteorological information was contained within several different historical sources. These largely fall into the following categories, from which it is possible to make some generalisations about the content of the sources and highlight issues with reliability.

i) Government records

These are the most varied of the categories. Government records include commissioned reports, such as the Reports of the Indian Famine Commission (Indian Famine Commission 1880; 1898, a series of reports by the Famine Inquiry Commission, that detail the intensity and extent of famines across British India), financial accounts or income and expenditure, and records of meetings and demands. Such documents are prominent sources of detailed information (Brázdil *et al.*, 2010; Kelso & Vogel, 2007). The records are often very well constrained, both temporally and spatially. They often take the form of reference documents that cover many decades, remaining homogenous in character due to the procedures adhered to by the government office. With the exception of newspapers, government records have some of the longest running documentary series, such as Letters to Fort St. George (1679-1765) and the Diary and Consultation Book (1672-1756). Some government documents are designed for storage or record keeping; these are comprised of copies of the original and can be altered or abbreviated forms, letters or minutes.

ii) Historical accounts

These are secondary sources, most commonly, previous studies by historians on certain aspects of history in their chosen study area. Ogilvie (2010) and Garcia-Herrera *et al.* (2008) caution against the use of this type of document for climate reconstructions. However, with care, it is possible to incorporate this type of document into an historical series if the quality of the document can be assured (Brázdil *et al.*, 2010; Nash and Adamson 2014). The books that were included in this study were written by renowned authors of their time and crucially, either accurately cite the sources of raw data used or include phrases or elements of the primary sources. Notable examples from this study include *A Calendar of Madras Despatches* by Henry H. Dowdwell (1879-1946) and *A History of Military Transactions of the British Nation in Indostan by* Robert Orme (1728-1801).

iii) Personal diaries and letters

Personal diaries and letters vary significantly according to the interests, both political and social, and writing style of the author (Adamson, 2016). For example, diarist James Walsh[4] ended almost every day's entry with a brief account of the weather that day, providing detailed meteorological information with a high temporal resolution. In contrast, Ananda Ranga Pillai mentioned the weather only in passing if it had affected the day's activities. The location at which entries were written is often well defined - with the notable exception of marching troops or travel diaries - and the dating is accurate. Furthermore, each entry represents an eyewitness account of the weather in each location. However, these sources may be prone to exaggeration, a commonly cited concern for historical climatology studies (Nash & Endfield, 2002; Norrgård, 2015). Exaggeration can be a deliberate result of an author attempting to excite a reader, or an artefact of a short residence in India and/or unfamiliarity with the severity of monsoon rains. Therefore, this study rejected documents written by authors who had resided in India for less than one year and/or had not yet experienced a monsoon season.

[4] MSS EUR D.168 – Madras Military Diary

iv) Weather diaries

Two distinct formats of weather diary were available to this study. The first was daily descriptions of weather, recorded in situ by professional and non-professional observers. The second format was early instrumental readings, which were most often recorded by professionals. The first diary format is often short in length and recorded as a matter of personal interest by an observer. In this research, no descriptive, personal weather diary exceeded two years. The second was often a product of a government-led initiative. An example of this is the data collected at the Madras Observatory from 1803 to 1890; however, during this period, the collection method varied considerably, and so cannot be directly combined with the modern instrumental series. Professional early instrumental data collection, namely the readings taken at Madras Observatory between 1803 and 1890, did invariably include a description of the collection methods, so breaks in the time series could be identified. Early instrumental weather diaries were very valuable as the temporal resolution was high, often daily.

v) Memoirs

Memoirs present a combination of the challenges expressed in ii and iii and should be treated with the same degree of caution. They were only used in this study where raw data were referenced, such as Hugh Pearson's *Memoirs of the Life and Correspondence of the Reverend Christian Frederick Schwartz,* and/or when the author had written their story immediately after the completion of an event or travel, such as Francis Buchanan's *A Journey from Madras Through Mysore, Canara and Malabar*.

vi) Early academic journal articles

Comparable to modern journal articles, these often contain reports of weather, extremes and unusual phenomena and propose a scientific explanation for each. An example of this source type is the *Madras Journal of Literature and Science,* published from 1835 to 1894.

vii) Newspaper articles

Newspaper articles are another invaluable data source (Neukom *et al.*, 2009). Often with a long publication history and a good temporal resolution, they provide a detailed account of the weather at the place of publication and often in neighbouring regions or allied cities. However, they are only present later in the time series. The earliest British-Indian serial with climatic information held at the British Library was the *Madras Courier*, published from 1795; unfortunately the holdings were intermittent. This was closely followed by the *Government Gazette* in 1802, the holdings of which were almost entirely complete. Not only do newspapers often provide excellent descriptive accounts of the weather, but they can also include early instrumental or descriptive weather tables, such as was standard procedure in the *Government Gazette* from 1827-1832.

A total of 1105 quotations were transcribed from these archival sources, each providing information about the weather and climate of Tamil Nadu. This number includes transcriptions of both direct and indirect evidence. Direct evidence refers explicitly to rainfall timing and/or quantity, including absence of rainfall. In contrast, indirect evidence refers to potential impacts or effects of rainfall variability. Indirect evidence, while valuable (Brázdil *et al.* 2010), must be assessed with more care than direct accounts of the weather (Grab & Nash, 2010). Common indirect indicators of rainfall variability include: harvest quality and/or quantity, including parched crops (Brázdil *et al.*, 2013; Nash *et al.*, 2019); grain prices (Kelso & Vogel, 2007; Luterbacher & Pfister, 2015); and floods or changes in river regime (Nash & Endfield, 2002). In Tamil Nadu, the dependence on rain and rain-fed water networks for agriculture (Bhanu Kumar *et al.*, 2004; Brugere & Lingard, 2003) meant crop production and failure were common indirect indicators used in this study, with documentary sources often describing grain price and famine relief works. Caution was needed, however, before attributing variations in food availability to rainfall surplus or deficit. The following example from Tamil Nadu illustrates the potential challenge: "*Your lordship will perceive that I allude to the present scarcity of rice, which I am sorry to say is no novelty in Madras. In 1773 when there was neither war nor unusual drought the government were so much at a loss to keep rice in the market that they erected a stockade on the esplanade where rice was served under guard of sepoys, some lives were lost daily scrambling for it*"[5]. Due to examples such as this, secondary quotations were only included in this study where they could be corroborated with explicit meteorological information.

The quotations provide information about numerous regions across the state, but are notably clustered around major administrative and trading regions (Figure 3.1a). Similarly, the number of quotations per year varies over time, with distinct peaks and troughs over the study period (Figure 3.1b). Individual or short-term peaks often coincided with multiple data sources describing a particular extreme event (e.g. the widespread flooding of 1752). In the 19th and 20th centuries, these peaks largely correspond with the availability of extant newspapers. To reiterate, due to geographical and language constraints, the data collected for this research was sourced solely from English-language or, less commonly, translated documents (e.g. the *Private diaries of Ananda Ranga Pillai*[6], translated from the original French). While this creates a bias towards colonial reporting, the wealth of colonial documents available and the numerous sources means it is often possible to crosscheck the information extracted with independent transcriptions. Furthermore, as stated above, it is possible to control for widely recognised pitfalls, such as an author's lack of familiarity with the climate and possible exaggeration by careful consideration of the source and the purpose of the document.

[5]IOR/F/4/59 – Board's collections. 1799 pp. 1349

[6] The private diaries of Ananda Ranga Pillai were written between 1736-1761. Translated by J. F. Price, and later H Dowdwell and published in 12 volumes between 1904 and 1928.

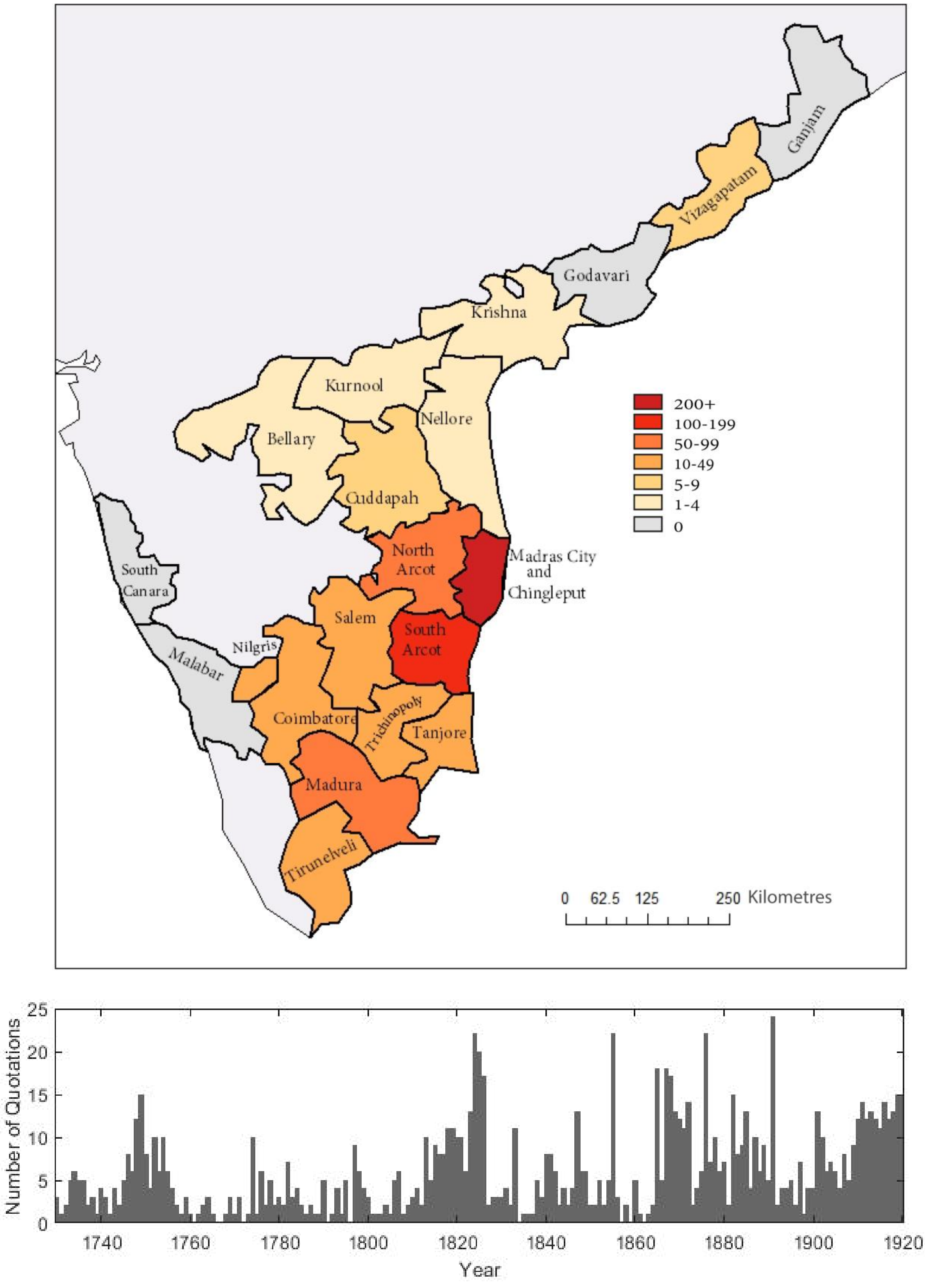

Figure 3.1 - The a) spatial and b) temporal distribution of data. Note the state borders changed throughout the study period. For early quotations, the location has been assigned to the most representative 1875 equivalent state.

3.3 Methods

3.1.4 Indices of monsoon magnitude; documentary data

In order to remain consistent, this research followed similar methods to Adamson and Nash (2014) to convert the raw data within the transcriptions into a five-point index of northeast monsoon magnitude. Firstly, keywords and phrases that occur throughout the full set of transcriptions were identified. For example, there were 43 instances where the descriptor *fair* was used to describe rainfall, the season or the condition of crops in relation to rainfall. Similarly, in 37 instances *good* was used. In 60 cases rainfall was described as *heavy*, 11 quotations included the term *flood*, and a further 11 included *failure* as a descriptor. Phrases that describe insufficient rainwater collected in storage tanks are used 17 times, similarly, those that describe damage to crops as consequence of insufficient rainfall occur 23 times. These keywords and phrases were subsequently compared against a degraded instrumental series to generate a calibration table (Table 3.4 - Summary of calibration codes used as indicators for reconstruction of monthly rainfall intensity (indicators added/modified after independent cross-checking are shown in italics). Calibration and verification were performed in the 49-year overlap period from 1871-1920 between the documentary data and modern instrumental data from the IITM. The modern instrumental rainfall data were first degraded to a five-point index series. The IMD already have in place a four-point scale of monsoon intensity, used to describe monsoon rainfall on a weekly-seasonal scale (Table 3.2). These categories represent deviations of monsoon rainfall from the long period average (LPA). The addition of a final category *extremely heavy*, as introduced by Adamson and Nash (2014), adds an equally weighted upper extreme value to act as the counterpart to the 'deficient' value (Table 3.2).

Table 3.2 - 5- point scale of monsoon magnitude.

Description	Index counterpart	Percentage deviation from the LPA
Extremely heavy	2	>160%
Above average	1	120 to 160%
Average	0	80% to 120%
Below average	-1	40% to 80%
Deficient	-2	<40%

Using each of the percentage deviations from the LPA described in

Table *3.2*, the modern instrumental rainfall data were degraded into a 5-point series with both a monthly and a seasonal resolution. The full 144 years of rainfall data were used to calculate the LPA. A Mann-Kendal test showed that trends over both the full series, and a shorter series that comprised solely of the 49-year overlap period (1871-1920), were not significant at $p<0.05$ (with p-values of 0.39 and 0.56 respectively). By using the full 144-year series, it is possible that any short-term cyclic influences will be smoothed, making the LPA more representative of overall long-term northeast monsoon rainfall.

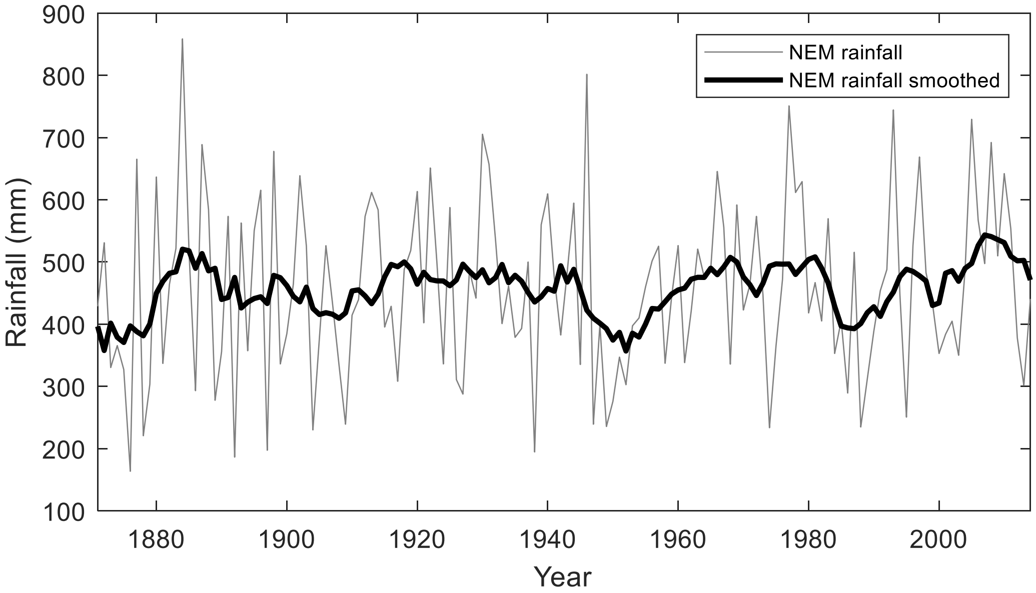

Figure 3.2-Annual total of northeast monsoon rainfall with a smoothed decadal moving average and a linear trend for the full 144-years.

The overlap period was broken down into a 35-year calibration period and a 14-year verification period. By aligning the identified indicator words and phrases with the degraded instrumental series for each year in the calibration period it was possible to infer which of the predefined index categories the authors are describing. Those indicator words that did not occur in the calibration period were cross-calibrated in years where they occur alongside a calibrated word or phrase. This process attempts to reduce the inherent subjectivity within the process of assigning index categories to the transcribed quotations. This is particularly important where the researcher is not native to the region being studied, and therefore unfamiliar with the region's cultural or colloquial terminology.

To further reduce the influence of individual researchers' interpretation of the qualitative data (Hsieh & Shannon, 2005), researcher agreement was investigated using an approach described in Kelso and Vogel (2007) and Nash *et al.* (2016; 2019). After calibration, a preliminary index value was assigned to each quotation during the full documentary period (1730-1920). From this, seventeen years were extracted using a random number generator, giving 103 individual quotations.

These were indexed independently by David Nash and George Adamson, both of whom have used similar methods to reconstruct rainfall in tropical and sub-tropical regions (Adamson & Nash, 2014; Nash *et al.*, 2016). Table 3.3 shows the similarities between author classifications.

Table 3.3 - Results of a comparison of independent indexing with the lead authors'. 'Separation' represents the percentage of cases where each index class differs by +/- one or two index levels.

Researcher	**Percentage of matches**	**Separation**	
		One class	Two classes
David Nash	72%	100%	0
George Adamson	65%	94%	6%

The largest discrepancy between each of the reconstructions was the classification of a +2 year. The lead author marked four quotations as +2, David Nash marked nine and George Adamson marked thirteen. As a result, of this exercise, two requirements for a +2 year were removed from the calibration table; a requirement for rainfall to be recorded in at least two districts, and noted as lasting for 7 days or longer, were reduced. It was deemed likely that +2 years were being, incorrectly classified due to the inability of the documentary to capture this level of detail, particularly in the earlier period when data availability was lower. A summary of the codes and the amendments made are shown in Table 3.4.

Table 3.4 - Summary of calibration codes used as indicators for reconstruction of monthly rainfall intensity (indicators added/modified after independent cross-checking are shown in italics).

Index Value	**Rainfall**	**Indicators**
2	Heavy	-Rainfall described as extraordinary or heaviest in memory. -Damage to property or infrastructure, land flooded. -Tanks burst, rivers burst, landslides. -Widespread crop damage *- Rainfall must be recorded in at least two districts* *- Rainfall must be recorded as lasting for 7 days or longer*
1	Above Average	-Rainfall described as heavy rain or unusually heavy, above average or excessive. -Some damage to property, local flooding. -Local damage to crops. -Rainfall described as general or nearly general
0	Average	-Rains described as timely and adequate, fair, good or sufficient. -Crops in fair or good condition and tanks full, or satisfactory -Rainfall described as fairly general or local.
-1	Below Average	-Local/short term absence of rain. -Partial failure of harvest. Want of timely/sufficient rains. Scanty rains.
-2	Deficient	-No rain. Failure of the monsoon. -General panic or widespread unrest. -Famine and/or public works in effect. -No drinking water, lack of fodder, resulting in starvation of people and cattle. -Little cultivation, Very high grain price. -Lack of rain must be referred to as prolonged

Following the amendments to the codes, the preliminary index values, previously assigned to each of the quotations were amended to bring them into line with the new calibration codes. These index values were then averaged for each month and for those quotations classed as seasonal descriptors, an approach adapted from the methodology used by Adamson and Nash (2014). In each case, the value was rounded to the nearest whole number. On occasions where the average value was calculated at +/- 0.5 from a boundary, quotations that provide information about the weather over a greater area, or for a greater time period, were given preference. Figure 3.3 demonstrates the process, using two quotes taken from October 1817 as an example. To create a seasonal series, the same averaging procedure was repeated, using the raw data on occasions where the average fell at the mid-point between indexes.

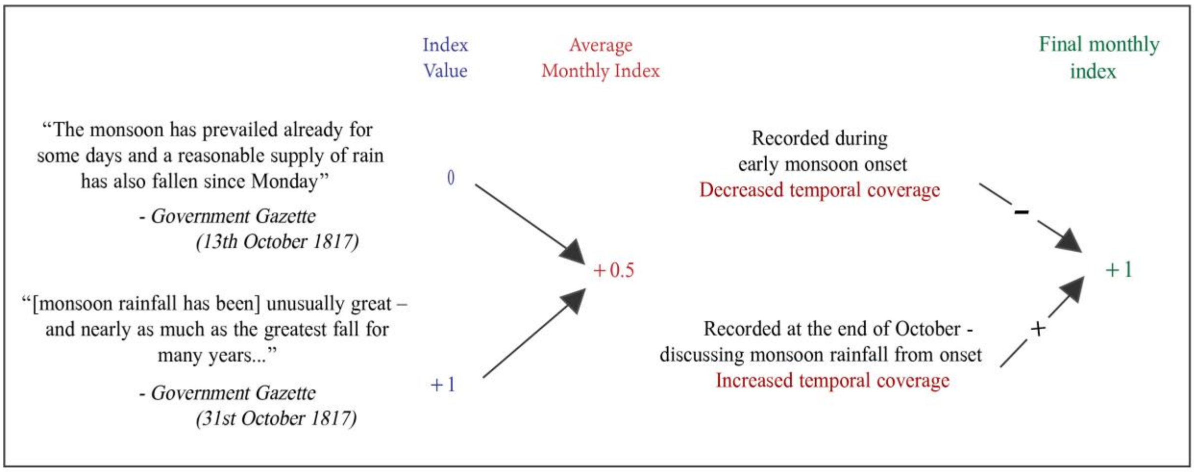

Figure 3.3 - The process for selecting index values where averages result in +/- 0.5

The final 14 years of the crossover period that were reserved previously for verification were also reconstructed using this process; reconstructions were derived without prior knowledge of the degraded modern instrumental values for the corresponding years. The correlation coefficients between the reconstructed index values and modern instrumental data for both the calibration and verification periods are shown in Table 3.5. In each case, the correlation remains high (and significant at $p<0.05$ for monthly, and $p<0.01$ for seasonal) between both the calibration and verification periods.

*Table 3.5 - The correlation between the reconstructed documentary series and the modern instrumental series. Figures in bold are statistically significant at the 0.05 level. Those marked with * are significant at the 0.01 level.*

	October	November	December	Seasonal
Calibration period (1871- 1905)	**0.67***	**0.81***	**0.78***	**0.89***
Verification period (1906-1920)	**0.73**	**0.72**	**0.61**	**0.83***

On no occasion is there complete agreement between modern instrumental series and the reconstructed monsoon magnitude. This is to be anticipated, and can be largely attributed to the following:

i) Many documentary quotations refer to short-term weather conditions. Unlike the modern instrumental series, changes in these conditions may not have been preserved in the archival data.

ii) The information within the documentary sources refers to weather conditions on a range of spatial scales, such as towns, districts, or entire states. As such, the spatial resolution of the qualitative documentary series varies considerably while the spatially averaged, degraded instrumental series remains consistently high.

iii) The weather conditions which prevail at the boundary of the index thresholds are challenging to interpret, often aligning with codes from more than one index category. These borderline conditions can be misinterpreted, particularly when compounded with *i* and *ii*.

3.1.5 Indices of monsoon magnitude; early instrumental data

Where available, this research also transcribed early instrumental data for rainfall from archival sources. This early instrumental period is defined as records of the weather created prior to 1871. These data are characterised by changes in collection methods and shorter, discontinuous series that are often spatially limited. Despite these challenges, they offer valuable information about the weather of the past, including temperature (Böhm *et al.*, 2010; Camuffo *et al.*, 2006; Camuffo & Bertolin, 2012), atmospheric pressure (Allan *et al.*, 2002; Brugnara *et al.*, 2015; Jones *et al.*, 1997) and rainfall (Fenby & Gergis, 2013; Llasat *et al.*, 2005; Nicholson *et al.*, 2012). This section will discuss the creation of an early instrumental rainfall series between 1792 and 1920. Data are transcribed for 50 years into the modern instrumental period to allow for crossover.

The transcribed early instrumental rainfall data comprise of eight shorter data sets ranging from 7-30 years in length. These short series represent changes in the source, instrumental location or collection methods. The Madras Observatory was the principal source of this early instrumental data. The observatory was located inland from Fort St. George, Madras (Supplementary Information, Figure S.1) and was constructed at the turn of the 1790s (Allan *et al.*, 2002; Kochhar, 2002). John Goldingham was the principal meteorologist from 1796 until 1825. There is a break in the series from 1808-1812 while he was on leave. Goldingham was succeeded by Thomas Glanville Taylor who continued the daily record keeping until 1843 (Allan *et al.*, 2002). From 1843-1890 contributions to the meteorological record were made by William Jacob, Norman Pogson, Charles Smith and William Worster. Records collected between 1822 and 1890 were published in four successive volumes entitled ‘Hourly Meteorological Observations made at the Madras Observatory’. A single change in the collection method occurred between 1822 and 1890:

on the 1st of October 1830, both the rainfall collection vessel and measuring methods were changed; this is described in the first of the four volumes[7].

A second series of extended length was collected by Benjamin Roebuck between 1771 and 1803. This series is a handwritten, monthly summary of daily data, preserved by the Royal Society[8]. Roebuck kept this rainfall series as a matter of personal interest, with his instruments assembled on his roof, approximately 5 km to the west of Fort St. George. Two further series were also transcribed, but not used for analysis. The first was a collection of meteorological tables from the Madras Observatory covering just two years, 1844 and 1845. The length of the dataset is restrictive and furthermore, the data are not accompanied by details of the rainfall collection and measurement methods. The second is a daily wind and rainfall series kept at Ootacamund (Supplementary information, Figure S.1) between 1847 and 1850. Ootacamund, is located in the Nilgiri Hills in northwest Tamil Nadu. However, the location and altitude of the weather station are not recorded, so the wider representativeness of the data is uncertain.

Any lack of consistency between the individual datasets can largely be attributed to:

1. Poor positioning of rainfall gauges. Details of the position of instruments are sometimes included in the record. For example, Benjamin Roebuck described the location of his instruments as *"on top of a house three miles West of Fort St. George and above trees or anything which could hinder the full quantity of rain which fell from getting into them."*[8]

2. Changes in the method for the collection and storage of daily rainfall. Different equipment was used during the early instrumental period; some were notably more effective than others. For example, between 1861 to 1890, the Madras Observatory used an automated hourly rainfall measure alongside standard rain gauges; this machine did not function well in light rainfall: *"When the receiver is filled up to a certain point it is emptied by a siphon on the principle of the Tantalus cup. This arrangement is far from satisfactory, especially in a light rain for at times the siphon does not act suddenly but the water only dribbles out at the same rate it comes in"*[9]. In this case, the failure of hourly monitoring described above was alleviated by the collection of rainfall in a second rain gauge for total rainfall monitoring, ensuring that the daily data used in this paper is of sufficient quality.

Some of these collection and measurement changes are well described, so corrections can be easily applied to the transcribed data. For example, between 1822 and 1830 records from the Madras Observatory were accompanied by the following description: *"To ascertain the quantity of rain fallen, the funnel was unshipped and a tin float with a 36 inch gauge rod graduated to inches was lowered into the cylinder, when the depth of water in the cylinder was shewn by the length of the*

[7] IOR/V/18/267 - Results of the meteorological observations made at the government observatory, Madras during the years 1822-1843

[8] MA/179 – An account of the rain which has fallen at Madras.

[9] IOR/V/18/276 – Results of the meteorological observations made at the government observatory, Madras during the years 1861-1890

rod remaining above its upper edge. This being divided by 4 gave the depth of the rain; - hence the numbers set down in the register, being the actual reading of the gauge rod, the depth of the water in the cylinder - in fact, require to be divided by 4 to give the true depth of the rain"[10].

Variations of the aperture size of the collection vessel were investigated to determine the potential effect of any changes. Table S.1 in the Supplementary Information lists each of the eight shorter early instrumental series, with their associated mean and standard deviation. Also given in this table is the funnel aperture if known. On visual inspection, the data suggest that changes in funnel aperture have a negligible effect on the rainfall statistics. To support this observation, a Levene's test and a one-way ANOVA test were both consistent with the hypothesis that the variance and means are equal across the group. A combined times series of the individual instrumental data sets from 1792-1920 is provided in Figure 3.4. Given the evidence of homogeneity, further correction of the data was considered unnecessary. To compare early instrumental data with the documentary record, the data were also degraded to a 5-point index using the same method employed for degrading modern instrumental data (i.e. using an LPA calculated from the early instrumental data for 1792-1920). A second method for degrading the early instrumental series was trialled that used the frequency distribution of the index categories in the modern reference period to generate index boundaries, see Neukom *et al.* (2014) for further details. This experiment assessed the effect of a degradation method less sensitive to changes in the collection method, however, agreement between the documentary reconstruction and the degraded early instrumental data over the study period was reduced (not shown), and therefore the former method was selected.

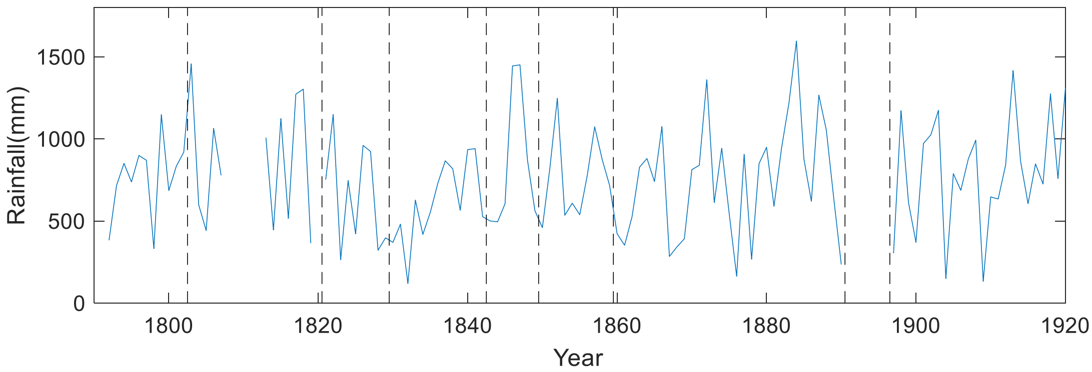

Figure 3.4 - Time series October – December rainfall from each early instrumental data set. Vertical dashed lines represent changes in the source data in the data set.

[10] IOR/V/18/267 - Results of the meteorological observations made at the government observatory, Madras during the years 1822-1843

3.3.3. Combining the early instrumental and the documentary series

Up to this point, this chapter has described the creation of two independent series of northeast monsoon magnitude, the first using documentary data and the second using early instrumental data; both are shown in Figure 3.5. This section discusses combining the two series.

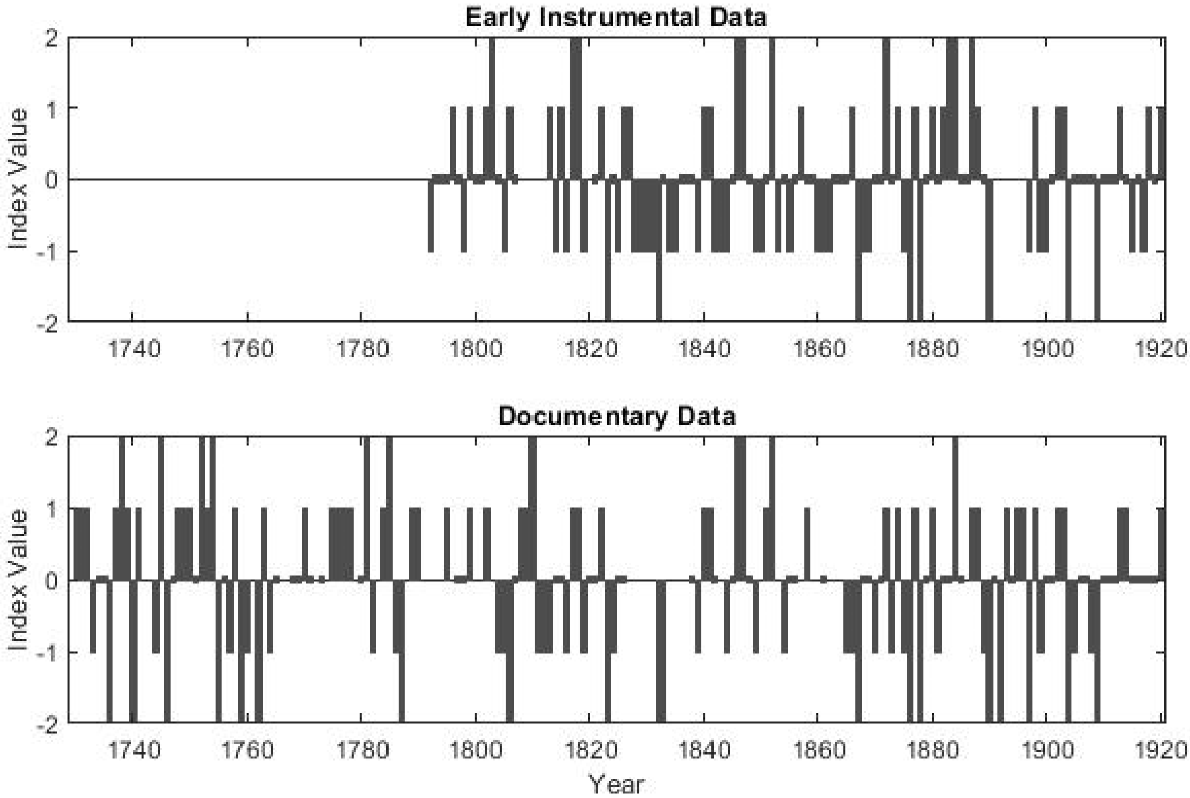

Figure 3.5 – The degraded early instrumental and documentary reconstructions of northeast monsoon magnitude over Tamil Nadu.

When combining the early instrumental and documentary series, it was important to find a balance between the superior temporal resolution of the former and the (often) superior spatial coverage of the latter. When data for a particular season or month was available from a single reconstruction only, this figure was used. When both series contained data, an average was taken from the two values and rounded to the nearest whole number. However, as discussed in Section 3.3.1 simple rounding is not applicable to those values that lay at +/-0.5 from an index threshold. In order to avoid creating a bias to the upper boundary, each case was considered individually. On occasions where both series had a reconstructed seasonal value that had been calculated with data from all three months of the northeast monsoon season, the raw data was consulted. If the documentary series demonstrated evidence of a wider spatial coverage than the instrumental series, the documentary value was favoured. If there is no evidence that the documents discuss conditions external to the town of Madras, then the higher temporal resolution of the instrumental index was favoured.

3.3.4. Confidence values

There are notable changes in the quality of the data collected over the duration of the study period. For example, a description of the northeast monsoon season of 1844 from the *Bombay Times and the Journal of Commerce* read, *"The monsoon of 1844 was almost a total failure until the middle of December, after which period it became very stormy and deluged the whole country"*[11]. In contrast, an excerpt from the diary of Edmund Lloyd in October 1855 noted, *"Caught in the rain as usual and got another ducking"*[12]. The former quote is retrospective and refers to the monsoon manifestation over a longer period across the wider Madras Presidency; the latter discusses a single incident in a single location. As a coarse generalisation, more structured quotations are found in formal sources such as government documents and newspapers; these can often address the state of the monsoon and the subsequent prospects for trade, travel and agriculture. Passing or sensationalist comments and remarks are more common within personal diaries and letters where the monsoon affects day-to-day life.

In addition to quality, the spatial resolution of the documentary and early instrumental data is also subject to change throughout the series. As noted in Figure 3.1a, sources of qualitative documentary data are clustered in major administrative districts. This is more prominent for early instrumental data, which is almost entirely sourced from the Madras Observatory at Fort St. George. Finally, there are also notable changes in the annual quantity of excerpts transcribed over the study period. Figure 3.6 shows the availability of historical data over the 191 years. Within the series, there are prominent periods of high data availability, which often coincide with the release of serial documents that regularly records the weather and its effects, for example, in newspapers such as the *Government Gazette*.

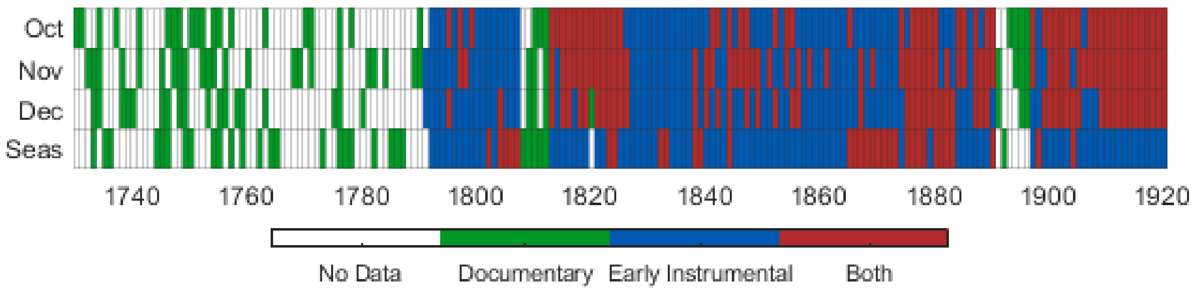

Figure 3.6 - Presence of data during the reconstruction period. Coloured bars denote at least one transcription for the corresponding month or season.

Confidence values are employed as an indicator of the quality and quantity of the information used to reconstruct the overall seasonal northeast monsoon magnitude. Since their introduction by Kelso and Vogel (2007) few subsequent studies have employed them (Nash *et al.*, 2016, 2019; Nash & Grab, 2010). All of the aforementioned studies used a three-point ranking system; here, this is increased to four by adding the category 'very low' for those years where data quality is too low

[11] Bombay Times and the Journal of Commerce – 2nd of December 1848, pp. 900.

[12] Photo.eur.240-The Lloyds of Harley Street – Entry by Edmund Lloyd, dated 18th of October 1855.

to generate a seasonal index value. This is distinct from its counterpart, ‘low’, where an index value can be generated for a season but there is potential for large error. The criteria for assigning confidence values is shown in Table 3.6. An example of confidence intervals for each rank is available in Table S.2 of the Supplementary Information.

*Table 3.6 - Summary of the criteria used to assign confidence values. *To be assigned high confidence the data must include information from regions external to Madras town.*

<table>
<tr><th>Confidence interval</th><th>Confidence</th><th>Months</th><th>Seasonal summary</th><th>Source</th></tr>
<tr><td rowspan="2">4*</td><td rowspan="2">High*</td><td>2-3</td><td>YES</td><td rowspan="5">At least one from:
- Newspapers
- Government records
- Historical accounts (including memoirs)
- Early academic journals
- Early instrumental data</td></tr>
<tr><td>3</td><td>NO</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Medium</td><td>0-1</td><td>YES</td></tr>
<tr><td>2</td><td>NO</td></tr>
<tr><td>2</td><td>Low</td><td>1</td><td>NO</td></tr>
<tr><td>1</td><td>Very Low</td><td>1</td><td>NO</td><td>Personal diaries and letters only</td></tr>
</table>

3.4. Results

The combined reconstruction of northeast monsoon magnitude between 1730 and 1920 using transcriptions from qualitative documentary records and early instrumental data is shown in Figure 3.7. Each bar is shaded to represent the confidence in the index value assigned. Confidence is lower in the early period where data availability is lower (Figure 3.6). The correlation between the combined seasonal reconstruction and the degraded modern instrumental series is 0.86, significant at the 0.05 threshold, within the range of 0.5-0.9 for equivalent reconstructions (Adamson & Nash, 2014; Neukom *et al.*, 2009; Rodrigo & Barriendos, 2008). The confidence increases after 1791 due to the introduction of early instrumental data.

The combined documentary reconstruction, and the assigned confidence values, are shown in Figure 3.7. A total of 15 (8%) seasons were classified as extremely heavy, 50 (26%) above average, 54 (28%) were average, 45 (24%) below average and 17 (9%) deficient. There was no data available for 10 (5%) years. During the 1730-1920 study period, there are two prominent wet periods, the first between 1748 and 1754 and the second between 1775 and 1781. During both, persistent normal to above average rainfall was recorded. The diary of Ananda Ranga Pillai notes that in Pondicherry on the 17th of November 1748 *“There is already five months' water in the Ugasudu tank: and should there be any rain, water will have to be let out”* (Pillai, 1918). Similarly, in 1753 what little grain had ripened in Tanjore, following warfare and political upheaval *“... was washed away by an inundation of water occasioned by excessive rains”* [13]. During the second

[13] Records of Fort St. George: Country Correspondence, Military Department, 1753. Printed in 1911 by the Superintendent Government Press (1911)

period, the monsoon is regularly described as fair or plentiful throughout the 8 years. For example, in November 1776, rainfall began on the 18th *"... and continued incessantly to the end of the month, except the 26th when it ceased for a few hours."* (Debrett *et al.* 1802: 489). Similarly, heavy rain hindered the British military efforts during a siege on the French-controlled town of Pondicherry in 1778, where *"the violent rain so swelled the water in the ditch that it ran into the gallery with such force that it seemed likely to destroy it"* (Vibart, 1881). Shorter periods of higher than average rainfall include 1807-1810 and 1837-1841.

The two driest periods occur between 1755-1765 and 1828-1834. During the first period, two episodes of drought are recorded. The first was documented by Ananda Ranga Pillai in 1759: "*There was a famine in town and no rain in the month of Karttigai"* (Pillai, 1927). Karttigai (Kārttikai) is the 8th month of the Tamil calendar, roughly coinciding with mid-November to mid-December. The long extended failure of monsoon rainfall was described by the weavers of Cuddalore in a letter to Fort St. George, "*for want of rains in due season... the famine exhausts one half of the money advanced by your petitions for cloth to [purchase] food"*[14]. The second dry period was characterised by prolonged below average rainfall where scarcity, drought and famine were all referred to frequently.

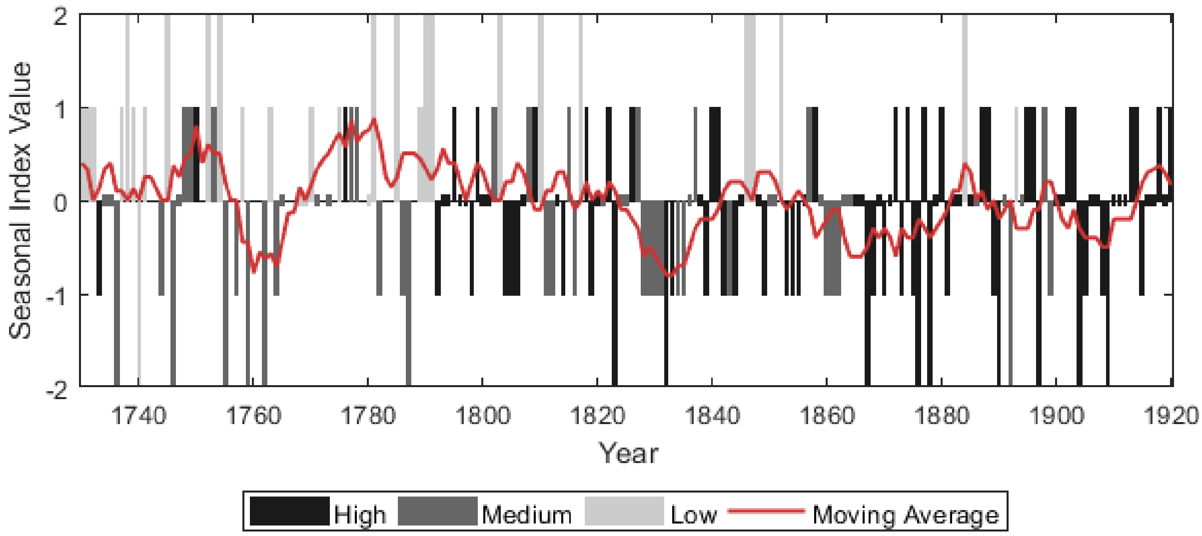

Figure 3.7 - Reconstruction of northeast monsoon magnitude over Tamil Nadu from 1730-1920, with confidence values represented by the shade of the bar, only 'high', 'medium' and 'low' confidence are included, 'very low' having been removed from analysis. Data are smoothed with a decadal moving average.

The term drought is used here and throughout this research. Drought is a complex recurring environmental disaster that varies in extent and magnitude. It is defined by the IPCC (2014: 122) as *"A period of abnormally dry weather long enough to cause a serous hydrological imbalance".* Drought events are typically classified into three main categories (Brázdil *et al.*, 2016; Dai, 2011;

[14] Records of Fort St. George: Letters to Fort St. George, Madras Office, 23rd of July 1763, pp. 86

Heim, 2002; Mishra & Singh, 2010). Firstly, *meteorological drought,* this represents periods of lower than average rainfall, typically on seasonal or annual timescales. Secondly, *hydrological drought,* which occurs as the total volume of water bodies such as lakes, rivers and reservoirs reduces below average levels; manifestation and recovery from hydrological droughts typically acts on longer timescales (Heim, 2002). Hydrological and meteorological droughts are not necessarily exclusive of one and other (Dai, 2011; Davis, 2002): poor rainfall in catchment areas will naturally influence total water availability. However, artificial influences can also have a large impact, such as prolonged over-abstraction of water or poor management of water infrastructure. Finally, there is *agricultural drought.* This category usually describes an excessive reduction in soil moisture and subsequent reduction in agricultural output (Mishra *et al.*, 2019). Agricultural droughts typically present in years with intermittent or poorly timed rainfall, coupled with a high evaporation rate (Heim, 2002). The northeast monsoon rainfall reconstruction created here is a seasonal aggregate of documentary and early instrumental data, calibrated to deviations from average rainfall as categorised by the Indian Meteorological department. Therefore, below average (-1 index category) and extremely deficient (-2 index category) monsoon seasons are predominantly representative of short-term meteorological drought conditions. The seasonal aggregation of the data obscures the distribution of the rainfall; therefore, agricultural droughts are not represented in the reconstruction. Despite this, while not explicitly considered in the reconstruction, both hydrological and agricultural drought conditions are alluded to in the qualitative data transcribed from the archives.

3.4.1. Extension of the documentary series to present

The new northeast monsoon reconstruction is extended to present using modern instrumental data from 1921-2014, shown in Figure 3.8. The instrumental data was degraded to a five-point index prior appending it to the documentary series. It was degraded using IMD thresholds, as described in Section 3.3.1. By degrading the data the change in quality between the documentary and the instrumental data is reduced (Neukom *et al.*, 2014). There is no significant monotonic upward or downward trend in northeast monsoon magnitude over 285 years (Mann-Kendall test statistic: 0.49, in excess of the 0.05 significance threshold). However, as with Kumar *et al.* (2010) there is a negative trend, significant at the 0.05 threshold until 1910 when the overall trend becomes positive, however, the trend in this second period is insignificant at the 0.05 threshold. The most substantial change over the study period is the decrease in seasonally deficient monsoon rainfall. This is most prominent during the twentieth century when only two seasons are classified as deficient (-2), compared with eight in the nineteenth century. This is somewhat supported by Das *et al.* (2016), who note a significant decrease in the magnitude of drought events in south peninsular India between 1901 and 2008. Although it should be noted that this trend is calculated using the standardised precipitation-evapotranspiration index, which incorporates both precipitation and temperature data. Despite the decrease in extremely dry northeast monsoon seasons, there are two periods of prolonged normal or below average monsoon rainfall occurring between 1947 and 1964, and 1984 to 1992. Six of these multi-year dry periods occur periodically between 1730 and 2014, approximately every 20-50 years. These epochs of above and below normal monsoon magnitude are well recognised in the literature (Kripalani & Kumar, 2004)

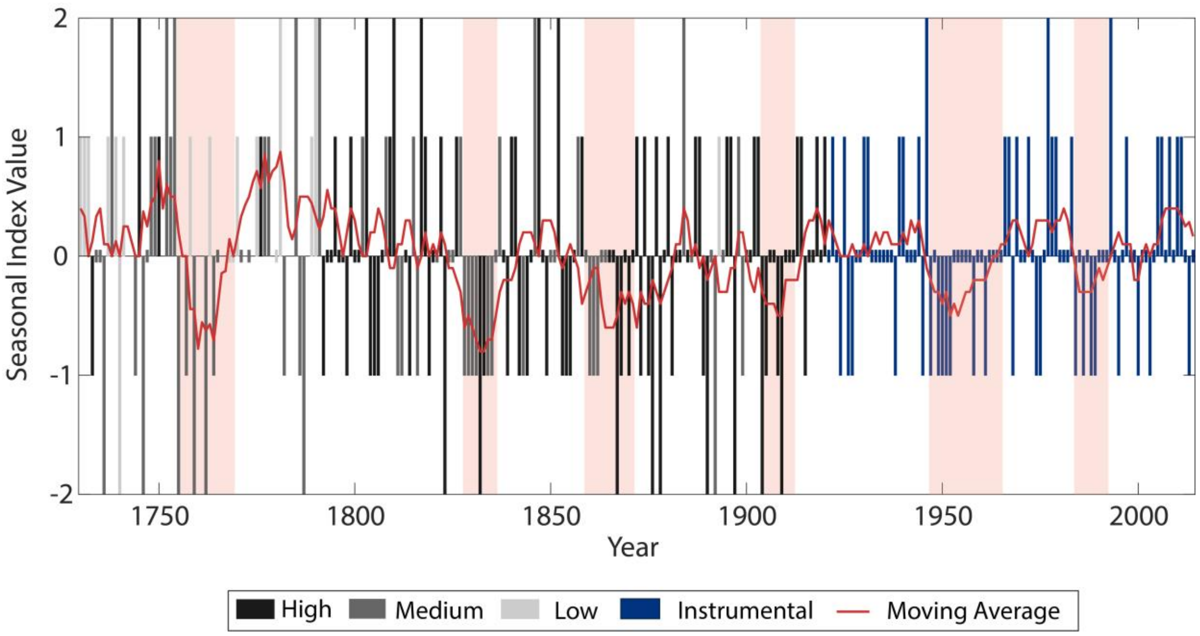

Figure 3.8 - The new northeast monsoon reconstruction extended to present using degraded modern instrumental data. Data are smoothed with a decadal moving average. Red shaded areas highlight prolonged normal to below normal northeast monsoon rainfall.

3.5. Comparison with existing rainfall reconstructions

3.5.1. Comparison with existing documentary studies

This reconstruction is one of the first examples of a documentary reconstruction of the northeast monsoon over southern India. As a result, establishing the long-term reliability of the reconstruction by comparing with similar examples is challenging. An earlier study by Walsh *et al.* (1999) used documentary records to infer the climate of Madras during the 18th century. In this study, a large proportion of the documentary data came from the German/Danish mission in Tranquebar read and translated by the authors. The data are summarised as a chronology of events from 1710 – 1799, noting months with heavy rainfall, flooding, cyclones (not used in this comparison) and drought. Twenty-nine years with rainfall information from Tamil Nadu spanning the months October-December are identified, of which 23 overlap with this study. A comparison of the two chronologies for these 23 years is shown in Figure 3.9. For this figure, the reconstruction of northeast monsoon magnitude created in this research is degraded to improve the comparison; the index categories +2 and +1 are combined as 'heavy rainfall' and -1 and -2 as 'low rainfall'.

There is good agreement between months where the rainfall is classified as heavy, but less so for those classified as dry/drought. There are two episodes where disagreement is strongest. The first is in 1768, where the new northeast monsoon reconstruction has a confidence value of 2; here, with data for the year collected from Madras, Tranquebar and Cuddalore, it is likely that Walsh *et al.* (1999) obtained information with greater spatial or temporal coverage. The second period of disagreement is in 1792. This year is marked with high confidence in the new northeast monsoon reconstruction due to the presence of daily instrumental data from Madras. Walsh *et al.* (1999)

specify that their information for 1792 was collected from Bengal as well as Tranquebar, with the majority of heavy rainfall reported during June to September and the timing of the rains in November reported as uncertain. This could therefore represent a strong southwest monsoon and deficient northeast monsoon during this year. Above all else, these differences highlight the importance of collaboration and data sharing to historical climatology. Information that is out of reach due to time, language or geographical constraints to some researchers will be available to others. Collectively this information could generate a more robust reconstruction.

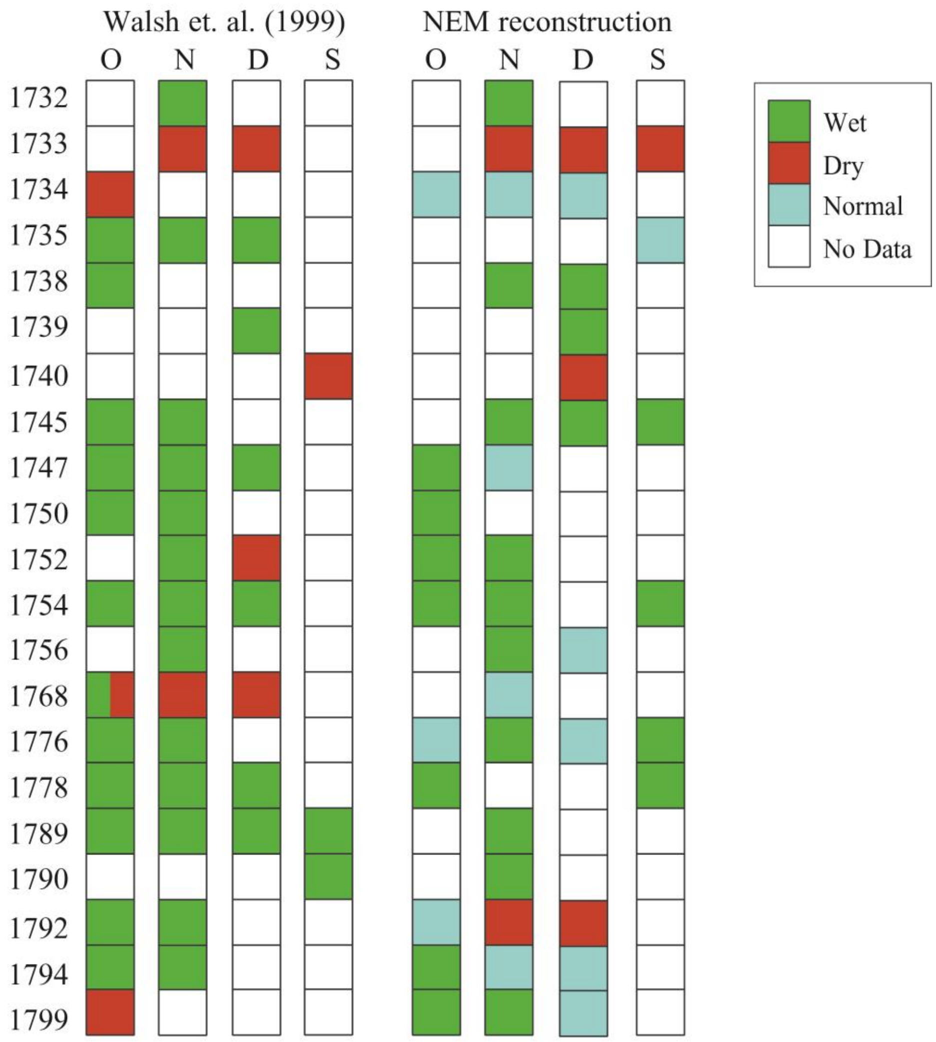

Figure 3.9 - A comparison of the rainfall chronology generated by Walsh et al. (1999) (left) with overlapping years in the NEM (northeast monsoon) reconstruction presented in this study. For O: October N: November, D: December and S: Seasonal. Note: 'Seasonal' refers only to the content of quotations which describe the season/year as opposed to specific months.

3.5.2. Comparison with dendroclimatic reconstructions

The number of dendroclimatic studies performed in tropical regions has increased in recent years (Ram *et al.*, 2011). Most studies analyse the hardwood species, Teak (*Tectona grandis)* which is widespread across Asia and is one of the few tropical trees with annual growth rings (Managave *et al.*, 2011). Teak growth is sensitive to both temperature and rainfall (Sengupta *et al.*, 2018). However, the strength of the relationship is limited by factors such as the age of the tree, local temperature and site-specific conditions such as soil moisture content (Hlaing *et al.*, 2014). Regional differences in the climate of India affect the success of dendroclimatic reconstructions. For example, the effect of rainfall on tree growth in the Himalayan region does not consistently capture monsoon rainfall at a seasonal resolution (Borgaonkar *et al.*, 2010). More success has been realised in the central region where the southwest monsoon is the dominant rain-bringing season (Shah *et al.*, 2007). Few dendroclimatic studies have attempted to reconstruct historical South Indian climate, where unclear ring boundaries and ill-defined seasonality, caused by the presence of two monsoon periods increase the difficulty of generating a precise data set (Ram *et al.*, 2011). Despite this, Sengupta *et al.* (2018) found that there is a significant relationship between teak growth and northeast monsoon rainfall for trees located in coastal regions with a higher dependence on northeast monsoon rainfall; this relationship breaks down inland.

There are currently no dendroclimatic data available for coastal Tamil Nadu. However, Borgaonkar *et al.* (2010) have extracted ring width data for Teak from Eastern Kerala, the data for which are available from the NOAA paleoclimate database (https://www.ncdc.noaa.gov/paleo-search/study/15171). They note that the data correlate most strongly with the Indian Summer Monsoon; however, there is some influence on the samples from the northeast monsoon. Boragonkar *et al.* (2010) identify 24 low growth years between 1730-1920, which they attribute to deficient rainfall. Of these 24 years half are reported as below average (-1) or deficient (-2) in the new northeast monsoon magnitude reconstruction. A further 20% were classified as average (0) and 29% were classified as above average or heavy (+1). These results suggest some agreement with the dendroclimatic reconstruction however, the significant influence of the southwest monsoon in the Western Ghats region, from which the samples were taken, prevents a detailed comparison.

3.5.3. Comparison with ENSO and IOD

Despite a recent increase in interest, there is an incomplete understanding of how large coupled mechanisms such as ENSO and the IOD are associated with northeast monsoon rainfall (Raj & Geetha, 2008; Sreekala *et al.*, 2012). As described in Chapter 2 section 2.3, there is some evidence that northeast monsoon rainfall is amplified during El Niño events (Kumar *et al.*, 2018; Nair *et al.*, 2018), potentially linked to an increase in cyclogenesis in the Bay of Bengal (Felton *et al.*, 2013). Studies with extended reference periods, c.1900–present, find that the relationship between northeast monsoon rainfall and ENSO exhibits secular variation. For example, Kumar *et al.* (2007), Yadav (2013) and Rajeevan *et al.* (2012) all find stronger positive correlations between 1930-1950 and 1980-2000, with weaker correlation coefficients outside of these periods. Nair *et al.* (2018) further find that El Niño events that originate in the Central Pacific have a notable impact on northeast monsoon rainfall, whereas those developing in the Eastern Pacific do not. Similarly, as also outlined in Section 2.3, the IOD phase has been shown to influence northeast monsoon rainfall, with the positive phase resulting in increased rainfall over southern India and vice versa (Kripalani & Kumar, 2004)

The inconsistent relationship between both ENSO and IOD with northeast monsoon rainfall makes it challenging to predict their influence on northeast monsoon rainfall. Understanding this relationship is particularly difficult when limited by short instrumental data sets and modern ENSO and IOD records. The following section compares the extended northeast monsoon magnitude reconstruction with two multi-proxy ENSO reconstructions and a single IOD reconstruction to investigate northeast monsoon and ENSO/IOD linkages on a longer time scale.

Abram *et al.* (2008) have created the longest reconstruction of the IOD with a sub-annual resolution with data available from 1846-1994 (https://www.ncdc.noaa.gov/paleo-search/study/8607). Their reconstruction is created using coral records from Mentawai, Bali and the Seychelles and is presented at a monthly resolution. For the purposes of this comparison, the period September-November is used as this represents peak IOD strength (Kripalani & Kumar, 2004) and overlaps with the active northeast monsoon season. There is a low correlation between the IOD mode and northeast monsoon rainfall over the full 149-year crossover period of 0.14; insignificant at the 0.05 threshold. It should be noted that the correlation between modern instrumental data and reconstructed IOD is also low (0.21, insignificant at the 0.05 threshold), which suggests that the resolution of the reconstruction has a negligible effect. Despite the poor long-term correlation, 95% of strongly positive IOD events (i.e. events greater than one standard deviation) correspond with a documentary index classification of normal or above. Similarly, 75% of strongly negative IOD events correspond with a documentary index classification of normal or below. In their research, Abram *et al.* (2008) found that the relationship between the IOD mode and all India monsoon rainfall underwent reversal from negative to positive during the twentieth century. They state that this reversal was likely driven by a reduction in the dominant inverse relationship between ENSO and the southwest monsoon. The long-term cyclic relationship between IOD and the northeast monsoon, independent of the southwest monsoon, shows no such reversal (Figure 3.10), supporting this hypothesis.

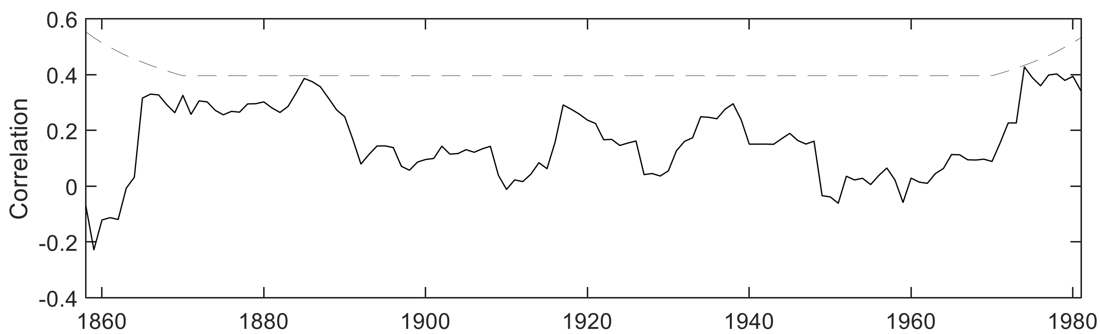

Figure 3.10 – Sliding correlation coefficient between the extended northeast monsoon reconstruction and IOD mode index (Abram et al. 2008). Window length of 25 years, significance shown as a dashed line.

Reconstructions of ENSO are more plentiful than the IOD, however, reliably reconstructing ENSO is challenging (Wilson *et al.*, 2010), due in part to the limited number of proxies available in the Tropical Pacific region (Gergis *et al.*, 2006; Mann *et al.*, 2010). Several attempts have been made to combine proxy indicators from known teleconnection regions (Emile-Geay *et al.*, 2013; Gergis *et al.*, 2006; Mann *et al.*, 2010; Mcgregor *et al.*, 2010; Wilson *et al.*, 2010), however, there is little scientific consensus as to which reconstruction best represents past ENSO activity (Barrett *et al.*, 2018b). Therefore, this chapter uses two multi-proxy reconstructions. The first reconstruction is from Wilson *et al.* (2010), whose 'centre of action' reconstruction includes inputs from coral records located in the Tropical Pacific Ocean and calibrated to SSTs from the Niño 3.4 region. This reconstruction was selected because of the exclusive focus on proxies from the Tropical Pacific and its proximity to the Indian monsoon region. The second is from Emile-Geay *et al.* (2013) who reconstruct SST (December-February) in the Niño 3.4 region. The reconstruction uses data from tree-rings, ice cores and corals from known teleconnection regions. It uses proxies from a wider region than Wilson *et al.* (2010), however, is still limited to teleconnection regions +/- 35° from the equator.

There is no significant monotonic correlation between either of the ENSO reconstructions and the new northeast monsoon magnitude reconstruction over the full 191-year series: 0.08 for Wilson *et al.* (2010) and -0.07 Emile-Geay *et al.* (2013). As with the IOD, the correlation with Emile-Geay et al.'s (2013) ENSO reconstruction does not improve when correlated with modern instrumental data: 0.09. However, the correlation with the Wilson *et al.* (2010) reconstruction increases to 0.29, significant at the 0.05 threshold. This suggests that the latter ENSO reconstruction may be more sensitive to the degradation of the northeast monsoon series. In the case of the Wilson *et al.* (2010) reconstruction, 81% of La Niña years (-1std from the mean) correspond with normal or below rainfall, and 68% El Niño (+1std from the mean) years correspond with normal or above rainfall. For the Emile-Geay *et al.* (2013) reconstruction 69% of El Niño years corresponded with normal or above northeast monsoon rainfall and 64% of La Niña years corresponded with decreased monsoon rainfall.

Given the suggestions of secular variability between the two variables, 25-year sliding Pearson's correlation coefficients were calculated between each of the ENSO reconstructions and the degraded instrumental series and documentary reconstruction; these are shown in Figure 3.11. There is evidence of persistence in the cyclic trend, particularly evident in the Emile-Geay *et al.* (2013) reconstruction, with extended positive peaks in correlation at 1767-1773, 1959-1971 and 1966-1981, correlations throughout each are significant at the 0.05 threshold. Further minor peaks occur at 1839-1844, 1909-1911, however significance is not consistent during each. The disparity between the two ENSO reconstructions and their relationship with the extended northeast monsoon highlights the difficulty in identifying the influence of tropical teleconnections on monsoon rainfall.

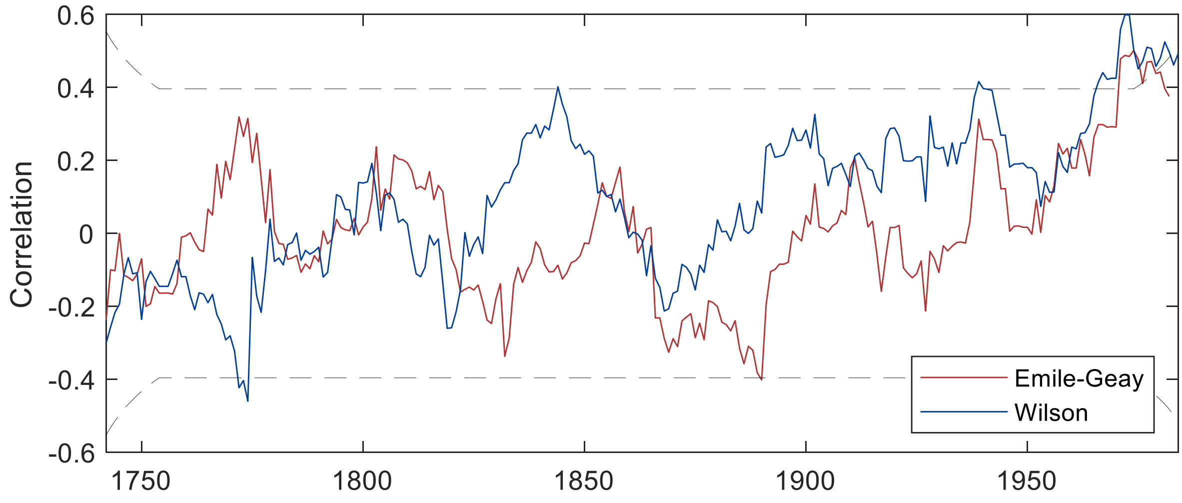

Figure 3.11 - Sliding correlation coefficients between the extended northeast monsoon reconstruction and the ENSO reconstructions of Emile-Geay et al. (2013) and Wilson et al. (2010). Window length of 25 years, significance is shown as a dotted line.

3.6. Conclusions

This chapter has presented a new 5-point documentary and early instrumental reconstruction of northeast monsoon rainfall magnitude, as manifest over modern day Tamil Nadu, from 1730 to 1920. The reconstruction has used English language documents including newspapers, government records and personal correspondence. Widespread colonial activity resulted in good spatial coverage of raw data during the study period. Nevertheless, it is the major administrative regions, such as Madras and Pondicherry that have the greatest volume of written records. Early instrumental rainfall data collected almost exclusively in Madras between 1791 and 1920 were also incorporated into the northeast monsoon rainfall chronology. Within the documentary reconstruction 10 northeast monsoon seasons are classified as deficient (-2) and 15 as heavy (+2). Prolonged dry conditions persisted between 1755 and 1765 followed by 1828 to 1834. Similarly, prolonged wet conditions were detected between 1748 and 1754, followed by 1775 to 1781.

Existing historical information for the northeast monsoon over Tamil Nadu is limited, so it is challenging to find appropriate data to compare to the new northeast monsoon reconstruction. There is good general agreement between the new reconstruction and overlapping years of the Walsh *et al.* (1999) time series for the weather and climate of Madras during the 18th century. The reconstruction also exhibits some relationship with low growth years of teak trees in Eastern Kerala as reported by Borgaonkar *et al.* (2010), although complete agreement was not expected given the geographical and climatic differences between Tamil Nadu and Kerala. There was evidence of a cyclic relationship between ENSO and northeast monsoon magnitude but this was not consistent between the two ENSO reconstructions selected for this research. In the case of ENSO and the IOD, an analysis strong El Niño/La Niña and strong positive IOD events corresponded well with normal-increased or normal-decreased northeast monsoon magnitude, as classified within the documentary reconstruction. Suggesting that extreme teleconnection events are captured in the documentary record.

Chapter 4: Reconstructing monsoon magnitude using data from ships' logbooks

4.1 Introduction

This chapter discusses attempts to use wind data contained within ships' logbooks to reconstruct seasonal rainfall over Kerala and Tamil Nadu. It will begin by discussing the origin of the data, its collection and pre-processing before producing a number of rainfall reconstructions. The target was to reconstruct the total rainfall during each of the wet and dry seasons for each state, however, data availability significantly hampered the process and thus, only winter, southwest monsoon and northeast monsoon rainfall reconstructions are created for each state. In all cases, the target length of reconstruction was 1750-1920.

This chapter is organised as follows: The remainder of Section 4.1 introduces ships' logbooks and the suitability of their content for climate reconstructions. Section 4.2 describes the pre-processing of logbook data, Section 4.3 introduces the study area to be used in the reconstruction, and establishes the relationship between wind and rainfall for each of the two states. Sections 4.4 – 4.6 describe the methods used for calibrating, verifying and reconstructing rainfall using the data within ships' logs. Section 4.7 presents the results of the reconstruction, and finally, 4.8 and 4.9 conclude the chapter with a discussion and a summary.

4.1.1 Ships' logbooks

Ships' logbooks are historic documents which contain records of systematic, daily and sub-daily oceanic and atmospheric measurements taken by officers on board ships during the pre-instrumental and early instrumental era (Brohan *et al.*, 2009; Wheeler, 2004). The act of keeping logbooks became standard practice in numerous countries worldwide, including much of Europe and the Americas, (García-Herrera *et al.*, 2005) as a result, there are copious documents covering major shipping routes and harbours around the world. These were primarily navigational documents, the accounts of experienced sailors at sea, recording the prevailing weather conditions and the route travelled. Their purpose was to ensure that the ship was on course for its destination and also, to build a collective understanding of shipping practices in order to improve the safety and efficiency of travel overseas (Wheeler, 2004). Records were made of:

i) *Latitude and longitude.*

    The latitude of the ship could be calculated by using an octant or a sextant to sight the midday sun or the pole star. The measurements were reasonably accurate, providing visibility was good (García-Herrera *et al.*, 2005). Longitude was more difficult to measure. Prior to the introduction of the chronometer in 1770 the longitude of the ship was commonly measured by dead ('deduced') reckoning, where the speed and course, along with the leeward wind, were used to calculate the progress of the ship (Wheeler, 2004). At the turn of the 19th century, longitude was calculated with lunar distances, using a reference time from standard meridian lines, and by charting the position of stars in the night sky. These could be compared to longitudes listed in a navigational almanac to acquire an accurate longitude reading (Wallbrink *et al.*, 2009).

ii) Wind direction and wind force

Wind direction was essential for calculating leeward drift; therefore, it was recorded with as much rigour as the ships' position. It was measured in accordance with modern-day observations by using a 32-point compass faced into the wind to measure the direction the wind is blowing from (Barriopedro *et al.*, 2014). Wind force, on the other hand, was recorded as a subjective measure of the wind by experienced sailors. The nomenclature was not standardised until 1838 when the Beaufort scale was formally adopted for naval ships. The Beaufort scale was the product of a long evolution in shipboard terminology as opposed to a sudden revolution, therefore classifications prior to this date can also be carefully interpreted (Prieto *et al.*, 2005; Wheeler & Wilkinson, 2004). The collection of data for wind speed and direction did not undergo any further significant changes until the widespread introduction of the anemometer on board ships. However, this change occurred later in the 20th century (García-Herrera *et al.*, 2005), outside of the study period for this research.

iii) *State of the weather.*

Space was allocated for notes on the state of the weather and sea where sailors could record details of the present weather, including thunderstorms, thick clouds, fog, etc. (García-Herrera *et al.*, 2005)

Despite their primary purpose not being meteorological data collection, the rigour with which these documents were kept, their high temporal resolution and the variables that were measured means they are exceptionally valuable to modern historical climatologists (Wheeler & García-Herrera, 2008). Logbook data can be targeted to a specific time and place, for example to provide a greater understanding of the progression and outcome of Naval battles (Degroot, 2014) or to track the occurrence or progression of historical hurricanes, endemic to particular regions (Vaquero *et al.*, 2008). The volume and distribution of records means that logbook data can also be used for a range of climatological studies; the most common logbook derived information used in these studies is wind direction and/or wind speed (García-Herrera *et al.*, 2018). This data has been used to reconstruct ENSO (Barrett *et al.*, 2018a) European and North Atlantic weather (Wheeler *et al.*, 2010), the North Atlantic Oscillation (Barriopedro *et al.*, 2014) and the Southern Oscillation Index (Jones & Salmon, 2005).

The substantial changes in wind speed and direction that characterise monsoon climates makes them excellent candidates for reconstruction using logbooks. Gallego *et al.* (2015; 2017) and Vega *et al.* (2018) have all used wind direction to create indexes for monsoon strength of the West African Monsoon, the Australian Summer Monsoon and the Western North Pacific Monsoon respectively. In each circumstance, a new directional index was calculated using only the wind direction from ships' logbooks, these indexes were all significantly correlated to their monsoon counterparts. Ordoñez *et al.* (2016) use a similar method to reconstruct monsoon onset off the west coast of Kerala by creating a westerly wind index from logbook wind direction data, employing a 21-day running mean in order to calculate a western circulation index (WCI); peak WCI was taken as onset for the year. Despite the success of the WCI for reconstructing onset of the southwest monsoon over Kerala, Indian monsoon rainfall could not be successfully reconstructed with direction alone because the prevailing winds dominated the WCI, capturing little of the intraseasonal variability (Ordoñez *et al.*, 2016; García-Herrera *et al.*, 2018). Hannaford et al. (2015) have shown that the combination of both wind speed and direction is capable of reconstructing rainfall for regions which are influenced by the global monsoon, in this case Southern Africa.

Extant logbooks, in archives across the globe, have been digitised in large international efforts to recover and preserve the information within them. One of these is the Climatological Database for the World's Oceans (CLIWOC), which digitised approximately 282,000 European records (García-Herrera *et al.*, 2005; Hannaford *et al.*, 2015a). An additional 273,000 records have been extracted from logbooks of the English East India Company (EEIC) (Barrett, 2017; Brohan *et al.*, 2012). The US Maury collection, digitised in the late 1990s, contains 1.4 million records (Wallbrink *et al.*, 2009). Atmospheric Circulation Reconstructions over the Earth (ACRE) offer further contributions. ACRE have called upon the public in a series of successful citizen science projects such as 'Old Weather', to assist with the digitisation and transcription process, reducing the time burden on scientists (Allan *et al.*, 2016). Other major contributions come from Recovery of Logbooks and International Marine data (RECLAIM) and the UK Colonial Registers and Royal Navy Logbooks (CORRAL) (Wilkinson *et al.*, 2011).

The International Comprehensive Ocean-Atmosphere Data Set (ICOADS), currently at release 3.1, is the most widely used collection of these digitised logbooks (Freeman *et al.*, 2017). ICOADS contains over 455 million records dated from 1662-present (Freeman *et al.*, 2016), of which, there are 109.6 million records from ships' logbooks that record wind direction and/or wind speed. Of these, 8.3 million were recorded prior to 1920 (Freeman *et al.*, 2016). These records are distributed along shipping routes across the globe (Figure 4.1). All observations to be included within ICOADS are processed into International Maritime Meteorological Archive (IMMA) format. This standard format allows for bulk processing of logbook records using metadata. During processing, the data also undergoes some basic correction and quality control, including standardising wind force measurements, eliminating duplicate reports, and flagging up potential errors which do not lie within a statistical climatology - including landlocked data points (Freeman *et al.*, 2017; Woodruff *et al.*, 2005).

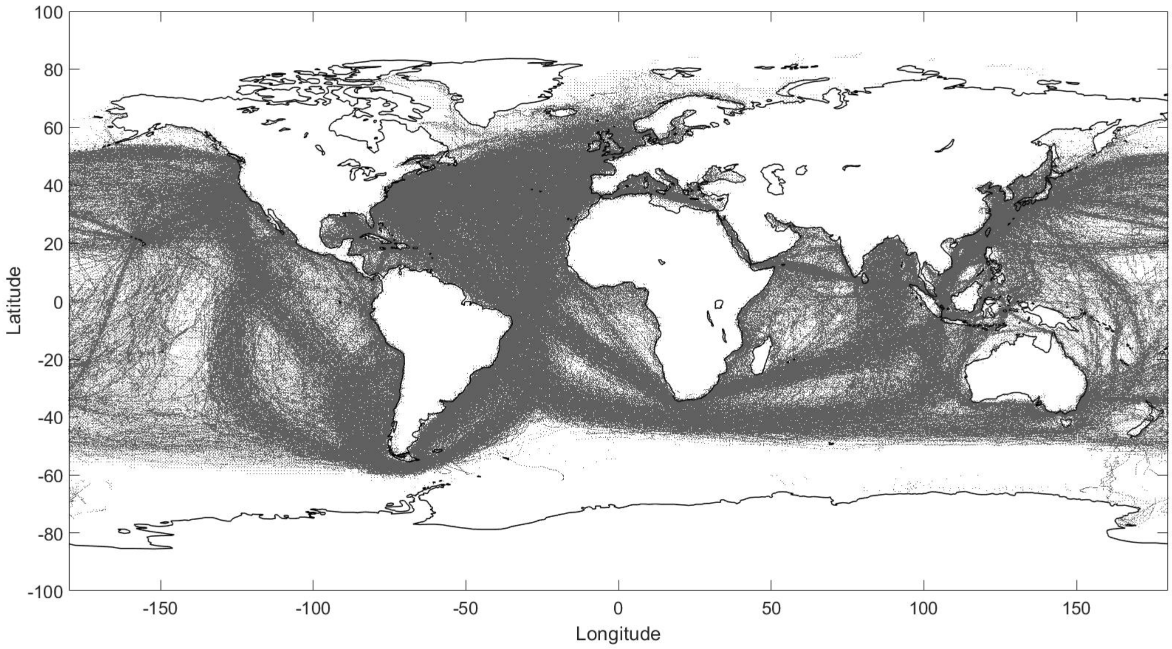

Figure 4.1 - The distribution of wind observations from ships' logbooks within the IOCADS r3.0 from 1662-1920

4.2 Pre-processing of logbook data

A geographical subsection covering 48˚E - 120 ˚E and 7.5˚S - 30˚N (Figure 4.2) was taken from the full global ICOADS release 3.0 dataset for the years 1750-1920. These data were then filtered by platform type to include only those data points originating from military, merchant or light ships. Following this, the data were reduced further to records which contained values for both wind direction and wind force. The final selection yielded 703,923 logbook records, an average of 3,705 per year over the 190-year period. Throughout the study period Tamil Nadu had several active trading ports, including those of the British trading post at Fort St. George, Madras and those associated with the French trading city Pondicherry (Supplementary information, Figure S.1). It was also a thoroughfare for trade to more northerly regions such as Calcutta (Chapter 2, Figure 2.9).

The spatial distribution of logbook-derived data changes considerably over the study period, concomitant with changes in major shipping routes. The most significant of these changes occurred during the 19th century with the development of steamboats. *The Enterprise,* a paddle steamer, was the first steam-powered vessel to journey from a European port to India, arriving in Calcutta in 1825 (Das Gupta (eds.) 2007). In 1840 the Peninsular and Oriental Steam Navigation Company (known today as P&O), heavily subsidised by the British government and the East India Company, were engaged to provide a regular mail and transport service to the East. The use of steam power meant that travel was no longer constrained by wind patterns (Stafford, 2017), significantly reducing overall travelling time and allowing year round travel to India, despite significant changes in prevailing winds during the Indian monsoon. The adoption of steam travel to India is visible in Figures 4.2c (ii) and 2d (ii) where the straighter paths contrast markedly between those shown in

Figures 4.2a (ii) and 2b (ii). A second major change in shipping routes came with the opening of the Suez Canal in 1869. Again, the change is so significant as to be visible in Figure 4.2, seen as a substantially increased data density in the Gulf of Aden in Figures 4.22c (ii) and 2d (ii) and the associated increase in logbook data traversing the Arabian Sea on a straighter path than those present in the earlier periods.

Along with these major changes in the spatial distribution of logbook-derived data, there are also notable changes in the volume of records over time, beyond the general increase over time as technology improved and maritime trade and travel become more commonplace. There are several peaks in the number of observations in the early period, specifically, during 1796-1799, 1856-1859 and 1884-1890. In each case, the peaks may simply be a result of an increased volume of extant logbooks and associated digitisation efforts. However, it should be noted that each peak does coincide with a major British war effort. The first corresponds with the fourth Anglo-Mysore war, which was fought between 1798-1799. During this time British soldiers also began occupying coastal Sri Lanka, prior to the first Kandyan war, which began in 1803 and ended in 1805. The second spike coincides with the Second Opium War, fought between the British and China and the third spike coincides with the third Anglo-Burmese War, which occurred in 1885, with rebel insurgents being defeated in 1890. While each of these instances may have increased the volume of logbook-derived information, there were many Euro-Asian wars during this study period which do not have an associated peak.

The logbook-derived wind data is stored in IMMA format as wind speed and meteorological wind direction. Prior to use, the data are converted to *u* (horizontal) and *v* (vertical) vector components (Equations 1 and 2) and then gridded into a 7.5˚ x 8˚ latitude – longitude grid. Because of the variability of the logbook data, this coarse spatial resolution is required to maximise the number of logbooks available for a reliable seasonal aggregation, without introducing too much noise and obscuring the local wind/rainfall relationships (Jones and Salmon, 2005; Kuttel et al. 2010; Neukom et al. 2014; Hannaford, 2015; Barrett, 2017).

$$u = ws * \cos(\theta)$$

$$\mathrm{v} = \mathrm{ws} * \sin(\theta)$$

Equations 1 and 2 – The calculation of 1) u wind and 2) v wind components, where ws is wind speed and θ is the mathematical wind direction.

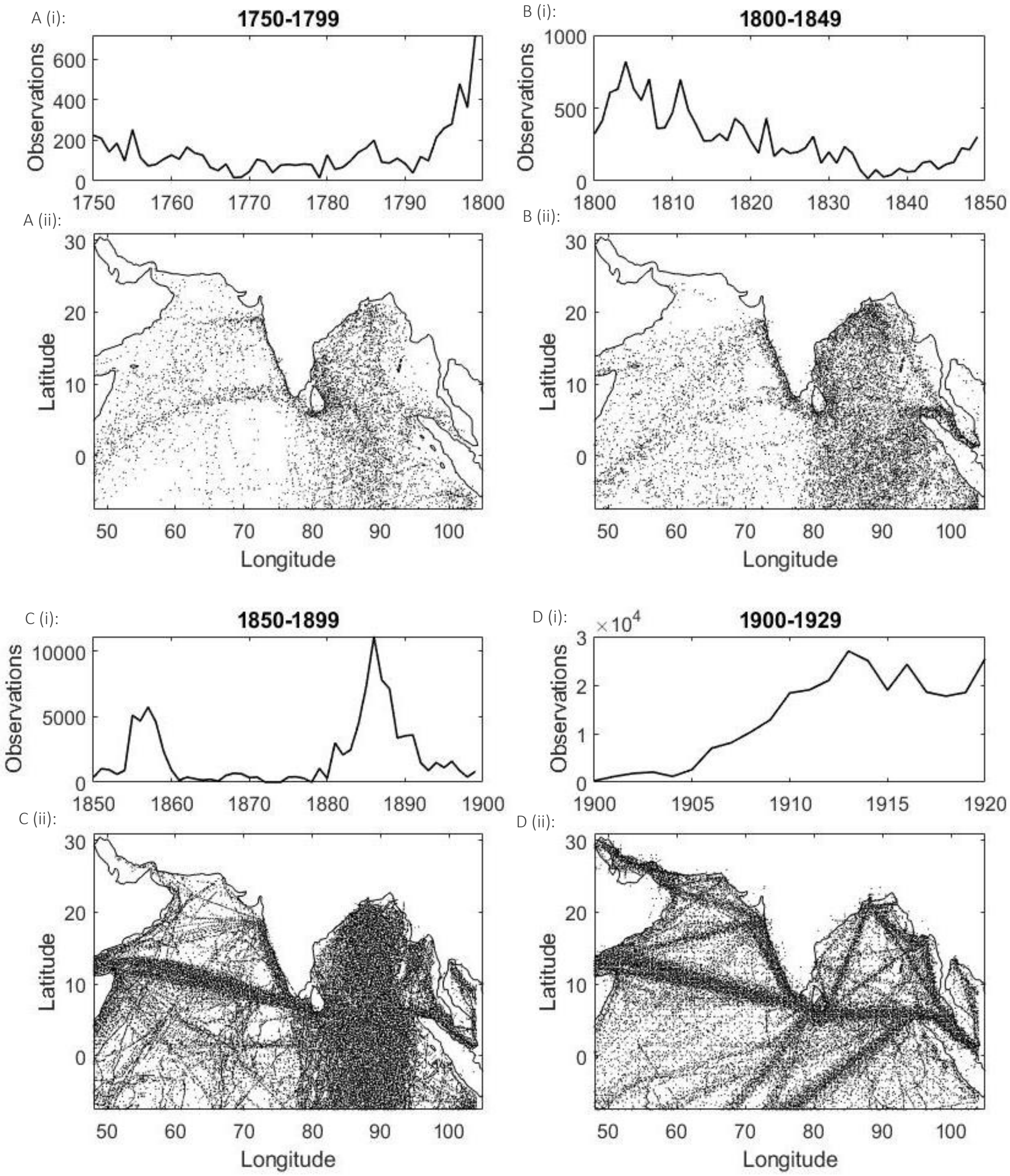

Figure 4.2 – The spatial and temporal evolution of logbook derived wind information over the study region. The graphs-A (i), B (i), C (i) and D (i), show the number of observations per year for each of the four periods. The maps- A (ii), B (ii), C (ii) and D (ii) show the spatial distribution of all logbook observations over the respective period.

4.3 Determining the spatial domain of the reconstruction

This reconstruction uses semi-instrumental wind data contained within ships' logbooks as a proxy for rainfall over Southern India. In order to determine the suitability of wind as a predictor, modern gridded reanalysis data is compared with contemporary monsoon rainfall data. ERA-Interim reanalysis data were selected for this study, see Section 4.3.1; 10m zonal and meridional wind components are correlated with IITM rainfall data for both Tamil Nadu (Section 4.3.2) and Kerala (Section 4.3.3) from 1979-2014. Both series were seasonally averaged and detrended prior to analysis to reduce the influence of modern trends. In addition, the ERA-Interim data were re-gridded prior to analysis into 7.5˚ x 8˚ latitude-longitude grids using the bilinear interpolation module from the Climate Data Operator software (Max Planck Institute for Meteorology, https://code.mpimet.mpg.de/projects/cdo), in order to reflect the spatial resolution of the logbook wind data.

The grid boxes chosen for the reconstruction are limited to those where the correlation between wind and rainfall is significant (Sections 4.3.2 and 4.3.3) and to those where there is sufficient logbook data to create a reliable seasonal average (Section 4.5).

4.3.1 *Reanalysis data*

Daily averages of 10m zonal and meridional wind values were extracted from the ERA-Interim Reanalysis dataset (hereafter ERA). The data are generated in 12-hourly cycles, in each cycle all available observational data is combined with background estimates from prior forecast cycles (for full information see Dee et al. (2011) and Balsamo et al. (2015). The data are available with a spatial resolution of 2˚x 2˚ for the years 1979-present.

Zonal and meridional wind values from the Twentieth Century Reanalysis data (20CR), Version 2c, were also trialled for use in this reconstruction. This version was the most recent version at the time of analysis. The 20CR dataset is a gridded 6-hourly reanalysis of tropospheric variability, with a spatial resolution of 2˚ x 2˚ covering a period from 1851-2014. The reanalysis is generated using an ensemble Kalman filter, which assimilates pressure records over the land and sea; see Compo et al. (2011) for full details. The wind data within this series consistently demonstrated a weaker correlation with instrumental rainfall (not shown). There is a sharp decrease in the number of sea level pressure readings available over the oceans surrounding India during World War One and an even more prominent decline during World War Two (Figure 4.3). Therefore, the relationship between rainfall and wind data from 1946-2014 was also trialled; however, this also displayed a weaker relationship than the ERA dataset.

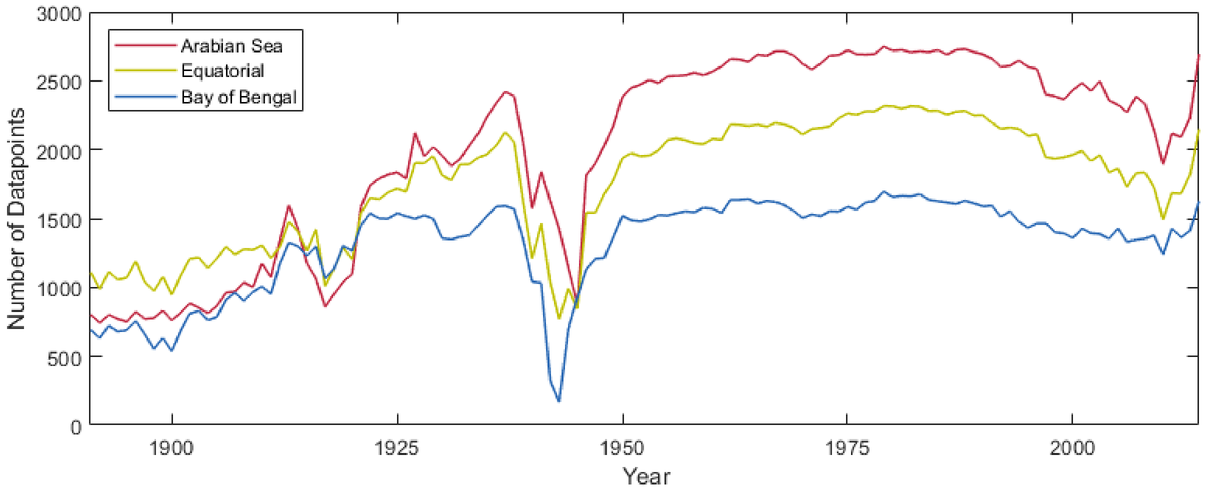

Figure 4.3 - Number of pressure records available from the ICOADS data set, available for assimilation in the 20CR data set.

4.3.2 ***The Relationship between Wind and Rainfall over Tamil Nadu***

To reiterate Chapter 2, Section 2.2, the two major rainfall seasons in Tamil Nadu are the southwest and northeast monsoons, the former of the two bringing approximately 33% (Nirmala & Sundaram, 2010) of the state's total annual rainfall and the latter delivering approximately 30-60% (Rajeevan *et al.*, 2012). The final two seasons, winter and pre-monsoon are both characterised by low rainfall. The significant changes in wind direction and strength within each season result in differences in the spatial relationship between rainfall and zonal and meridional wind, as can be seen in Figures 4.4 and 4.5 respectively (Rajeevan *et al.*, 2012). A positive zonal wind blows from the west, therefore a positive correlation will indicate higher rainfall with stronger westerly winds. A positive meridional wind blows from south, in this case a positive correlation indicates higher rainfall with stronger southerly winds. The final two seasons, winter and pre-monsoon are both characterised by low rainfall. The significant changes in wind direction and strength within each season result in differences in the spatial relationship between rainfall and zonal and meridional wind, as can be seen in Figures 4.4 and 4.5 for Tamil Nadu.

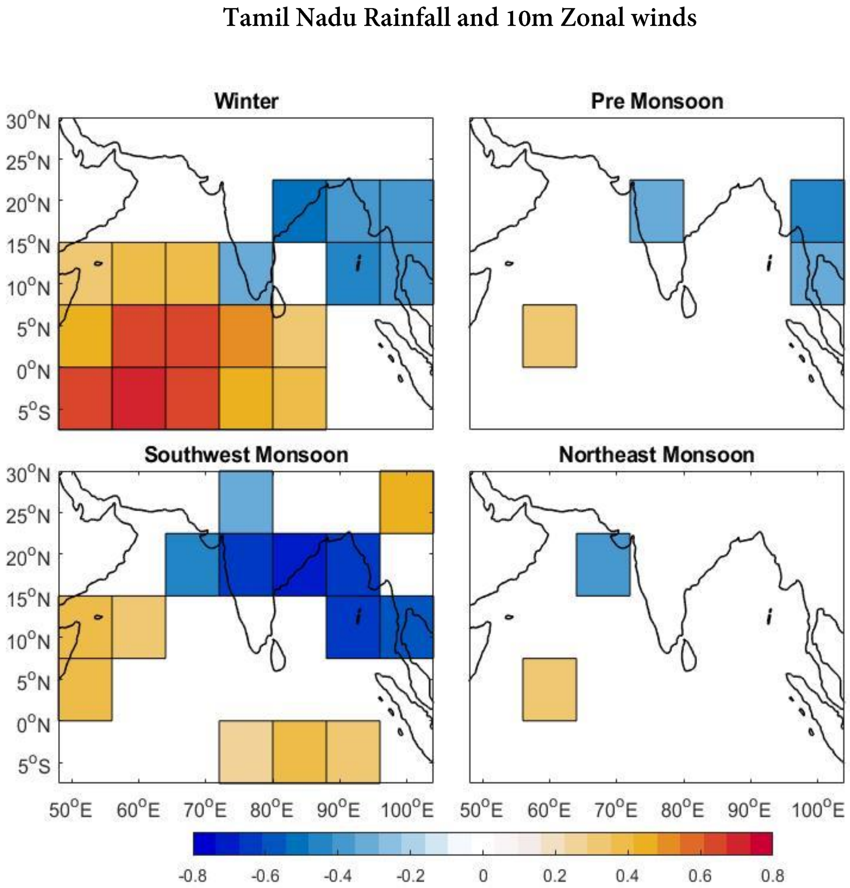

Figure 4.4 - Correlation between state-wide rainfall over Tamil Nadu and 10m zonal wind. Only those correlations that are significant at 90% are shown.

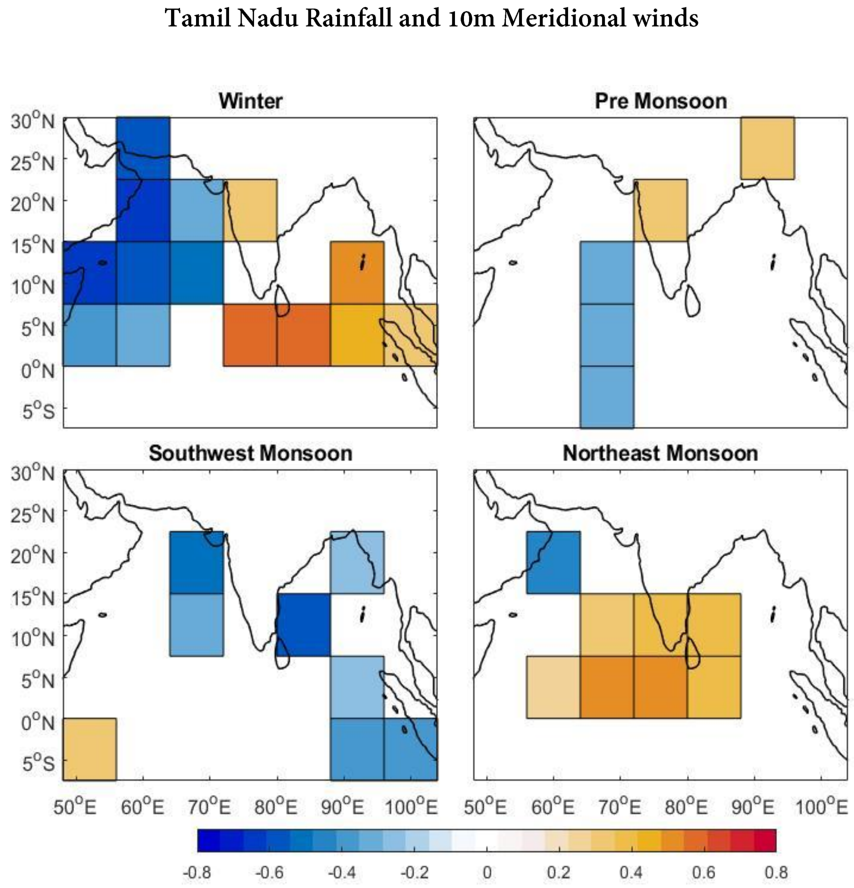

Figure 4.5 - Correlation between state-wide rainfall over Tamil Nadu and 10m meridional wind. Only those correlations that are significant at 90% are shown.

4.1.1.1 Winter and the pre-monsoon

During winter, trade winds from the northeast prevail over India (Chapter 2, Section 2.2.1). These winds are characteristically dry land winds that yield little rainfall, however, in the case of Southern India, these winds can pass over the Bay of Bengal, increasing their moisture content resulting in higher winter rainfall in Southern India. The correlations between zonal wind and winter rainfall, shown in Figure 4, are largely positive over the Arabian Sea. This indicates that rainfall is increased over Tamil Nadu when the zonal wind vector is higher, particularly, south of the Arabian Sea. Zonal winds are positive in a westerly direction. Remembering that the prevailing winds are northeasterly during winter, this positive correlation suggests that a reduced easterly wind - a westerly wind anomaly - over the Arabian Sea, is concomitant with increased rainfall over Tamil Nadu during winter. Correlations between the meridional wind component and rainfall, Figure 4.4, are negative over the Arabian Sea and positive over the Bay of Bengal, indicating that rainfall is increased when the meridional wind vector is higher over the Bay of Bengal and lower over the Arabian Sea. Meridional winds are positive from south to north; therefore, this indicates that elevated rainfall occurs with reduced northerly winds in the Bay of Bengal, and stronger northerly winds over the Arabian Sea. Figure 4.6 summarises these conditions, showing average 10m wind anomalies for the 5 years with a) the highest and b) the lowest rainfall. These conditions indicate that in years with higher (lower) rainfall, weaker (stronger) trade winds increase (decrease) the amount of moist ocean air that makes landfall over Southern India. This moist air is delivered from the south, having passed over the tropical Indian Ocean.

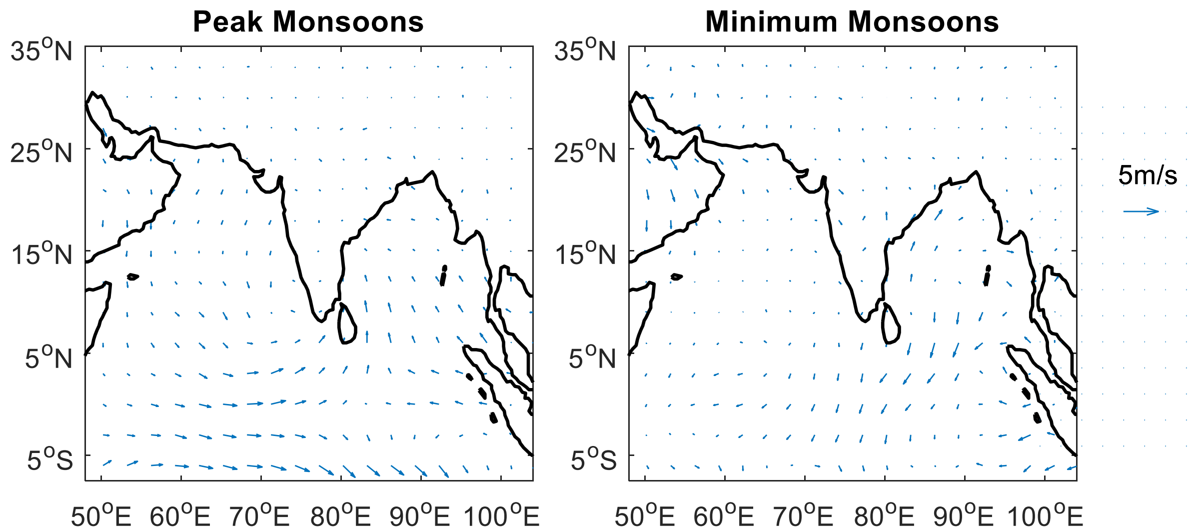

Figure 4.6 - Average 10m wind anomalies for a) the 5 wettest and b) the five driest winters over Tamil Nadu, during the years 1979-2014

During the pre-monsoon season, there is little discernible relationship between rainfall over Tamil Nadu and zonal winds (Figure 4.4). However, there is some indication from the negative correlation between meridional winds and rainfall in the narrow region between -7.5˚N to 15 ˚N and 64 ˚E to 72˚E that increased rainfall during the pre-monsoon occurs with reduced southerly flow during the northeast monsoon (Figure 4.5). As the pre-monsoon rains are delivered to Tamil Nadu primarily through cyclogenesis originating in the Bay of Bengal, this negative correlation south of the Arabian Sea is reminiscent of the winter season, where a decrease in the prevailing trade winds over the Arabian Sea was concomitant with increased ocean to land winds.

4.1.1.2 Southwest monsoon

During the first of Tamil Nadu’s two rainy seasons, the prevailing wind direction over land is southwesterly, Chapter 2, Section 2.2.3. Figures 4.4 and 4.5 show that a seasonal reduction in this prevailing wind over northern India and the north and east of the Bay of Bengal results in increased rainfall over Tamil Nadu. However, to the south of the study area and the west of the Arabian Sea, there is a positive correlation between rainfall and zonal winds, suggesting that an increased westerly component will occur with increased rainfall. This spatial change in the zonal winds indicates that throughout the southwest monsoon season, when the dominant conditions produce a well-established monsoon circulation in the northern reaches of the country, reduced rainfall in the south is experienced. Figure 4.7 demonstrates this phenomenon using 10m u winds from ERA-Interim. During the southwest monsoon, when there is a positive (negative) anomaly in the north of the Bay of Bengal, a negative (positive) anomaly is seen in the south. In cases where a positive zonal wind anomaly prevails in the north, a more widespread deficit of westerly monsoon winds over Southern India and Sri Lanka is apparent. This pattern likely represents the rate of northward migration of the ICTZ. Gadgil (2018) discuss the influence of the mean ITCZ position on interannual rainfall variability; in this case years where the propagation is rapid, the anomalous westerly winds are likely to resemble Figure 4.7a, and a slower migration is most likely to resemble the conditions in Figure 4.7b. If this is the case, a retarded northward propagation of the ITCZ is associated with greater rainfall over Tamil Nadu.

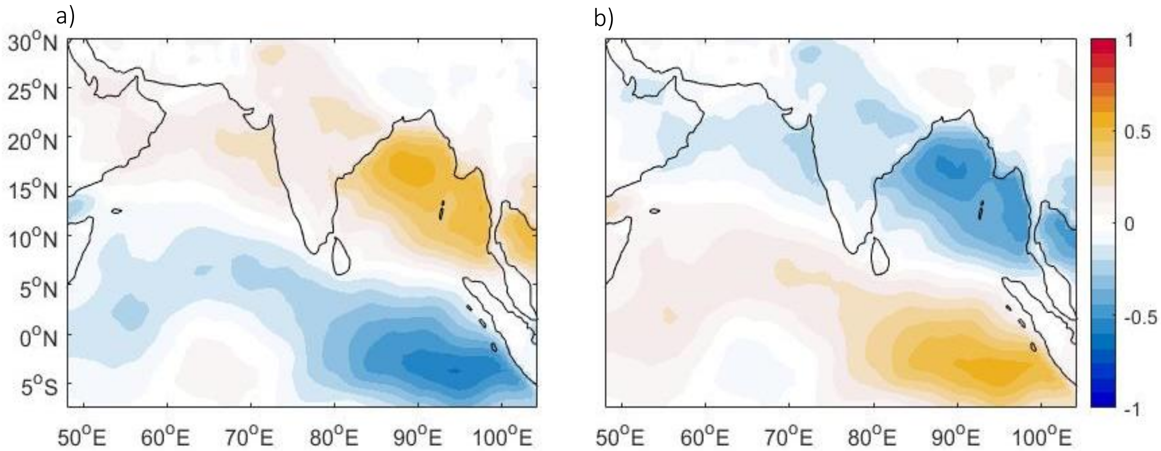

Figure 4.7 – Average June-September zonal 10m wind anomalies in m/s. The panels correspond to the years where the average anomaly in the northern Bay of Bengal (15 ˚N -22.5˚N, 80 ˚E -96 ˚E) is a) positive and b) negative, using data from the years 1979- 2017

4.1.1.3 Northeast monsoon

During the northeast monsoon, no clear relationship can be established between seasonal 10m zonal wind and rainfall over Tamil Nadu. However, Figure 4.5 indicates that stronger northerly winds over the southern reaches of India lead to reduced rainfall over Tamil Nadu. During the northeast monsoon, rainfall is typically delivered through large scale circulation and atmospheric disturbances such as tropical cyclones, and depressions (Sreekala *et al.* 2012; Sing *et al.* 2017; Kumar *et al.* 2018). The findings indicate that stronger northerly winds off the coast of Southern India are concomitant with reduced cyclone landfall and/or reduced moisture accumulation in the air mass.

The average anomalous wind patterns of the top five rain years between 1979 and 2014, shown in Figure 4.8, are reminiscent of the findings of Felton *et al.* (2013) who show increased cyclogenesis and moisture uptake in the Bay of Bengal leads to increased rainfall in Southern India. In the case of their research, these conditions were found to prevail during La Nina years. The average anomalous wind patterns for the five minimum rainfall years over the same period, show that there is significant increase in north-easterly winds beyond the south coast of India. This finding is in line with both Sreekala *et al.* (2012) and Yadav (2013) who find that in deficient years the position of the ITCZ or convergence zone is located further to the south, therefore the precipitation is reduced.

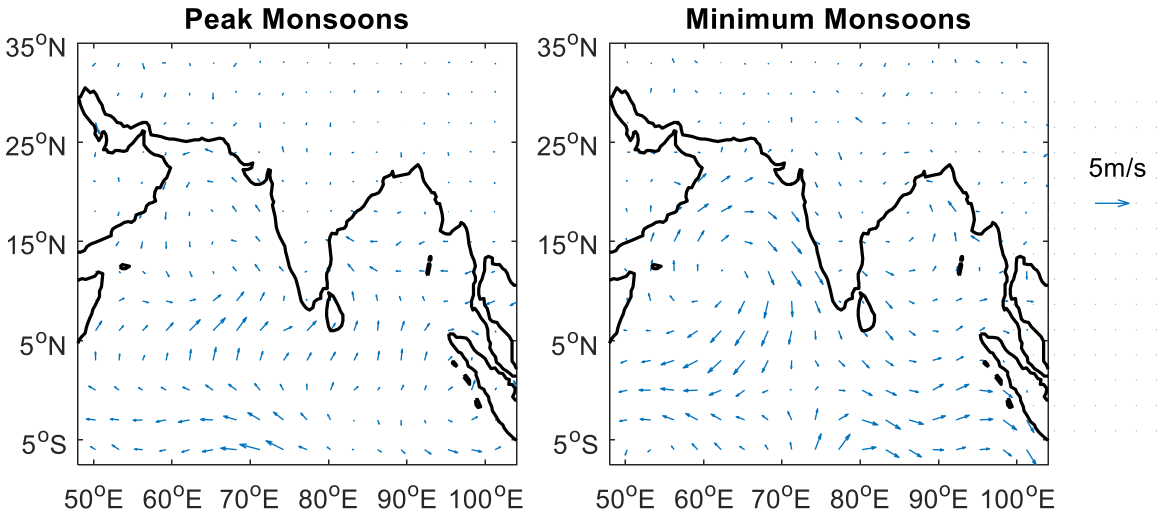

Figure 4.8 - Average ERA 10m wind anomalies for a) the 5 wettest and b) the five driest northeast monsoon seasons over Tamil Nadu, during the years 1979-2014

4.3.3 ***The Relationship between Wind and Rainfall over Kerala***

The rainfall regime of Kerala is also comprised of two wet and two dry seasons. The southwest monsoon is the primary rain-bringing season for the state (Guhathakurta *et al.*, 2015); between 1871 and 2014 it brought an average of 68% of the state's annual rainfall. During the same period, the northeast monsoon delivered 17%, with the remaining 15% falling in the dry seasons. As with Tamil Nadu, the spatial relationship between wind and state-wide rainfall is highly variable; Figures 4.9 and 4.10 show the strength of the correlation between Keralan rainfall and zonal and meridional winds respectively. Only those significant at 90% or above are shown.

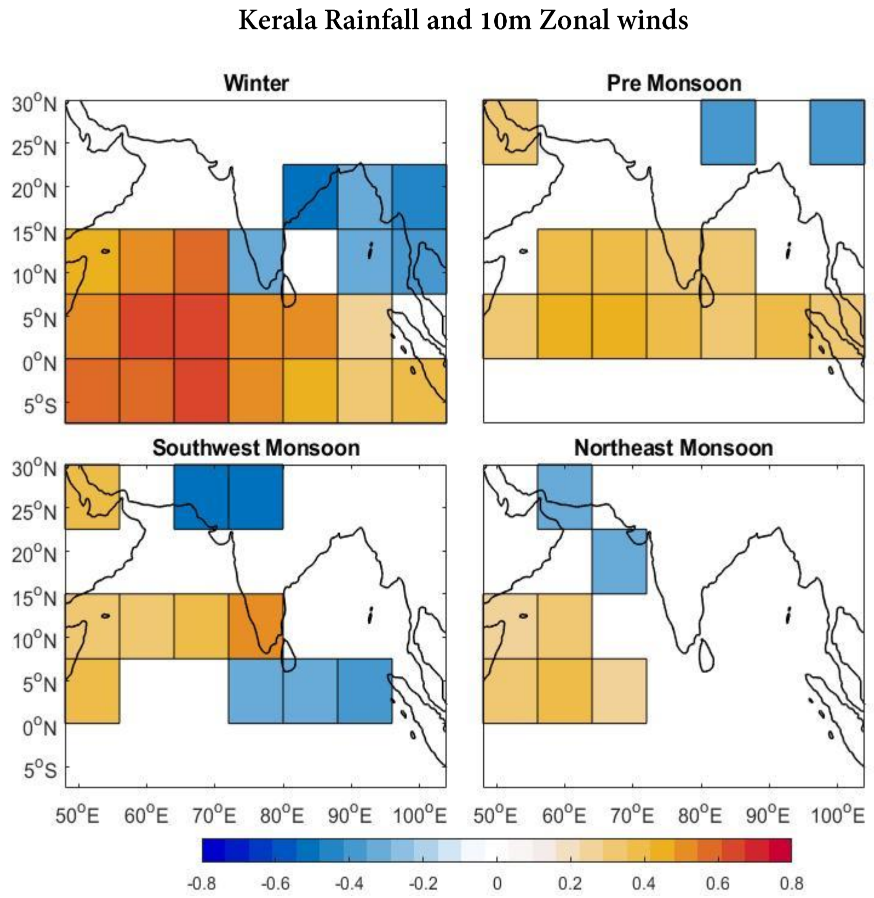

Figure 4.9 - Correlation between state-wide rainfall over Kerala and 10m zonal wind. Only those correlations that are significant at 90% are shown.

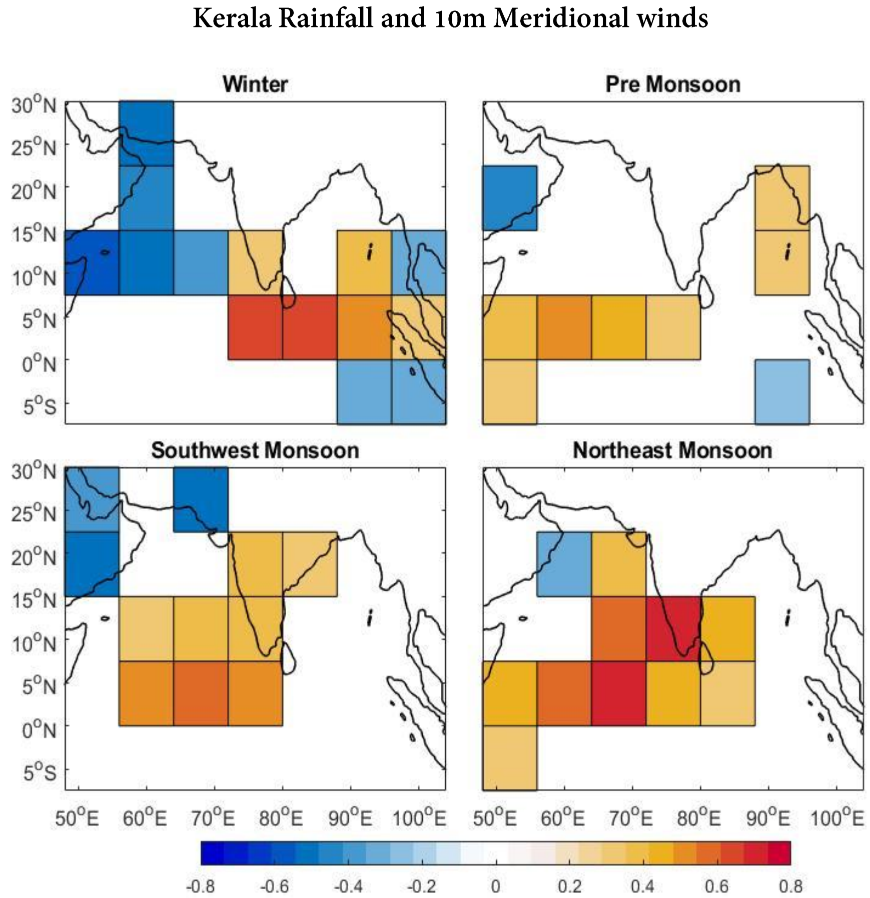

Figure 4.10 - Correlation between state-wide rainfall over Kerala and 10m meridional wind. Only those correlations that are significant at 90% are shown.

4.1.1.4 Winter and the pre monsoon

During winter, the spatial correlations between wind and Keralan rainfall (Figures 4.9 and 4.10) are similar to those for Tamil Nadu (Figures 4.4 and 4.5), where the correlation between zonal wind and rainfall is largely positive in the south and east of the study area, and negatively correlated in the northeast. Similarly, the meridional wind shows the same pattern, with negative correlations largely located in the Arabian Sea and positive correlations in the Bay of Bengal. Collectively, these conditions suggest that, on average, stronger trade winds during winter have the same effect on winter rainfall over Kerala, driving the rainfall away from the coast, reducing the amount of moist ocean air that that makes landfall on the peninsula.

During the pre-monsoon there is a band of positive correlation between zonal winds and rainfall between the equator and 15 ˚N (Figure 4.9). A less expansive area of positive correlation exists between meridional wind and rainfall to the South of the Arabian Sea (Figure 4.10). Together, these correlations suggest that when mean pre-monsoon wind is southwesterly, there is higher rainfall over Kerala. This is likely due to early monsoon onset. Monsoon onset over Kerala typically occurs on the 1^{st} of June, +/- 8 days (Pai & Rajeevan, 2009).

4.1.1.5 The southwest monsoon

During the southwest monsoon, increased southerly and westerly wind components over the Arabian Sea, are both positively correlated with rainfall over Kerala. Figure 4.9 shows the anomalous surface wind patterns present during Kerala’s five wettest and driest southwest monsoon seasons in the years between 1979 and 2014. In the former, there is a southwesterly wind anomaly over the Arabian and Laccadive Seas. This anomaly is synonymous with prolonged or vigorous active periods during the southwest monsoon season (Krishnamurthy & Shukla, 2000; Sharmila *et al.*, 2015). In contrast, during the weak monsoon seasons a northerly wind anomaly dominates the Arabian Sea extending into the equatorial Indian Ocean, conditions which are synonymous with monsoon break periods (Gadgil & Joseph, 2003). Asymmetry in the lengths of active and break periods significantly influences mean southwest monsoon rainfall (Dwivedi *et al.*, 2015), with longer active periods resulting in increased seasonal mean rainfall, and vice versa.

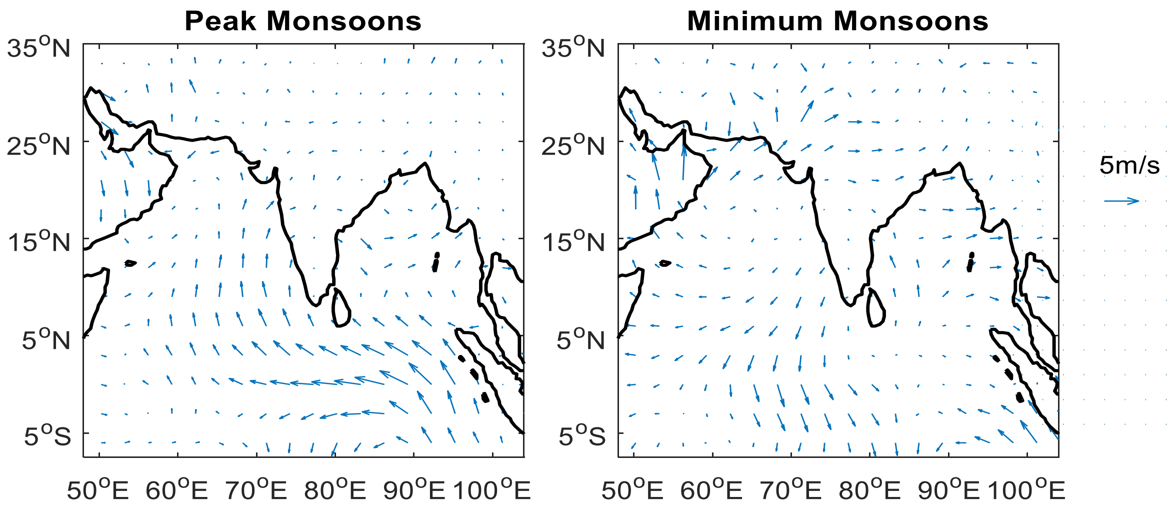

Figure 4.9- Average ERA 10m wind anomalies for a) the 5 wettest and b) the five driest SWM seasons over Kerala, during the years 1979-2014

4.1.1.6 The Northeast Monsoon

Finally, during the northeast monsoon there is a strong positive correlation between meridional winds and rainfall surrounding south peninsular India, indicating that seasonal rainfall between October and December increases with a stronger southerly wind anomaly. As with Tamil Nadu, the prevailing winds over Kerala during this season are northeasterly, and a large proportion of total seasonal rainfall is delivered to Kerala via storms and depressions (Simon & Mohankumar, 2004). Krishnakumar *et al.* (2009) find that the recent increase in cyclogenesis over Kerala during the northeast monsoon, specifically in November, caused increased rainfall over the state. Decreased northerly winds in high rainfall years, may be due to increasing landfall of tropical storms and cyclones.

4.4 Reconstructing monsoon magnitude

The significant spatial correlations between the 10m zonal and meridional components of wind over the oceans and terrestrial rainfall, discussed above, indicate that in each circumstance the relationship between the two is sufficient to attempt a reconstruction. A popular method used for climate reconstructions is Composite Plus Scale (CPS) (Abram *et al.*, 2014; Mann *et al.*, 2007; PAGES 2k, 2013). CPS is a simple reconstruction method which uses local statistical relationships to rescale a predictor - typically a composite series of proxy data, in which each series can be weighted prior to averaging - using a predictand (Mann et al. 2008), such as a modern instrumental temperature or rainfall series. CPS uses variance scaling, whereby the mean and variance of the target climate indicator are applied to a suitable proxy series that has been reduced to mean 0 and variance of 1. In this case, the zonal and meridional components of wind will act as the predictor and the modern instrumental rainfall data will act as the predictand. The strength of the CPS reconstruction method is its superior ability to capture variance, when compared to regression-based reconstructions (Christiansen *et al.*, 2009; McCarroll *et al.*, 2015; Neukom *et al.*, 2011; PAGES 2k, 2013). A recent publication by

(Barrett *et al.*, 2018a), who used wind from ships' logbooks to reconstruct ENSO, found that CPS performed well throughout the reconstruction period, particularly when data availability was low.

The reconstruction is repeated using a second method, Principal Component Regression (PCR). PCR is a popular method for implementing Climate Field Reconstructions (CFR) (Barrett *et al.*, 2018a; Hannaford *et al.*, 2015b; Jones & Salmon, 2005; Küttel *et al.*, 2010; Mann *et al.*, 2008b) and is largely found to complement CPS. In CFR, unlike in CPS, more of the spatial information within the predictor is preserved in the final reconstruction (Rutherford *et al.*, 2003). In this method, Principal Component Analysis (PCA) reduces the predictor series to its dominant modes of temporal and spatial variability, removing a proportion of the noise present within the data. By reducing the predictor series to its principal components, the problem of multicolinearity between each of the predictors, in this case each grid box, is removed. Simple linear regression can then be performed between those principal components of wind that explain the most variance in rainfall. Both methods assume stationarity in the relationship between wind and rainfall over the calibration and reconstruction period. A recognised challenge for historical climate reconstructions (Rutherford *et al.*, 2003).

For each method fitting and validation would ideally be performed directly between the predictor and the predictand during an overlap period between the two series. In this case, there was insufficient logbook data in the 1871-1920 overlap period between logbook derived wind data and modern instrumental rainfall data to create a continuous series in each of the predictor grid boxes. Therefore, as in Barrett et al.'s (2018) and Hannaford et al.'s (2015) reconstruction, modern reanalysis data acts as a substitute for logbook wind data for the purpose of model fitting and validation. Due to the substantial differences in the wind-rainfall relationship for each season/wind component, a model is fitted to each combination.

4.1.2 Model fitting and validation using CPS

Model fitting is carried out using detrended 10m zonal and meridional winds from ERA-interim between 1979 and 2014, and detrended rainfall data from the Indian Institute of Tropical Meteorology (IITM). Detrending the data prior to model fitting minimises the possibility that unrelated trends in both the predictor and the predictand influence the reconstruction. To create the predictor wind series, each of the 7.5˚ x 8˚ grid boxes where wind correlated significantly with rainfall during the grid box selection process were weighted based on the corresponding correlation between rainfall and wind, before being averaged to form a composite series, equation 3. This series is then converted to z-scores, before being rescaled to the mean and variance of the rainfall series over the corresponding period (Mann *et al.*, 2007; PAGES 2k, 2013).

$$Composite = \frac{\sum_{i=1}^{n} x_i * c_i}{n}$$

Equation 3 - The creation of a composite value. Where x *is the average wind value in the grid box.* c *is the corresponding correlation between wind and rainfall. Finally,* n *is the total number of viable grid boxes with data available over the study period.*

The short, 36-year crossover period limits the ability to reduce the series into representative calibration and verification periods; the success of the calibration would suffer if a large proportion of the available years were removed for verification. Therefore, to achieve an independent verification series we use a leave-one-out cross validation approach (Wilks 2005), performing the calibration procedure using 35 years of the crossover and saving 1 year for verification. This procedure is repeated 36 times, with the verification year migrating +1 year throughout the series. Each of the independently reconstructed values are concatenated to form a 36-year verification series (Hannaford et. al. 2015). Figure 4.10 demonstrates the observed and reconstructed time series for each rainfall seasons for both states.

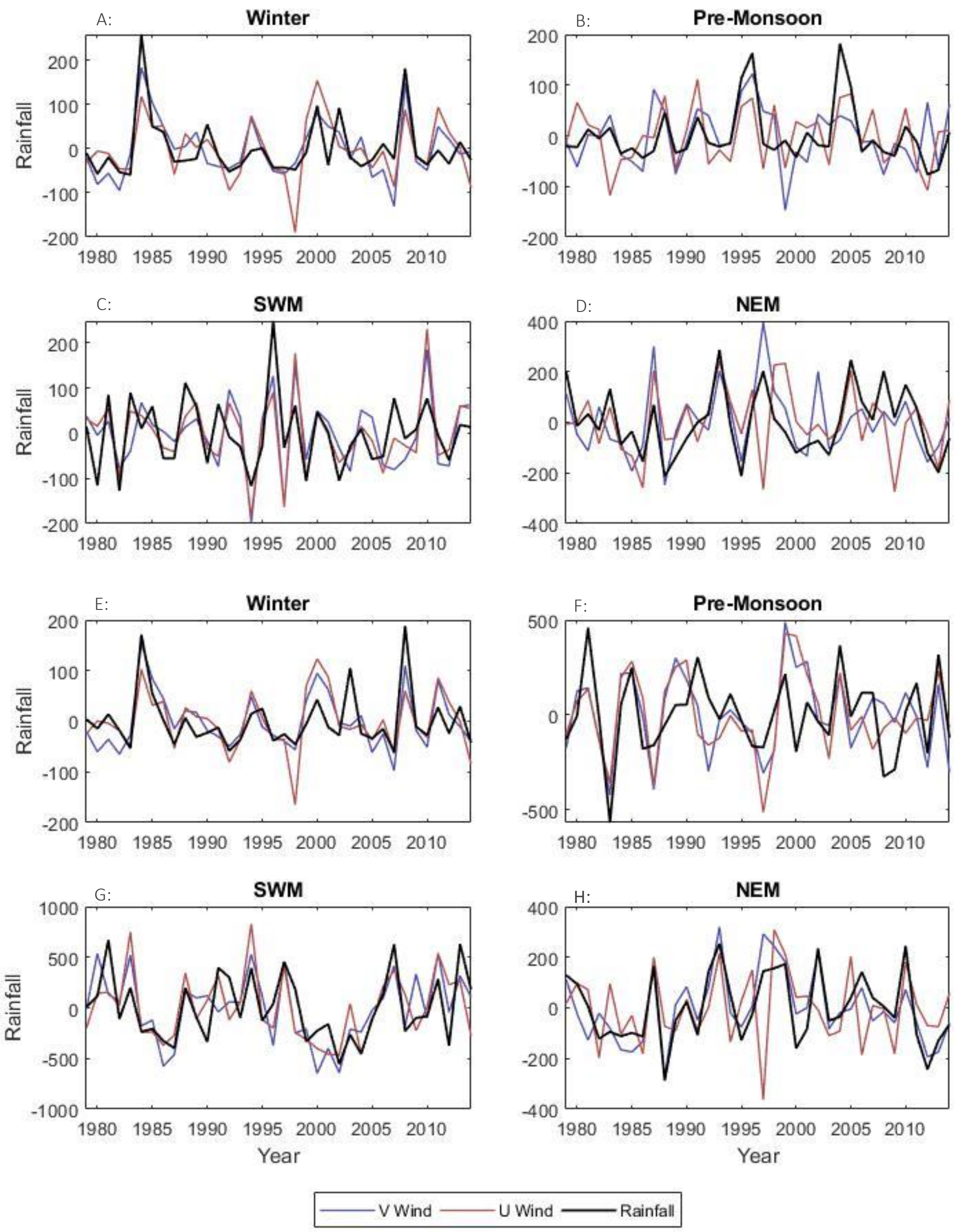

Figure 4.10 - Graphs demonstrating the agreement between rainfall and verification series, constructed using the leave one out method for both U and V wind. The corresponding r- squared values are listed in Table 1. A-D display the results for Tamil Nadu and E-H display the results for Kerala

Table 4.1 – The unadjusted R^2 values between each reconstructed series and rainfall data.

	Tamil Nadu		Kerala	
	U wind	*V Wind*	*U Wind*	*V Wind*
Winter	0.37	0.57	0.35	0.54
Pre-monsoon	0.32	0.23	0.21	0.31
Southwest monsoon	0.40	0.26	0.41	0.45
Northeast monsoon	0.14	0.38	0.14	0.74

The r^2 statistic for each of the models created during the fitting period varies considerably, for example, in Tamil Nadu and Kerala, the U wind model fit is poor, however, this is to be anticipated given the reduced spatial coverage of significant correlations between U wind over the oceans and terrestrial rainfall, shown in Figures 4.5d and 4.9d. In comparison, the northeast monsoon model improves substantially when fitted between rainfall and the stronger and more widely correlated V wind. Reduction of Error (RE) scores (see Equation 4 below), and Pearson's correlation coefficients are two further tests of the skill of the reconstruction. RE scores are a robust, standardised measure of skill, whose scores range from -∞ to +1, the test indicates how well the reconstruction performed compared with using the mean for the calibration period. A score of less than 0 indicates that the reconstruction performs worse than the climatology, 0 is equal to the climatology and 1 represents complete agreement with the predictand (Cook *et. al.* 1994; Gomez-Navarro *et. al*. 2014; Hannaford *et. al.* 2015).

$$RE = 1 - \left(\frac{\sum_{i=1}^{n}(x_i - \hat{x}_i)^2}{\sum_{i=1}^{n}(x_i - \bar{x}_c)^2}\right)$$

Equation 4 – Calculation of the Reduction of Error, from Cook et al. (1994). Where x is instrumental rainfall, $\hat{x}_i$ is reconstructed rainfall, $\bar{x}_c$ is the mean of instrumental rainfall data during the calibration period.

Figure 4.13 shows the skill of each of the fitted models; those with a positive RE score and a significant correlation coefficient are carried forward to the logbook reconstruction. For Kerala, this is all except the pre-monsoon and northeast monsoon, reconstructed using U Wind. For Tamil Nadu no reconstruction will be attempted for the pre monsoon and the southwest monsoon using V wind, nor the northeast monsoon using U wind. The final models for the skilful reconstructions are built using non-detrended data from all 36 years in the crossover period.

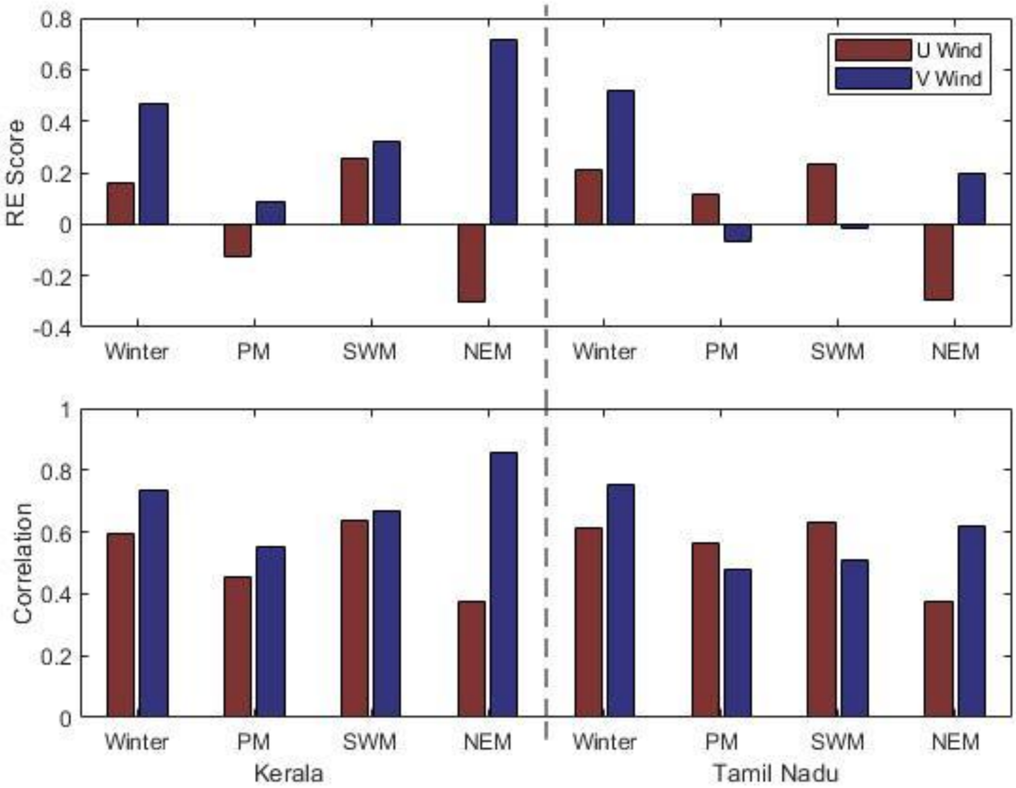

Figure 4.11 - RE scores (upper) and Pearson's correlation coefficients (lower) for each season, state and wind component. All correlations significant at the 0.05 threshold.

4.1.3 Model fitting and validation using PCR

As with CPS, model fitting is carried out using 10m zonal and meridional winds from ERA-interim between 1979 and 2014 and rainfall data from IITM. The predictor series is comprised of those grid boxes, identified in Sections 4.3.2 and 4.3.3, which correlate significantly with rainfall at 0.1 or greater and the data within them are seasonally averaged before PCA is used to extract the dominant modes of variability. The amount of variance explained by each of the principal components is different for each of the eight models – those generated for each season and from each wind vector. Therefore, experiments were performed to assess the ideal amount of variance to be explained by the principal components. To achieve this fitting regression was carried out with the number of principal components accounting for an explained variance at thresholds of 75%, 80%, 85% and 90%. The resulting skill scores from the model fitting were analysed and the 75% threshold was chosen as the most appropriate because, with minor exceptions, the skill scores show no substantial increase at higher thresholds and the number of principal components remains low enough that the likelihood of overfitting is reduced. The amount of variance explained by each of the principal components is different for each of the eight models (those generated for each season and from each wind vector) and the number principal components to be included in the final models ranges from one to four.

As with CPS, cross validation is used to generate an independent verification series within the overlap period, in each instance, one year is extracted from each of the wind and rainfall series, before PCA and fitting regression are performed. The resulting model is then applied to the extracted year. Again, as with CPS, the final independently reconstructed years are concatenated, creating a verification series. Figure 4.12 shows the observed and reconstructed rainfall for both states, the corresponding skill scores are shown in Table 4.2.

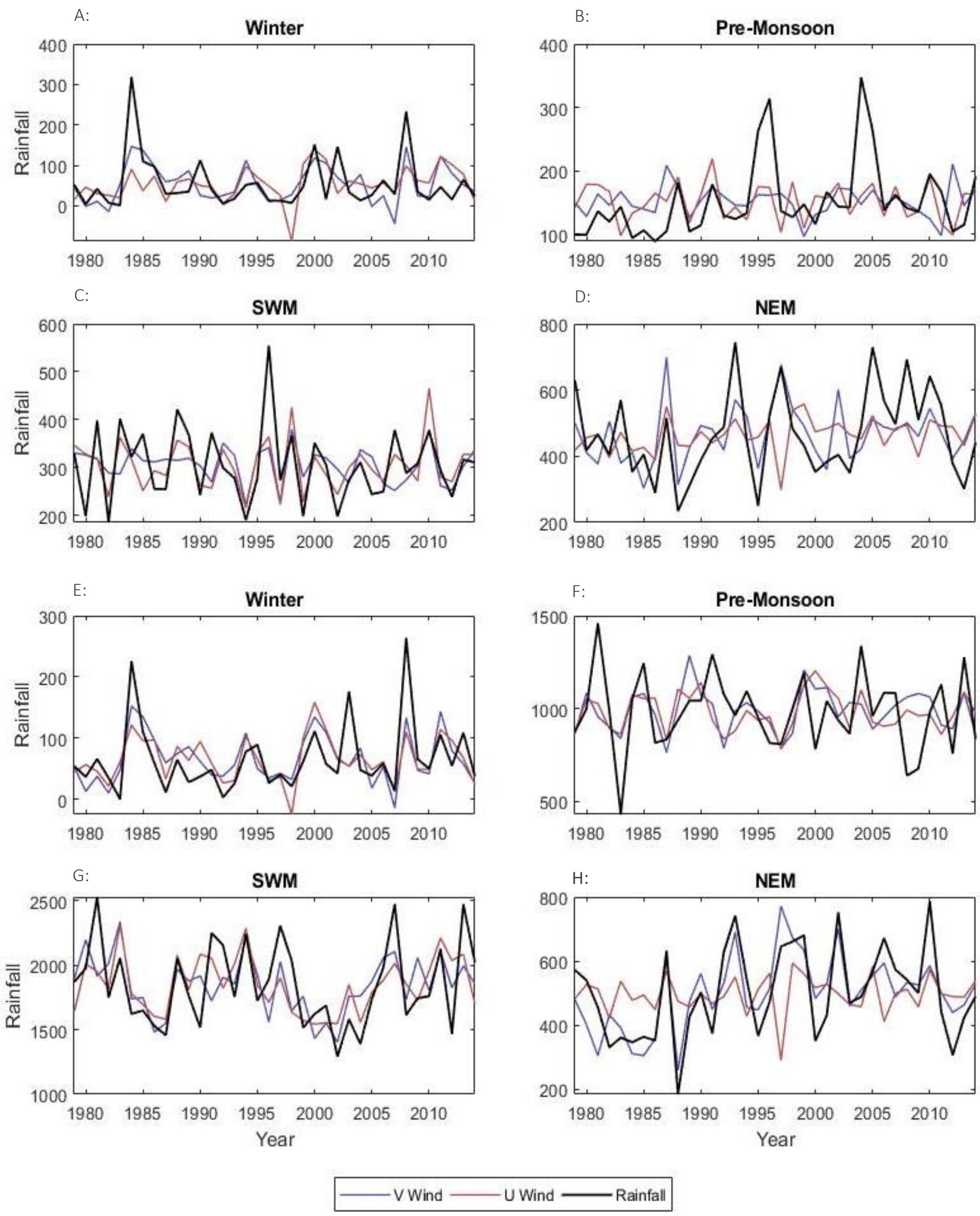

Figure 4.12 - Graphs demonstrating the agreement between rainfall and the verification series, constructed using the leave one out method for both U and V wind. The corresponding r-squared values are listed in Table 2. A-D display the results for Tamil Nadu and E-H display the results for Kerala.

Table 4.2 - The unadjusted R^2 values between each reconstructed series and rainfall data. All values are significant at $p<0.01$.

	Tamil Nadu		Kerala	
	U wind	*V Wind*	*U Wind*	*V Wind*
Winter	0.14	0.38	0.32	0.41
Pre-monsoon	0.11	0.07	0.08	0.09
Southwest monsoon	0.38	0.13	0.32	0.33
Northeast monsoon	0.03	0.32	0.04	0.66

Following Section 4.4.1, Table 4.2 shows the RE scores and the correlation coefficients calculated between each of the verification series and the corresponding instrumental rainfall. There are occasions, for example, the southwest monsoon, where the r^2 value and the correlation decrease, yet the RE score increases. The RE score compares reconstructed rainfall with climatology, whereas both the goodness of fit and the correlation compare the relationship between the variables. This demonstrates the value of using multiple approaches to measure the skill of the reconstruction. Therefore, only those with both a positive RE score and a significant correlation are carried forward to the logbook reconstruction. The models show a similar level of agreement to those created using the simpler CPS reconstruction method. From Figures 4.12 and 4.14, the most prominent difference between the two reconstruction methods is their ability to capture extreme values, this difference is most apparent in the pre monsoon (4.12b and 4.14b) and northeast monsoon (4.12d and 4.14d), where the PCR method fails to capture a number of substantial peaks.

Again, only those models with a positive RE score and a significant correlation are carried forward to the final logbook reconstruction. For Kerala this is winter and the southwest monsoon for both U and V wind, and the northeast monsoon using only V wind. For Tamil Nadu, this is the same as Kerala, with the addition of the pre monsoon, reconstructed using U wind.

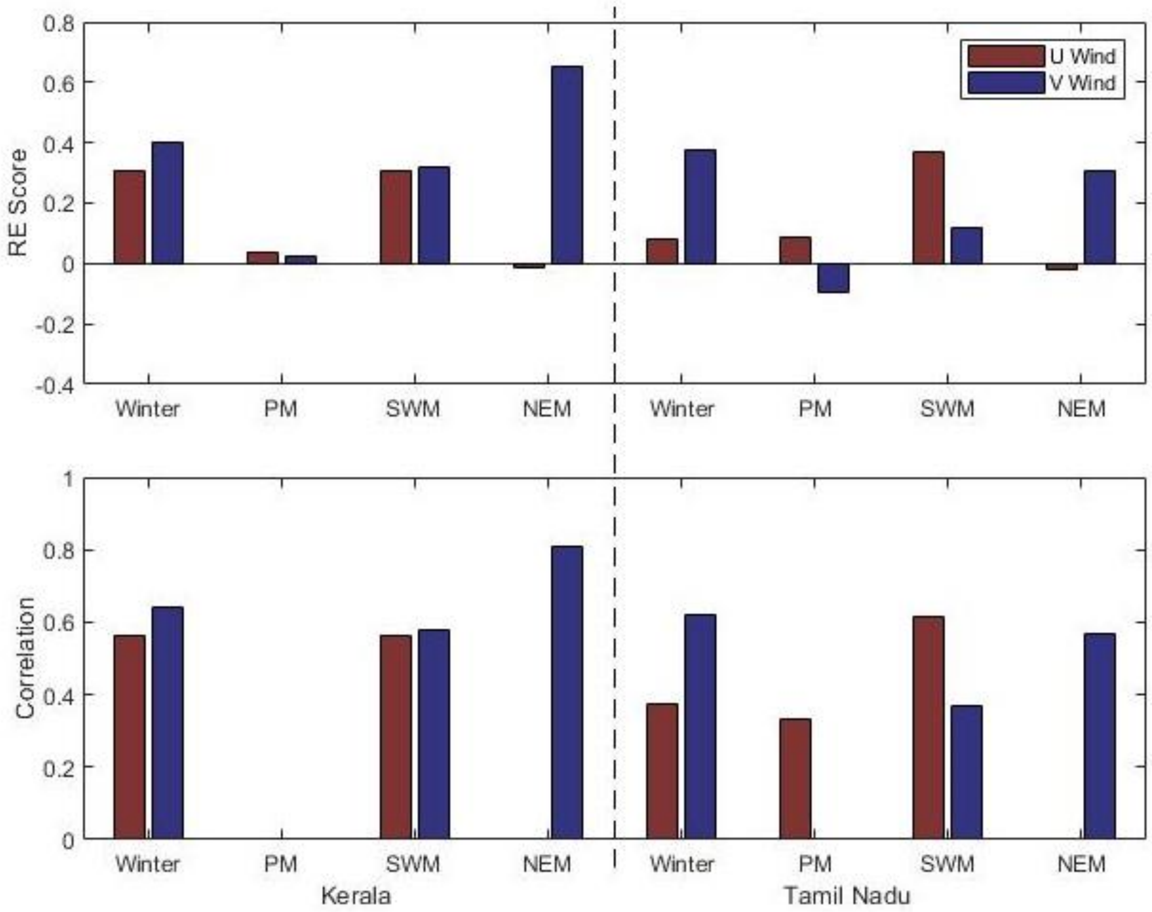

Figure 4.13 - Re scores (upper) and Pearson's correlation coefficients (lower) for each season, state and wind component. Only those correlations significant at the 0.05 threshold are shown.

4.5 Threshold selection

As discussed in Section 4.2, the availability of logbook data in each of the aggregated 7.5˚ x 8˚ grid boxes varies substantially over time; this causes changes in the quality of the seasonal mean created using logbook data for each year. A common approach to ensuring that the mean of the target season is well captured by the available data is to apply a minimum to the number of data points available per grid box, per season. In this case, the minimum will apply to the number of days with logbook-derived wind data available. This figure should be high enough to reduce noise from under-sampling but low enough to maximise the number of seasons available to the reconstruction (Küttel *et al.*, 2010). Jones and Salmon (2005) define sparsely populated grids as those with less than five observations per season, however, thresholds as low as three values per season have been used successfully by Küttel *et al.* (2010) and Neukom *et al.* (2014). Hannaford *et al*. (2015), use a minimum of 10% of data days per season, as they can exploit a higher than average density of logbook data for their Southern African rainfall reconstruction. More recently, Barrett *et al.* (2018) introduced a method where each reconstructed data point has an associated skill score, calculated based upon the data available to the reconstruction for that season. This provides a clear understanding of which reconstructed years should be treated with more or less caution.

At the time of writing, this is the first attempt at using the data within ships' logbooks to reconstruct seasonal monsoon rainfall in Southern India. As a result, it is important to establish whether the unique monsoon climate and its characteristic wet seasons with active and break periods and increased cyclogenesis will affect the ability to capture monsoon magnitude with limited data input throughout the season. In order to achieve this, each of the models created for the viable seasons, for both PCR and CPS, are tested to determine the absolute minimum number of data points per season required to create a skilful reconstruction. Reconstructions with positive RE scores are considered skilful, therefore, to test for the absolute minimum data availability, an RE score above zero will act as the cut off; there must also be a statistically significant (<0.05) correlation between the reconstructed data and modern instrumental rainfall data.

The threshold test is performed using ERA-Interim 10m wind data from 1979-2014 using the grids identified in Sections 4.3.2 and 4.3.3, a seasonal average is calculated from randomly selected data points, per grid box per season. The number of data points used to create the seasonal average increases by one with each iteration until the full series is used, the same randomly selected days are used across each of the grid boxes used for the reconstruction. For example, in the southwest monsoon season, the full season is 122 days, and the sample sizes ranged from 1-122. In each case, for the CPS method a weighted composite is created using the relevant grid boxes identified during the grid box selection procedure. This composite is then standardised and rescaled to fit the predictand using the appropriate model for the wind/season combination. In the case of PCR, the random sample is extracted and PCA and fitting regression is carried out for each iteration in sample size. This process is then repeated 100 times for each instance. Validation statistics are performed upon each iteration and an average value is calculated. Where the average RE score exceeds zero, and the correlation with rainfall data is significant, this sample size is used as the minimum number of data points required to create a viable reconstruction. The results for threshold selection are shown in Table 4.3.

In all cases, the number of logbook data days required for a successful reconstruction exceeds the commonly used minimum of three values per season. The lowest data requirement is for southwest monsoon rainfall over Tamil Nadu, in this case, just four data days are required per season to create a viable reconstruction using PCR. In comparison, to reconstruct the pre monsoon over Kerala using CPS, a minimum of 47 data days are required; a substantial figure. This higher than average data requirement is present across both reconstruction methods and would suggest that it is the characteristics of monsoon rainfall itself that make capturing representative sample of data days more challenging. This is most prominent during the pre-monsoon season where data demand is the highest for both states. It is likely that this substantial increase in demand is caused by the unique rainfall regime of the season, where cumulative pre-monsoon rainfall will be largely comprised of rainfall that has fallen after monsoon onset, in May/June; a larger data requirement is needed to ensure that this is adequately captured.

During the remaining three seasons, this higher demand will be required to capture extremely heavy rainfall from short-term weather conditions, such as cyclogenesis or during the characteristic active and break seasons of the southwest monsoon.

Table 4.3 - Minimum number of data days per season that are required to create an average RE score above 0, which correlates significantly with rainfall at a threshold of 0.1. NEM is the northeast monsoon and SWM is the southwest monsoon.

	V wind				**U Wind**			
	Winter	Pre - Monsoon	SWM	NEM	Winter	Pre - Monsoon	SWM	NEM
Kerala								
CPS	7	47	14	8	5	-	15	-
PCR	8	-	8	18	6	-	11	-
Tamil Nadu								
CPS	9	-	-	16	5	42	10	-
PCR	11	-	4	12	5	-	7	-

This high demand for raw data input presents a challenge for reconstructions using historical logbook data, particularly in the early period when data from ships' logbooks are fewer. In all cases, using these thresholds for the minimum number of days with logbook data generates an incomplete reconstruction. The paucity of reconstructed data is most prevalent during the primary rain-bringing seasons. There is notable improvement in the winter season, which generally has a lower data demand than its counterparts for the same wind component in each state (Table 4.3).

In an attempt to increase the data available to the reconstruction, a process of including surrogate data points from neighbouring grid boxes was trialled using the CPS reconstruction method. Using logbook wind data from within surrogate grid boxes to increase data availability is not unique to this research, Barrett *et al.* (2018) and Hannaford *et al.* (2015) both perform surrogate data capture. In this case, surrogate grid boxes are considered for inclusion if they are within one grid square from the target grid box and have a correlation coefficient of the same sign whose value is not more than 50% closer to 0. Data from within viable surrogate grid boxes is treated as though it was from the target grid box, all weightings, which apply to the target, will also apply to the surrogate. In six out of eleven cases, the use of surrogate grid boxes increased the overall percentage of values that could be reconstructed. However, the average increase was low, 2.5%, the equivalent of approximately four additional years. Considering the minor benefit to the number of years which can be reconstructed and the increased risk of introducing data from poorly fitted grid boxes, the use of surrogate grid boxes was not pursued further.

Table 4.4 – The percentage of years that can be reconstructed from within the target period (171 years) with each viable model using the threshold minimums calculated above. SWM is the southwest monsoon and NEM is the northeast monsoon.

	Winter		**Pre-Monsoon**		**SWM**		**NEM**	
	U	V	U	V	U	V	U	V
CPS								
Tamil Nadu	74%	55%	4%	-	46%	-	-	22%
Kerala	80%	69%	-	8%	31%	23%	-	46%
PCR								
Tamil Nadu	40%	48%	-	-	58%	80%	9%	33%
Kerala	78%	66%	-	-	43%	42%	-	22%

4.6 Confidence Values

The significant increase in the number of seasons that can be reconstructed when a lower threshold for data days is used is evident in Table 4.4, southwest monsoon rainfall over Kerala reconstructed with U wind, requires only four data points per season creating the most temporally complete series. While the rigorous threshold selection procedure is likely to reduce the likelihood of an erroneous reconstruction, it also may eliminate years that could be successfully reconstructed from a smaller number of data points. Figure 4.14 shows an example of the results of a threshold test for both a PCR and CPS reconstruction, it shows the minimum, maximum and average RE scores which can be obtained using each sample size iteration. It demonstrates that there is substantial variability in the skill of the reconstruction at each sample size. Therefore, as opposed to eliminating those reconstructed seasons that have been created with reduced data, they are instead highlighted as years to treat with caution (Barrett *et al*. 2018) with the use of confidence values, as used in Chapter 3, Section 3.3.4. As with the documentary data, a four-point scale of confidence is used (from high to very low), these are summarised in Table 4.1. Those data points classed as very low will not be used in the final reconstruction. In order to remain sensitive to those years that have a higher data requirement due to the nature of the season, high medium and low confidence is calculated relative to the threshold values established in Section 4.5.

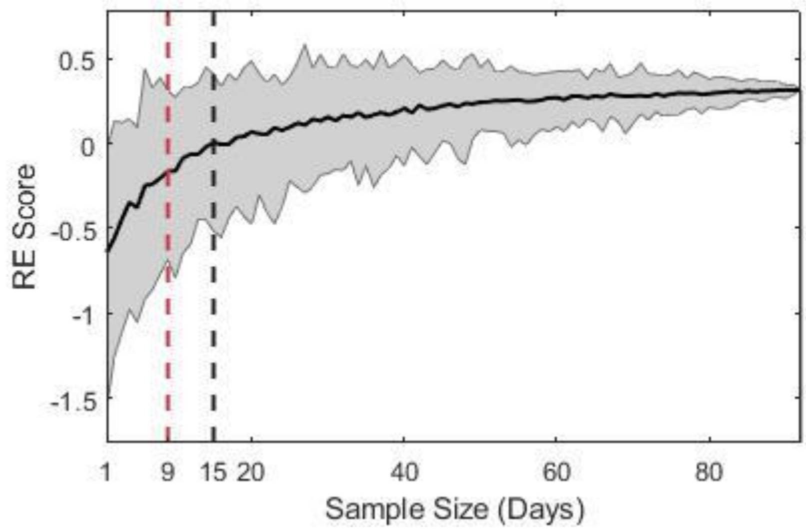

Figure 4.14 - An example of the RE scores associated with each sample size created for the northeast monsoon over Tamil Nadu using V wind. The vertical red line represents the point where the average significance for the 100 iteration is below 0.05 and the vertical black line represents the point where the RE score exceeds zero. The shaded area is the difference between the maximum and minimum score from the 100 iterations, and the thick black line represents the average.

In order to determine an absolute minimum value to distinguish a very low confidence value, CPS and PCR reconstructions were performed on the logbook data using threshold minimums from three to ten. This encompasses standard minimum thresholds used most commonly in the field. Skill scores were calculated between IITM rainfall data and the logbook reconstruction, in the crossover period between 1871 and 1920 to determine the most effective minimum value. Interestingly, increasing the threshold minimum largely reduced the overall skill of the final logbook reconstructions; further analysis demonstrated that an increased threshold is often linked with a reduction in the number of grid boxes available to the reconstruction. Figure 4.14 summarises the response of a logbook reconstruction as the minimum threshold is incrementally increased. This example uses v wind as predictor series for the northeast monsoon, reconstructed using the CPS method. The target spatial field in this instance is eight grid boxes; the term cumulative grid boxes represents the total number of these grids available per season, over the total 50-year crossover period.

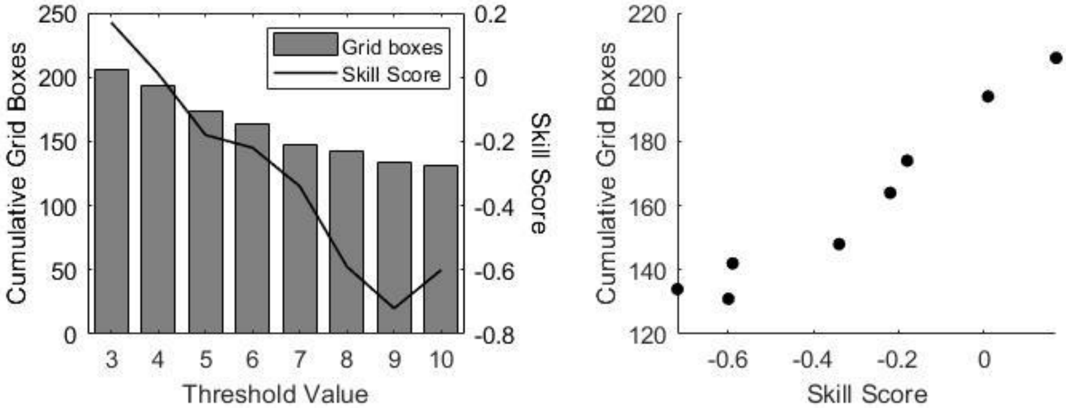

Figure 4.15 – The reconstruction skill and the spatial field for each threshold. Cumulative grid boxes is the sum of the grid boxes available to the reconstruction of the northeast monsoon, using v wind, per year between 1871 and 1920.

The relationship between the two variables, shown in Figure 4.15b, suggests that the spatial field has a significant impact on the final reconstruction quality. A summary of the changing skill scores of each iteration of the threshold minimums for all reconstructions is shown in Supplementary Information, Table S.3. The threshold minimum for this study is set to three, maximising the spatial field; this figure is also in line with previous logbook studies (Küttel *et al.*, 2010; Neukom *et al.*, 2014).

Table 4.5 - Confidence values criteria assigned to logbook data availability. Referring to the number of data days required in each grid box for each model.

Confidence Value	Criteria
High	Meets or exceeds the threshold.
Medium	Between 50% and 99% of the threshold.
Low	Greater than three data days, but less than 49% of the threshold.
Very Low	Less than three data days in total.

4.7 Results of the logbook reconstructions

A reconstruction is created for each component of wind, for each state and during each season, for those iterations where the relevant model, calibrated between ERA reanalysis data and modern instrumental rainfall, was sufficiently skilful. In each case, the model was applied to gridded, seasonally averaged, non-detrended logbook wind data from the from those grid boxes where the relevant 10m wind component correlated significantly with rainfall, as described in Section 4.3. The results are displayed in figures 4.18-4.20 for Kerala, and 4.21-4.23 for Tamil Nadu. No reconstructions for the pre monsoon season are shown; in this season, the very high threshold values cause the low and medium confidence values to dominate (~91%) the reconstruction. None of the reconstructions form a full series from 1750-1920; where there are non-consecutive data points, these are shown as individual markers. These gaps were to be anticipated given the length of the study period and the changes in temporal data availability throughout the study period. The thin grey lines present on each graph represent the 95% confidence intervals. Finally, for ease of viewing, where the reconstructed value falls below zero, the rainfall figure is corrected to zero, this correction is performed most frequently in the drier winter season for both states.

The overlap between the logbook records and instrumental rainfall from 1871-1920 was insufficient for model calibration due to the temporal and spatial data gaps. However, it does provide an excellent opportunity to test the quality of the final reconstructions. In each case, an RE score and a correlation coefficient are calculated between the available reconstructed data points and the instrumental rainfall from IITM. For each season, reconstructions for the prevailing seasonal wind component are shown, i.e. meridional wind for winter and the northeast monsoon and zonal wind for the southeast monsoon.

4.1.4 Keralan rainfall reconstructions

The reconstructed rainfall series for the winter season over Kerala is the most temporally complete of all six reconstructed seasons, with 145 reconstructed data years out of the 171-year target series. This increase is most likely a result of the large spatial coverage of the predictor series for this season, where there was sufficient data in 23 grid boxes. The RE score calculated between instrumental rainfall and both the PCR and the CPS reconstructions indicates that there is little skill in either case; however, the correlations indicate that in this instance, the PCR reconstruction performs better. Visual analysis of the two reconstructions supports the statistical skill summary, where the reconstructed rainfall line shows little overall agreement with Keralan winter rainfall. However, there are notable periods that capture rainfall adequately; this is particularly evident in the latter period for the PCR reconstruction, from 1910 to 1920. During this period, the reconstruction appears to capture a general upward trend over the 10 years, alongside the high frequency annual variability. This improvement coincides well with an increase in data availability during this time (Figure 4.2d(i)).

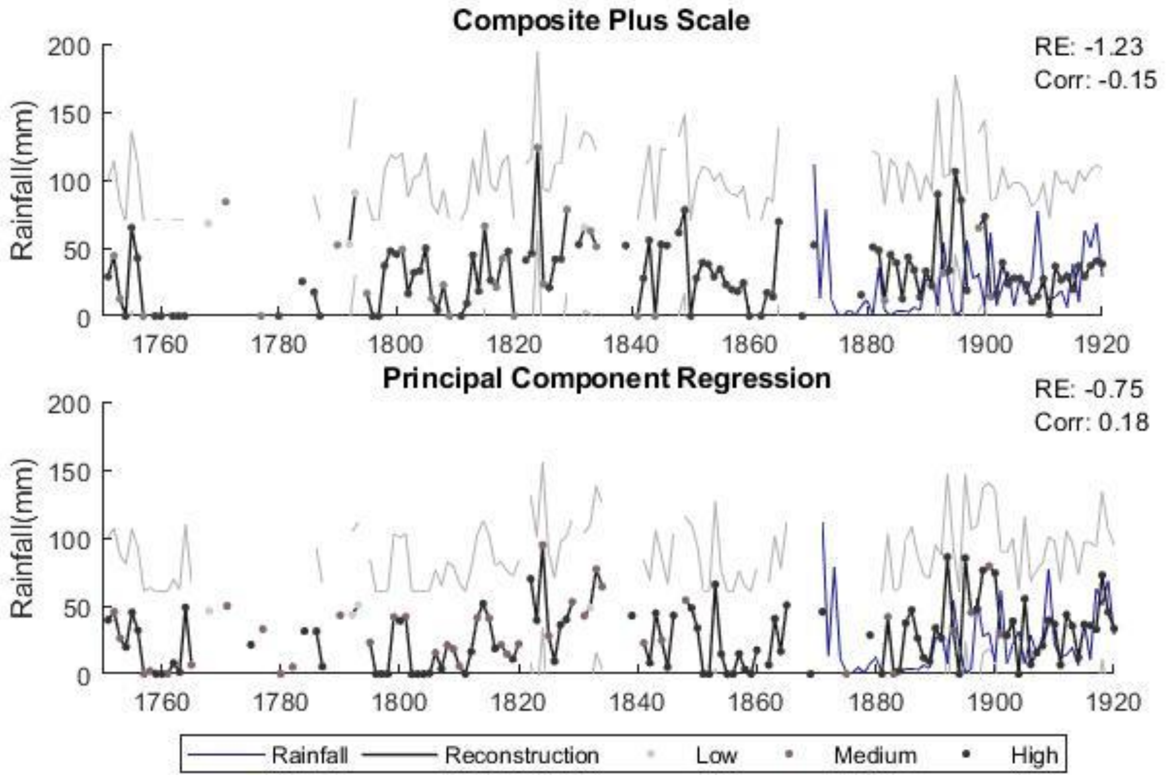

Figure 4.16 - Reconstructed winter rainfall over Kerala. The thin grey lines represent upper and lower 95% confidence limits. The upper panel shows the rainfall reconstructed using composite plus scaling, and the lower panel shows rainfall reconstructed using principal component

The reconstructed southwest monsoon rainfall shows little improvement in skill (Figure 4.17). In this instance the CPS reconstruction fails to capture the variability of the southwest monsoon in the modern instrumental period. This is also the case for the PCR reconstruction, where, with the exception of the period from 1895 to 1905, the variance in seasonal rainfall is poorly reconstructed. The CPS reconstruction shows considerably higher variance in reconstructed rainfall prior to 1790, there is a possibility that the predictor data may contain errors during this period, which may be affecting the scaling in the remainder of the reconstruction.

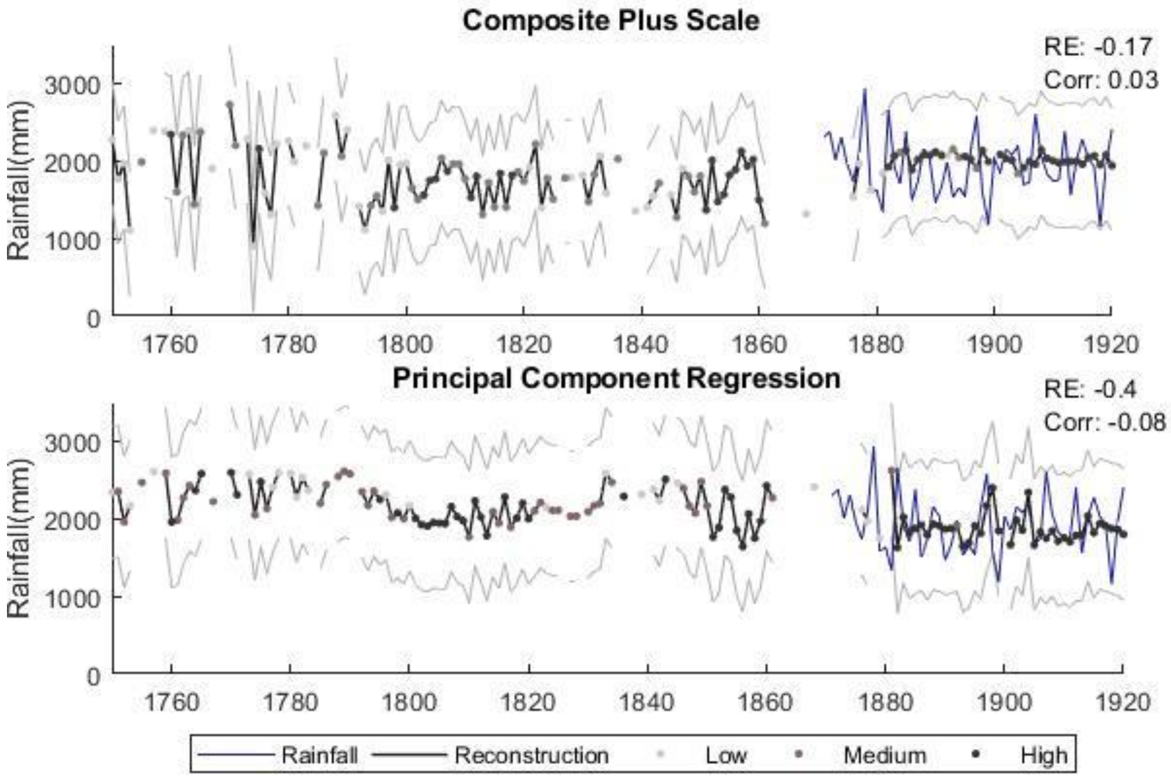

Figure 4.17 - Reconstructed southwest monsoon rainfall over Kerala. The thin grey lines represent upper and lower 95% confidence limits. The upper panel shows the rainfall reconstructed using composite plus scaling, and the lower panel shows rainfall reconstructed using principal component regression.

Finally, the reconstruction of northeast monsoon magnitude over Kerala had similarly low skill scores. The lack of relationship between instrumental and reconstructed rainfall is surprising for this season. The spatial relationship between Keralan rainfall and wind over the oceans were the strongest between these two seasons and the strength of the model during fitting and validation was considerably stronger that the other models for both CPS and PCR. This could indicate that the 30-year fitting period is insufficient to capture the variability of the northeast monsoon over Kerala (Ho *et al.* 2015), or it could suggest that the data availability was insufficient to create a reliable seasonal mean.

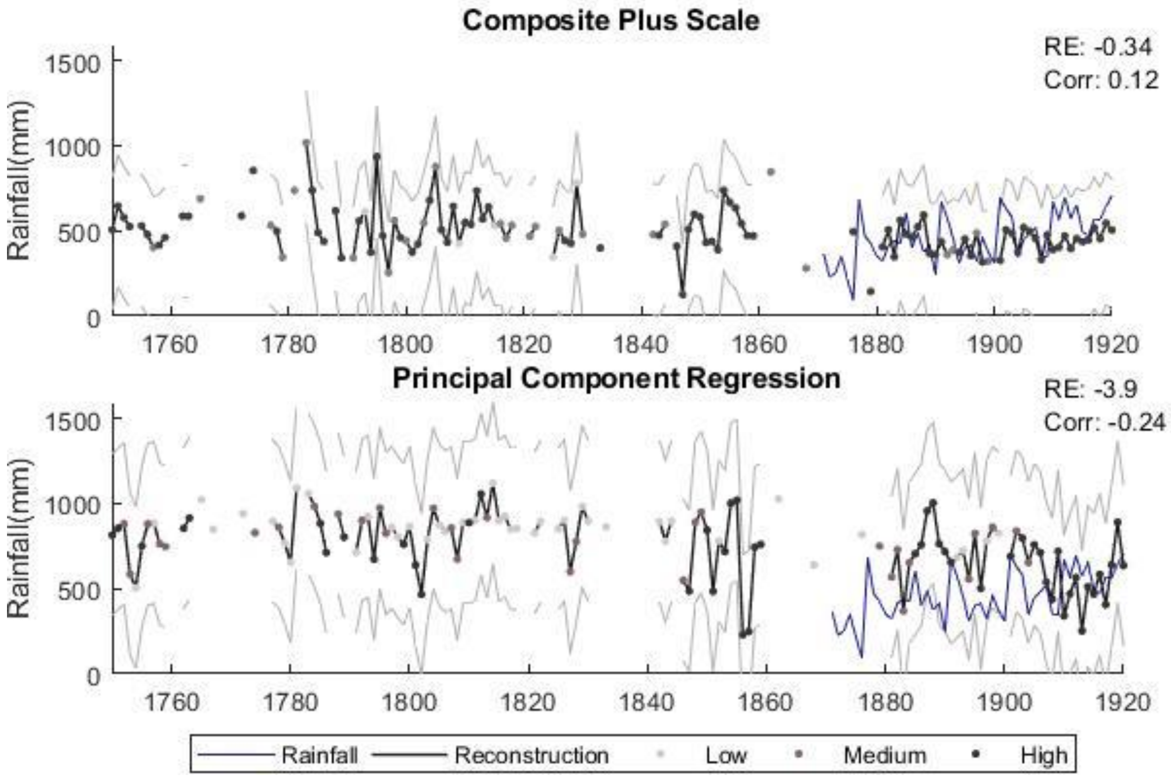

Figure 4.18 - Reconstructed northeast monsoon rainfall over Kerala. The thin grey lines represent upper and lower 95% confidence limits. The upper panel shows the rainfall reconstructed using composite plus scaling, and the lower panel shows rainfall reconstructed using principal component regression.

4.1.5 Rainfall reconstructions for Tamil Nadu

As with the Keralan rainfall reconstructions, the winter and southwest monsoon seasons over Tamil Nadu, figures 4.21 and 4.22 respectively, both have a low reconstruction skill. Again, the reduced variability present in the PCR reconstruction is striking, it is likely that the principal components extracted from the predictor series were ineffective at capturing the dominant modes of winter rainfall variability over Tamil Nadu.

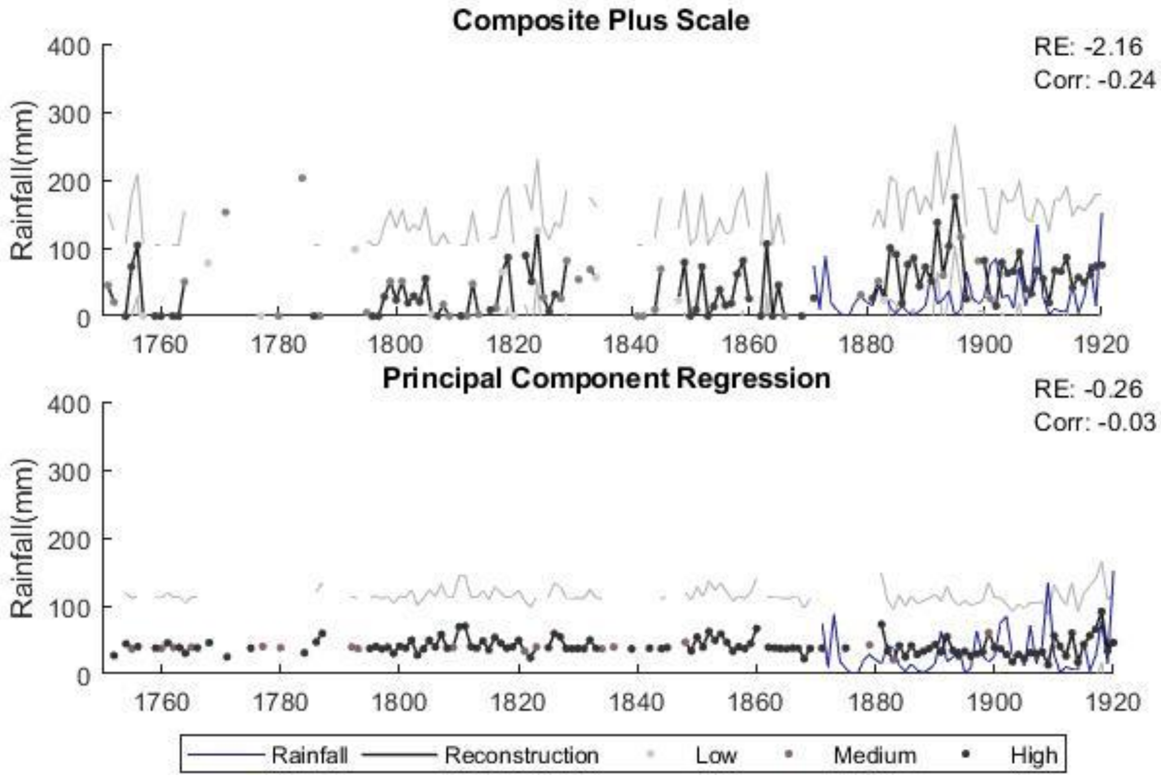

Figure 4.19 - Reconstructed winter monsoon rainfall over Tamil Nadu. The thin grey lines represent upper and lower 95% confidence limits. The upper panel shows the rainfall reconstructed using composite plus scaling, and the lower panel shows rainfall reconstructed using principal component regression.

In the case of the southwest monsoon over Tamil Nadu (Figure 4.20), visual assessment of the CPS and PCR reconstructions agree that there is very little skill in either instance. In the case of the CPS model there is very good agreement for the short period between 1904 and 1908. There is no improvement in the spatial field nor increase in the data availability that is beyond what is expected at that point in the study period. In the case of the PCR reconstruction, there is some visual improvement in the fit of the reconstructed rainfall during the 20th century, however, the improvement is not considerable.

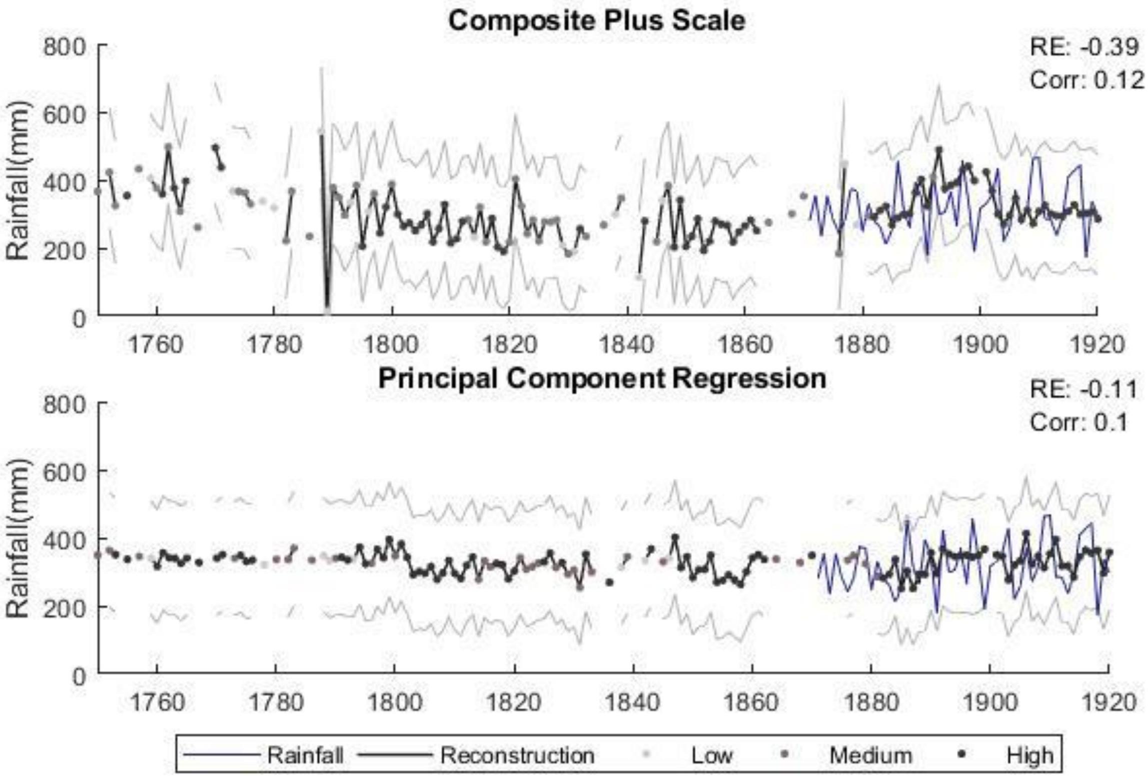

Figure 4.20 - Reconstructed southwest monsoon rainfall over Tamil Nadu. The thin grey lines represent upper and lower 95% confidence limits. The upper panel shows the rainfall reconstructed using composite plus scaling, and the lower panel shows rainfall reconstructed using principal component regression.

In contrast to the previous five reconstructions, the CPS reconstruction of the northeast monsoon over Tamil Nadu is the first with a correlation significant at the 0.05 threshold. It is also the only reconstruction that achieves a positive RE score. In contrast, the PCR reconstruction shows no improvement in skill. Barrett et al. (2018) also noted the superior performance of simpler CPS reconstruction method over the PCR method. In this case, the full spatial field for this reconstruction consists of just eight grid boxes, therefore, the value of using the PCR method, which preserves a greater spatial element, is reduced. However, it should be noted that for the CPS reconstruction, the high-frequency variability during the overlap period is lower than the instrumental rainfall for the equivalent period. This reconstruction, while the strongest, is also the least populated with 108 out of 171 years reconstructed.

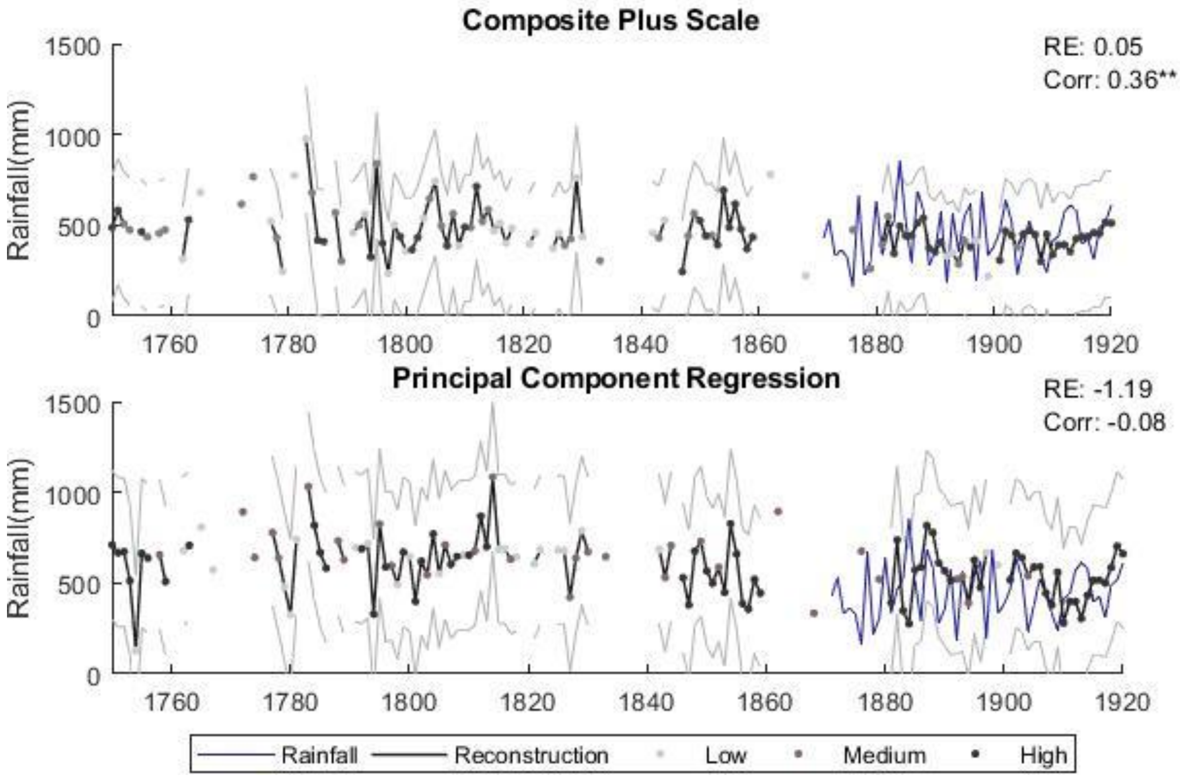

*Figure 4.21 - Reconstructed northeast monsoon rainfall over Tamil Nadu. The thin grey lines represent upper and lower 95% confidence limits. The upper panel shows the rainfall reconstructed using composite plus scaling, and the lower panel shows rainfall reconstructed using principal component regression. '**' denotes value is significant at the 0.05 threshold*

4.1.6 Comparison with the documentary reconstruction

Due to the moderate success of the northeast reconstruction over Tamil Nadu, there is an opportunity to compare both the logbook and the documentary reconstructions for that season. In order to achieve this, the logbook reconstruction is degraded into a 5-point index series, to match the resolution of the documentary reconstruction. The logbook data is degraded using the same methods that were used to degrade modern and early instrumental data in Chapter 3 Section 3.3.1, using those thresholds that are defined by the India Meteorological department, summarised in Table 3.2.

Both the documentary reconstruction and the logbook reconstruction, created using the more skilful CPS method, are shown in Figure 4.22. The confidence value assigned to each reconstructed data point is shown by the colour of the marker. For ease of viewing, only those years where both reconstructions have data are shown. The vertical line for each year shows the difference between the two reconstructions. Therefore, lack of a line demonstrates agreement between the two. In this case, 23% of the reconstructed years have identical values and a further 54% are within one class. On four occasions (4%), three index classes separate the two reconstructions. While identical values are rare, 61% of reconstructed values have the same sign.

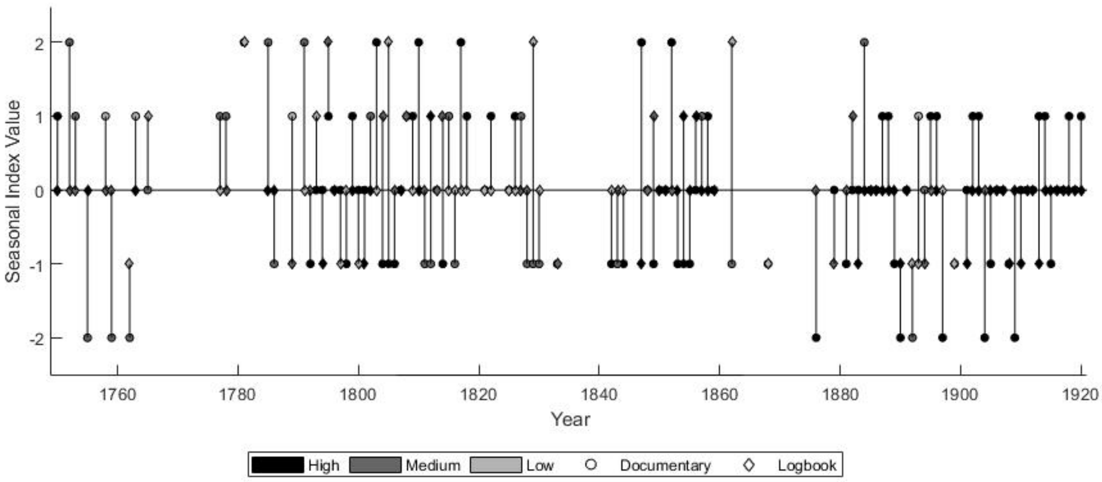

Figure 4.22 – Documentary and logbook reconstructions of Northeast monsoon magnitude. Only those years with data in both reconstructions are shown. The vertical lines represent the difference between each reconstruction.

The confidence values can offer an insight into some of the mismatches, for example in 1816 the documentary data suggests that northeast monsoon rainfall was deficient with an index class of -1, while the logbook data suggests an above average monsoon year, with a class of 1. In this instance, the confidence in the documentary reconstruction is high; it is based upon quotations from each month of the season, in addition to early instrumental rainfall data from the Madras Observatory. In contrast, the confidence in the logbook data is medium, 50-99% of the recommended threshold minimum for the season.

> "The wind from the monsoon quarter has blown with a steadiness unusual for this early part of the season; the fall of rain has been very moderate and the weather uncommonly pleasant. Heavy dews have been on the ground in the morning, accompanied by a coolness more like the weather later in the rains."
>
> - *Government Gazette, 25th October 1816*

> "The flag staff was re-hoisted on Monday last. The monsoon has continued mild and pleasant throughout but the quantity of rain that has fallen in the vicinity of the presidency has not yet quite been sufficient for the annual consumption."
>
> - *Government Gazette, 19th December 1816*

There are also examples where the logbook confidence outweighs the documentary. For example in 1755, the documentary evidence is limited to a seasonal quotation, see below, and a monthly quotation from October. From the documentary evidence this was classified as a medium confidence year, while the logbook data meets the recommended threshold minimum. The two reconstructed rainfall values differed by two signs; the documentary data suggested a deficient monsoon year with an index category of -2 and the logbook data presented a normal year, with an index classification of 0.

> “We returned home by noon. Owing to the troubles, town and country had already lost their beauty; but now the rains have failed, and famine has fallen like a mill-stone falling on a sore finger. I have dwelt here these 33 years but never have I seen so bad a year.”
>
> – *Private diary of Ananda Ranga Pillai* (Dowdwell, 1924)

There are cases of mismatched data points where both reconstructions are labelled as high confidence, for example 1847 and 1909. Where these mismatches occur, it can be assumed that one of the reconstructions has failed to capture the true temporal or spatial extent of the rainfall during the season. In this study, logbook data has a wider catchment than the documentary data, however, incomplete seasonal logbook data reduces its ability to capture higher resolution temporal changes, and the reconstruction is based on the assumption that the relationships derived during the fitting period remain stable throughout the reconstruction period. The year 1802 stands out as an excellent example of the failure of the seasonal mean within the logbook reconstruction to capture the full northeast monsoon variability. In an article from the *Government Gazette*, written in 1812, the monsoon of 1802 was described as having a late and mild onset with a good overall seasonal outturn as a result of good late season rains. In this instance, the monsoon is recorded as above average in both the documentary and early instrumental data. However, the logbook reconstruction records this year as deficient, at -1. This may be attributed to the distribution of the raw data, which originate from 36 days in October and 13 days in November, where the latest data record is the 18th of November, which would not capture the late season rains described in the documentary record.

Another consideration is the asymmetric capture of extremes between the two data sets. As shown in Figure 4.22, the documentary reconstruction classifies ten years as -2 and eight years as +2, whereas the logbook reconstruction classifies just one and three respectively, which is more in line with the modern instrumental period between 1871-2016, where just one extremely deficient year (-2) and four exceptionally high years (+2) are recorded. It is, therefore, a possibility that the documentary data over-emphasises the extreme values in relation to modern events, a concern often levelled at documentary studies (Ahuja, 2002a; Nash & Endfield, 2002; Norrgård, 2015) and discussed in Chapter 3, Section 3.2.2. However, there is also the possibility that the logbook data underestimates the extreme values in the historic period, which, again could be linked to gaps in seasonal daily data. While variance scaling methods, such as CPS, are thought to capture variability more effectively than regression-based reconstructions, like PCR (McCarroll *et al.*, 2015), there are still concerns that variance could be poorly estimated. This possibility is exacerbated if the fitting period is insufficient as to produce a linear model that can suitably capture longer-term changes in historical variance (Ho *et al.*, 2015).

4.8 Discussion

This chapter has described the methods for using logbook-derived wind data to reconstruct rainfall in each season over Kerala and Tamil Nadu. It focused on the methods for threshold selection, model fitting and skill testing before comparing the results of the reconstructed northeast monsoon rainfall over Tamil Nadu with the result of the documentary reconstruction for the same season from Chapter 3.

4.1.7 Threshold testing

As a result of considerable changes in logbook data availability over time, threshold testing was used in order to suggest a minimum number of data days required per grid box to generate a skilful reconstruction. The results of the threshold testing indicated than in the case of the major rain-bringing seasons, the northeast monsoon and the southwest monsoon, the number of data days required per grid box to create a skilful reconstruction was far higher than the standard for the field. In 14 out of a 22 possible reconstructions, less than 50% of target series could be reconstructed; this high figure is most likely a result of the highly variable monsoon climate. While the threshold minimum was developed to minimise the risk of introducing poorly constrained reconstructed data points, the substantial variability in the results of the threshold testing indicated that even at very low sample sizes a skilful reconstruction could be created. Therefore, as opposed to eliminating data, confidence values were used to represent the likelihood of a spurious data point. In this instance, the absolute minimum was set at three data points, in line with other studies in the field (Küttel *et al.*, 2010; Neukom *et al.*, 2014); a minimum threshold value of three also maximises the spatial field available to each year of the reconstruction, which was shown to be equally as valuable as an increased number of days with data available in each season. The results of the northeast monsoon reconstruction over Tamil Nadu demonstrate that the increased risk associated with including poorly populated grid boxes is worthwhile. In this instance, 17 out of 38 reconstructed data points in the overlap period have reduced confidence, yet the reconstruction remains skilful.

To increase data availability, there were no restrictions placed on the month from which the data originates for the monsoon season. During the Age of Sail voyages to India were often timed carefully to both coincide with the direction of the prevailing wind (Tripati & Raut, 2006), and to avoid boisterous conditions at sea, therefore, the seasonal distribution of data is not even. The distribution of data in the primary rain-bringing seasons, for the entire study area is shown in Figure 4.23. Data is reduced to years dominated by sail (1750-1845) and steam (1846-1920). During the age of sail, data availability reduces from November until the last week of December.

Interestingly, there are accounts within the documentary data, collected for Chapter 3, that the waterways in the proximity of the major trading outpost Fort St. George (Supplementary information, Figure S.1) were closed for travel between October 15th and December 15th in order to protect the vessels from seasonal storms. The effect of this cannot be seen in Figure 4.23, but the more detailed analysis may indicate that there is a bias within grid boxes in close proximity to Fort St. George.

"According to annual custom the flag staff of Fort St. George was struck on the 15th to prepare for the change in weather expected at this time of the year. As yet, there have been no serious indications of a change. On the contrary, the weather has the last part has been uncommonly fine, more like the conclusion of the monsoon season than its approach. All ships however quitted the roads and sailed on Sunday night to seek shelter."

- *Government Gazette, 15th October 1815*

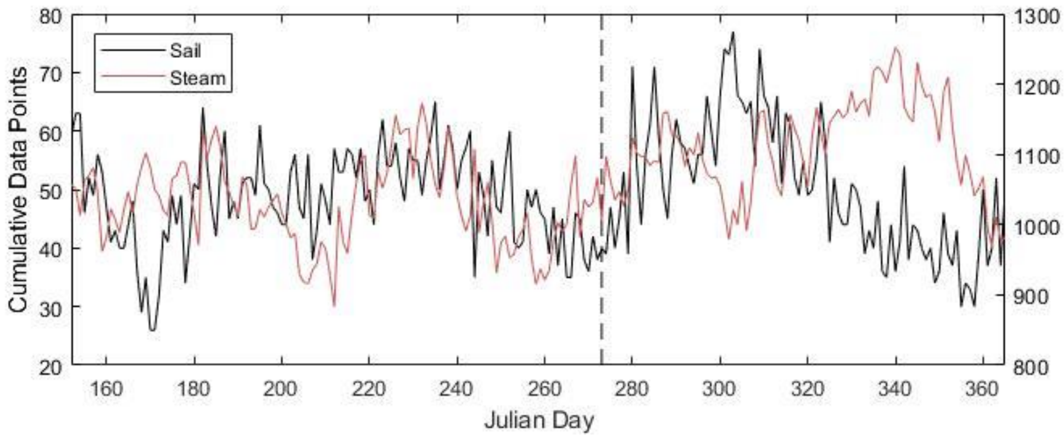

Figure 4.23 - The distribution of data throughout the two primary rain-bringing seasons during the age of sail (1750-1845) and the age of steam (1846-1920).

4.1.8 Comparison between PCR and CPS methods

Both CPS and PCR methods were used to reconstruct rainfall in each season for each state. Each method has associated benefits and limitations and together the two methods complement each other (Barrett *et al.*, 2018; Mann *et al.*, 2008). For example, the CPS method used employs variance scaling, which is generally thought to result in increased error, however, it is superior to the PCR method at capturing extremes (McCarroll *et al.*, 2015). During the 1871-1920 crossover period the CPS and PCR methods perform at a similar skill; while CPS does generate more successful models the skill of the successful PCR models is in line with the CPS counterpart. In both instances, there is evidence that rainfall, reconstructed using components of wind from ERA reanalysis data, can capture both high and low frequency variability. As could be anticipated, the CPS method captures more extreme values during the crossover period.

The opportunity to verify the final logbook reconstructions against instrumental data during the 50-year overlap between IITM rainfall data and logbook data was exceptionally valuable. The logbook data was insufficient during this period for it to be used in model fitting and therefore the period remains independent of model fitting. The results showed that while the skill scores for the fitting and cross validation period were good, this skill is not indicative of the success of the model derived from logbook data. The most prominent example of this mismatch is the northeast monsoon over Kerala, where during fitting and validation the model performed very well, with an RE score greater than 0.6 for both the PCR and the CPS models. When this model was applied to the logbook data however, both returned negative values.

When the models are applied to the logbook data, PCR performs worse than CPS in five out of the six reconstructed seasons. The cause of this reduction in skill could be a result of the changing spatial field in the logbook data caused by fluctuating data availability. Climate field reconstructions are known to preserve more of the spatial domain than the CPS methods; therefore, their application to an incomplete or reduced spatial domain in the historical period may cause a reduction in skill although further research would be required to substantiate this claim.

4.1.9 Comparison with the Documentary Reconstruction

The most skilful logbook reconstruction in the 1871-1920 crossover period was of the northeast monsoon over Tamil Nadu using the CPS method, the same season that the documentary reconstruction targeted. This provided an excellent opportunity to compare the two reconstructions. The logbook reconstruction was degraded to a five-point index scale, in line with the resolution of its documentary counterpart, and the number of years in agreement were compared. There was particularly good agreement in the early 20th century and, while the number of exact matches decreased further into the historical period, the most common separation between the two reconstructions was one index value. The most substantial difference between the two reconstructions is the number of extremes identified. Whether this is due to exaggeration on the part of the author or a false assumption of stationarity in the climate conditions between the modern and historical period, is challenging to conclude with confidence. This asymmetry between the two reconstructions demonstrates the value of creating multiple reconstructions that use different sources (Gergis & Fowler, 2009). Furthermore, for studies that focus on collecting and analysing historical extreme events, it is possible to suggest that terrestrial documentary data, such as that collected and used in Chapter 3, is more appropriate. While there remains the possibility of some exaggeration on the part of the author, the data itself is not subject to the assumptions of model fitting, therefore it is less likely to be constrained by the modern climatology.

4.9 Summary

This chapter has discussed the creation of seasonal reconstructions of rainfall over Southern India using the wind speed and direction contained within ships' logs between 1750 and 1920. In total, six reconstructions were created; the winter season, the northeast monsoon and the southwest monsoon as manifest over Kerala and Tamil Nadu. Of these, only the northeast monsoon over Tamil Nadu demonstrated any reconstruction skill. This was compared to the documentary reconstruction created in Chapter 3. The two were found to largely agree, with three quarters of the reconstructed data points falling within one sign of the other. However, the skill of the logbook reconstruction in comparison to the documentary is considerably lower, correlating with modern instrumental rainfall at 0.36 significant at the 0.05 threshold, compared to documentary data that correlated at 0.74, also significant at the 0.05 threshold. With present logbook data availability, terrestrial documentary reconstructions more effectively reconstruct the Indian monsoon climate. Furthermore, the two reconstruction capture extreme values rather differently, with the logbooks identifying less than a third of the extremes identified in the documentary data. The two rainfall reconstructions for the northeast monsoon over Tamil Nadu are the first of their kind in this region.

Two common methods were trialled for the logbook reconstruction, CPS and PCR, and while both performed sufficiently well during model fitting and validation, their skill declined substantially during the historical period. This reduction in skill was most prominent in the PCR method suggesting that the simpler CPS method is more suitable for intermittent historical data. The ability to verify the reconstructions against an independent instrumental rainfall series was invaluable to this research. It demonstrated that, in this case, the cross-validation process carried out in the fitting period between ERA wind data and IITM rainfall was not indicative of the skill of the resulting model when it was applied to the logbook data.

Threshold testing demonstrated that a substantial number of days per season with logbook data are required in order to create a skilful reconstruction in the monsoon climate, particularly in the primary rain-bringing seasons that experience increased variability. In each of these cases, the minimum threshold proposed by the testing procedure was considerably higher than the average for the field. This threshold placed excessive constraints on the reconstruction, reducing the number of years that could be reconstructed. Further exploration also demonstrated that the increasing the demand for sufficient data days also reduced the number of grid boxes available to the reconstruction which had a detrimental effect on the quality of the final reconstruction. Evidence that fewer data points can create a good reconstruction providing the spatial field is sufficiently large led to the reduction of the minimum number of days per season, and the application of confidence values, used to indicate the increased risk of a spurious reconstruction due to the number of data points available to the reconstruction. A scale of one to four was used to mirror the documentary data. As always with historical studies, one of the most prominent themes throughout this chapter is the need for more data. More data would increase the reliability of the seasonal means generated from each grid box, and increase the spatial field, subsequently strengthening the logbook data as predictor series.

Chapter 5: A famine history of Tamil Nadu 1730-1920

5.1 Introduction

This chapter presents a famine history of Tamil Nadu from 1730 – 1920 as told through the documentary records. It starts by describing the role of historical social information within the field of historical climatology, before introducing the data that was collected and analysed for this study. It goes on to present a chronology of famine events that affected Tamil Nadu within the study period, with a particular focus on the political responses and famine management strategies, which addresses this research's third question. Finally, this chapter explores how these famine events were recorded by past societies in conjunction with monsoon rainfall, which begins to answer the fourth research question.

5.1.1 *Climate and society in historical climatology*

Chapters 3 and 4 have focused on using historical documentary sources to reconstruct the Indian monsoon as manifest over South India. However, as noted in Chapter 3, Section 3.1.1, what makes historical climatology so unique is the opportunity to capture both climatic and social information. To consider the evidence of the physical manifestation of weather contained within the documentary evidence without considering its place in the social setting risks the loss of valuable information; specifically, detail of the risks of long term climate changes or short-term shocks on humankind (Allan *et al.*, 2016; Jasanoff, 2010; Stern *et al.*, 2013). Historical climatology is concerned with the interaction between society and the local climate (Brázdil *et al.*, 2010; Degroot, 2018; Pfister, 2010), so understanding how climate affected societies in the past is valuable knowledge in light of present and projected climate change (Adamson *et al.*, 2018; Carey, 2012; Hulme, 2015; McMichael, 2013).

Social responses to climate are not consistent through time or space. For example, they vary temporally with the changes in local government policy and the development of new technologies. They also vary demographically, for example, with wealth or an individual's political or social standing (Adamson & Nash, 2014; Busby *et al.*, 2018; Felsenstein & Lichter, 2014; Formetta & Feyen, 2019; Maiti *et al.*, 2015). The relationship between climate and society is also multifaceted, and may change in over time or between social elements (Endfield, 2012; O'Brien *et al.*, 2004; Xenarios *et al.*, 2016). The myriad of potential pathways between climate and society (Paschen & Ison, 2014) makes understanding the nature of the relationship challenging. However, numerous studies have responded to the demand for more analysis of the interaction between climate and society using historical, empirical data from archival sources (Adamson, 2014; Brázdil *et al.*, 2005; Endfield, 2007; Hannaford *et al.*, 2014; Hannaford & Nash, 2016b; Messerli *et al.*, 2000). While, like those physical climate reconstructions, there is a bias towards European regions (Adamson *et al.*, 2018) expansion into other regions with a long written history is taking place as described in Chapter 3, Section 3.1.1.

Three studies of climate – society interactions, as told through historical documentary sources, are of particular note for to this study. The first, by George Adamson (2014) investigates the social and political responses to climate variability in Western India between 1790 and 1860, focusing particularly on social vulnerability and institutional responses during periods of drought. The second, by David Hall-Matthews (2002, 2005) presents a detailed study of drought, famine and peasant society, in the Ahmednagar district, in modern day Maharashtra (Chapter 2, Figure 2.1). Unlike Adamson's longer study period, he focuses particularly on the 14-year period of 1870-1884, surrounding the 1876-1878 famine. The third study by Damodaran et al. (2019) investigates famines in late eighteenth century India - here, the authors focus on the relative roles of climate and politics and challenge the anachronistic causal-link between drought and famine in colonial India (Coombes & Barber, 2005; Slettebak, 2012).

5.1.2 *Climate and society in the archives*

The collection of historical social information occurred in tandem with the collection of the data for monsoon rainfall for Chapter 3; see Section 3.2.2 and Table 3.1 therein for details of the archives consulted and the types of documents analysed. As with the collection of weather information, evidence of social reaction to or interaction with weather was transcribed along with records of its source, including details of the archive, the date and location where it was written and, if applicable, its catalogue number or date and place of publication. The social information was stored in the same database as the meteorological data and was separated from it prior to analysis.

All of the documents that were read during this research were written in the English language. Just two sources are published as translated documents; the first is the diaries of Ananda Ranga Pillai translated from their original French by twentieth century historians. The second is a collection of newspapers, translated from their original Tamil by the British colonial government, with the purpose of monitoring local dialogue that discussed the British administration. Therefore, collectively, there is a bias that favours the perspective and location of British actors. As Endfield (2012: 3680) notes, the documents consulted in studies such as this thesis were written *"at a particular time, from a particular perspective and for a particular purpose"* and, as such, may contain *"intentional and accidental bias".* The British government or East India Company officials wrote 68% percent of those documents from which social information was extracted. The authors of these documents are few in number; in the 1881 census of India, there were 254 million people accounted for; excluding British troops only 33,900 of these were British-born (Bradlaugh, 1890). As a result, the evidence obtained from the documents originates from only a small portion of the many demographic groups (Queen, 2015) existing in Southern India between 1730 and 1920.

In its early stages, this research intended to respond to the demand for studies that assess the changing vulnerabilities and resiliencies of historical communities in the face of extreme weather (Allen *et al.,* 2016). However, because of the two aforementioned biases alone, it was clear that this aim was beyond the ability of the data collected here. In fact, it was decided that to make assumptions about the decision making, responses, or motives of non-British societies, as described from the perspective of the British colonial populace, would risk the inclusion a fictitious or deterministic narrative (Adamson, 2018). Not only this, but it would have been unjust to the historical populace as the voice of local communities was not recorded in the documents studied for this research.

As a result of these biases, the data were reconsidered, it was clear when taking a step back that where the data collected here did excel was in the provision of empirical evidence of the socio-economic impacts of historical climatic shocks on society and the high-level responses by British government. The prevalence of information concerning human-climate interactions increased during extreme weather events such as flooding, tropical storms, but most significantly during drought. This increase in data was likely to be influenced by the severity and longevity of drought events and their extended impact on society, agriculture and water supply, in comparison to the immediate effects of high winds and rain. This bias towards extreme events is seen most prominently in newspapers; 10% of the documents from which social information was extracted were newspapers. With the exception of the translated excerpts noted above, these were English language newspapers. Of them, *The Government Gazette* and the *Madras Courier* were published in Madras town. *The Bombay Times and the Journal of Commerce,* later the *Times of India*, was published in Bombay and the remaining newspapers were published in Britain using Indian sources.

Due to the increase in documentary data available during times of drought – particularly when drought occurs in conjunction with a famine – these periods are the focus for this chapter. Famine, as Sen (1981) describes, can be understood without the need for a complex scientific description. Here the term is applied to periods of extreme hunger, as described in the documentary record, which resulted in widespread mortality from starvation. Famine events such as these are understood to be the result of a unique and complex combination of political, social, economic and environmental failures (Howe, 2018), each of which affect the manifestation, longevity and spatial extent of each crisis (Fraser, 2007; Slavin, 2016). Famine events were frequent throughout the history of India (Bhatia, 1967; Damodaran *et al.*, 2019; Major, 2019; Mishra, 2013), were the cause of thousands, on some occasions, millions of deaths (Ahuja, 2002a), and were responsible for exceptional suffering. While this chapter is free of vivid descriptions of suffering, it should be remembered that these events brought untold misery to the people of India.

5.2 Dearth and famine

> *"Your lordship will perceive that I allude to the present scarcity of rice, which I am sorry to say is no novelty in Madras"* [15]

There are fourteen occasions during the study period where a famine event is reported to have affected the lands of modern-day Tamil Nadu: 1733-1736, 1746, 1755, 1759; 1762, 1781-1782, 1787, 1806-1807, 1812-1813, 1833, 1865-1867, 1876-1878, 1891, 1904. Unfortunately, in three of these cases 1762, 1787 and 1904 there is little data beyond an acknowledgement of the crisis. The famine of 1762 was reported in Cuddalore, and the famine of 1787 was reported in

[15] IOR/F/4/59 – Boards Collections. 17th December 1799: pp.1349

Coimbatore (see Supplementary Figure S.1); the British had a minimal presence in both regions at the time of each event so it is likely that there were fewer descriptions of the events. However, the famine of 1904 was reported in the *Times of India,* along with a record of unusually poor rains. It is the only report of famine at this time despite a good volume of extant copies of the daily newspaper, therefore, it is possible that the use of the term famine on this occasion was spurious, or sensationalist.

However, the remaining eleven events are well documented, with particularly good detail available for famines in the second half of the nineteenth century. The following text provides details of these eleven periods of famine that occurred within the Madras Presidency, as described within the documentary sources. It focuses on the manifestation of the events and outlines the principal government discourse and response methods. In each case, the cause of the famine, as stated within the documents, is also recorded, although this should be read with consideration of the aforementioned biases within the documentary data, discussed further in Section 5.4.

The social and political landscape of Southern India changed dramatically over the 191 years covered by this study period. Therefore, for narrative ease, the timeline is broken down into four periods. It commences with the 'pre-colonial period' between 1730 and 1767, followed by the 'East India Company expansion' (1767-1807), the 'East India Company Rule' (1807-1858) and finally, 'Crown Rule' (1858-1920). The breaks between each period represent significant political and territorial changes in the lands of modern day Tamil Nadu.

5.2.1 *Pre-colonial period: 1730-1767*

Four famine events occurred during the period 1730-1767 that were sufficiently documented within the archival literature to allow for discussion. This period represents the earliest data collected for this research, until the first Anglo-Mysore war, which is described in Chapter 2, Section 2.4.1. The extent of the land occupied by the East India Company in Southern India during this period was minor, predominantly confined to Madras Town, Fort St. David and the fort of Devicottah, with some land exchanges due to the protracted Anglo-French conflict in the region (Joppen, 1907).

A protracted period of food scarcity occurred between 1733 and 1736; in two years, 1734 and 1736, the scarcity is reported to have reached famine levels. In 1733, Benjamin Schultze, a Christian missionary wrote on the 20th of December that those crops between Madras town and Sidambaram that were not watered by irrigation were "*parched up for want of rain*" (Schultze 1858: 130). In consequence, there was a general increase in grain price (Love 1913) and in order to increase supplies, the importation of grain by land to the East India Company's establishments was permitted free of the usual customs duty[16]. The scarcity continued on the Coromandel Coast[17] into early 1734, "*On account of the great scarcity, consequent on want of rain, we wrote to an eminent German at Vizingapatum, requesting him to send us some rice,*

[16] IOR/G/18/4 – Fort St David Consultations 1733. 7th December 1733.

[17] Coromandel Coast largely corresponds to the Eastern coast of modern day Tamil Nadu.

on payment" (Schultze 1858: 139). In September of the same year, conditions are described as famine for the first time. Deaths from starvation are recorded along with individuals borrowing money against themselves or their children[18]. No record of impact on European inhabitants is reported, so it is likely that the events were felt most severely by the Indian population. Normal rains in the northeast monsoon season of 1734 were attended by a reduction in grain prices at the prospect of a good harvest[19] (Schultze 1858). In 1735, the monsoon rains were also good[20], although notes on the pressures that were felt as a result of the depopulation of regions faced with scarcity and reduced trade during the previous years can be found in Letters from Fort St David[21] and in *Madras in the olden time* (Wheeler 1861). In 1736, the failure of the rains led to another famine, "*Following a long period of scarcity the rains of 1736 failed entirely. Hungry vagrants crowded into Madras, and the council apprehended a famine that we have reason to fear will be more cruel than we have ever felt*" (Love, 1913: 278). There are further accounts of a severe famine in Salem (Chapter 2, Figure 2.9) which extended into early 1737[22].

During this pre-colonial period there was a well-documented and chronic demand for skilled labour[23] (Ajuha, 2002). Trade was low in the British territories of southern India[24], attributed to "*the long continuance of famines, wars and disturbances",* which discouraged merchants from trading in the region[25]. The most substantial references to these issues occur during and immediately following this protracted scarcity. For example, instructions to the president and council of Fort St. George in 1737 were to *"continue all Proper Encouragement to Weavers, and other Manufacturers and Handicrafts, to reside within Our Bounds"*[26]. So severe was the labour crisis in Fort St David that incentives included the construction of houses using company funds that were to be freely distributed to new Indian settlers[27]. Furthermore, a petition by the inhabitants of Fort St. David to reduce customs and duties on luxury items and cash crops such as tobacco, indigo and betel was granted, and maintained beyond the period of scarcity itself to boost trade in the region and improve the general prosperity of the inhabitants[28].

---

[18] The act of borrowing money against ones person or dependent indebts them to their creditor, as described by Schultze (1858: 140) "*It is a common occurrence for parents of low caste to borrow money on themselves and their children and pay it back in instalments by daily hire when they are in service to their creditors. It comes to pass that a man may spend half or even the whole of his life as a slave to his creditor."*

[19] IOR/G/18/9 – Fort St. David Letter, 23rd January 1735

[20] Diary and Consultation Book 1736. Reprinted 1939.

[21] IOR/G/18/9 – Fort St. David Letters. 30th December 1735

[22] IOR/G/18/4 – Fort St. David Consultations. 13th February 1737; Despatches from England: 1737-1740. Reprinted, 1932, pp. 12.

[23] IOR/G/18/4 – Fort St. David Consultations 1733. 13th November 1733; Records of Fort St. George: Diary and Consultation book 1759. Reprinted 1953

[24] IOR/G/18/9 – Fort St. David Letters. 30th December 1735

[25] Diary and Consultation book 1736. Reprinted 1939, pp.171

[26] Despatches from England: 1737-1740. Reprinted, 1932, pp. 12

[27] IOR/G/18/4 – Fort St. David Consultations 1733. 13th November 1733; Records of Fort St. George: Diary and Consultation book 1759. Reprinted 1953

[28] IOR/G/18/4 – Fort St. David Consultations 1733. 13th November 1733

The next period of famine occurred in 1746. What little information was found about this event originated exclusively within the translated diary of Ananda Ranga Pillai, a dubash[29] in the service of the French East India Company at Pondicherry. It occurred during the first Carnatic war, fought between the British and the French East India Companies during between 1746 and 1748, and the consequences of the war feature equally as prominently as his reports of drought. For example, a message from the Governor of Pondicherry to the Nawab of Arcot reads, *"that what with famine and want of rain on one side, and war on the other, the country was being laid waste and the inhabitants were distressed"* (Pillai 1904: 219). In addition, he records abandonment of homes and farms by the Indian population because of troop movement around Pondicherry, stating, *"this circumstance is enough to cause neglect of cultivation. Add to this the failure of the monsoon. Throughout the country there is absolutely no sign of any agricultural operations. The residents of Porto Novo, including the merchants have left the neighbourhood and have gone to settle at Chidambaram"* (Pillai, 1904: 196).

The third famine within this period occurred in 1755; this is the least well documented. The famine followed exceptionally heavy rainfall during the northeast monsoon of 1754 (Chapter 3, Figure 3.7) "*which destroyed all the crops on the ground*" in Devakkotai and prevented the collection of taxes[30] and whose "*floods had carried away the factory house*[31] *at Porto Novo*"[32]. In December the following year, Fort St. David dispatched a request for a speedy supply of grain to prevent the inhabitants of the settlement starving[33]. Similarly, in Pondicherry, Ananda Ranga Pillai (1925: 1) writes, *"now the rains have failed, and famine has fallen like a mill-stone falling on a sore finger. I have dwelt here these 33 years but never have I seen so bad a year".* Little information beyond this is available.

The final famine in this period is akin to that of the second (in 1746). It occurred during the Third Carnatic War (1756 – 1763), during which French/British rivalries resumed in the Indian subcontinent (the Carnatic Wars are described in greater detail in Chapter 2, Section 2.4.1). A scarcity of food was recorded in Fort St. George while the town was under siege; this was attributed to the destruction of grain crops. In response, duties on import of grain supplies to British territories were completely removed, but, even with these measures in place, the stock remained insufficient to meet the demand[34]. In December of the same year, this scarcity is report to have deepened into famine, attributed to the failure of the northeast monsoon rains. During this time, exceptionally high grain prices were reported in Madras town, along with famine conditions from Cuddapah to Nellore (Pillai 1927).

---

[29] Interpreter

[30] Diary and Consultation Book 1755. Reprinted 1942

[31] 'Factories' are British controlled trading posts.

[32] IOR/G/18/8 – Fort St. David Consultations. 13th January 1755.

[33] IOR/G/18/8 – Fort St. David Consultations. 8th December 1755

[34] Records of Fort St. George: Diary and Consultation book 1759. Reprinted 1953; Records of Fort St. George: Letters from Fort St. George 1759. Reprinted 1942

During this pre-colonial period, it was common practice for the British Government to maintain a stockpile of grain, which was continually purchased on the Company's account when the grain price was low[35]. This purchase included the importation from British territories outside of Southern India. For example, instructions were sent to Bengal in 1737 that dictated that the frequency of famines in southeast India *"very much impedes our investment"* and as a result, Company funds were to be used to purchase grain to fill all spare cargo space with rice for the Coromandel Coast[36]. It was the intention that this stockpile of grain, which was to be sufficient for one season, was dispensed to the benefit of the Company's dependents in time of scarcity or famine[37].

Where possible, the Company Officials were instructed to sell the Company's grain at a profit[38], but at a price that did not detract from the welfare of the settlement[39]. An intended consequence of the sale of this grain during times of scarcity was the reduction in the market value of grain: *"It has always been usual to sell out rice when there is a scarcity as also at other times in order to lower the price of the market that the monopolisers of grain may not impose upon the poor inhabitants"*[40]. However, while under siege in 1759, this stockpile was distributed, at a reduced price, as a grain ration, as opposed to bulk sale in the markets. While this improved the immediate condition of those receiving rations, the supply was insufficient for all occupants and the demand remained very high. Furthermore, during the period the government actively prevented the stockpiling of grain by private merchants. For example, following the famine of 1736 the government forcibly diverted imported grain supplies away from major ports to encourage increased distribution of supplies[21]. In 1759, it was suggested that it "*may be necessary to strictly enforce the Laws against forestalling or engrossing provisions that the labouring part of the people may be supplied on the cheapest terms*"[41].

5.2.2 *East India Company expansion: 1767-1807*

This period encompasses all four Anglo-Mysore Wars, from 1767 to 1799, and the subsequent Governorship of Lord Wellesley (1798-1805) and his vast political and military conquests. It ends with the commencement of Lord Minto's governorship in 1807. During this period, there was a rapid expansion of British Territory and protected states in India, see Chapter 2, Figures 2.10a and 2.10b. Two widespread and very severe famines occurred in this period. The impacts and governmental responses during each famine was remarkably different; the first occurred during the second Anglo-Mysore war against Hyder Ali and his French allies, the second less than a decade after the cessation of the fourth war.

---

[35] IOR/G/18/5, Fort St David consultations, December 1743

[36] Despatches from England: 1737-1740. Reprinted, 1932 pp.24

[37] Despatches from England: 1734-1737. Reprinted, 1931 pp.65

[38] Despatches from England: 1734-1737. Reprinted, 1931 pp.126

[39] Despatches from England: 1737-1740. Reprinted, 1932

[40] IOR/G/18/5 - Fort St David consultations, 1743, pp.101

[41] Diary and Consultation book 1759. Reprinted 1953 pp. 214

The first famine occurred between 1781 and 1782. In the Report of the Indian Famine Commission the government states that it was *"Caused mainly by the devastation of the war with Hyder Ali, but partly by drought"* (Indian Famine Commission 1880: 9). The famine affected large tracts of the Carnatic region and all parties to the war had difficulty procuring and maintaining an army[42]. On the 31st of March 1781, details of the prevailing scarcity were sent from Madras to the Board of Governors, stating that the grain supplies were critically low, with not more than 42 days' supply available in Madras town (Love 1913). The agricultural output in parts of Bengal was good; however, the import of supplies was hindered by attacks from French troops on rice shipments and by storms in the Bay of Bengal that sank a number of ships headed to the region[43] (Marshman 1905). In May of the same year, a grain committee was established to control the distribution of the government's foodstuffs and to ascertain the stocks available in the city. Later, in July, the committee expressed their concern about the concealment of grain in the city and the detrimental effects of the government's price cap on the commodity (Dalyell 1867), suggesting that that the only method to bring out stockpiled supplies was to lift the cap (Love 1913). Grain was imported both on the Company's account and privately from those regions unaffected by the destructive Anglo-Mysore wars (Marshman, 1905; Love, 1913). In Madras town the demand for subsistence was severe and while food was distributed, the allowance was low; "*In a climate such as this, and even for men unemployed, the allowance of three quarts a day is surely very inadequate."* [44]. In 1782, Lord Macartney, then Governor of Madras, attempted to reduce the demand on the grain stores of Madras town by sending unemployed Indian inhabitants away from the town, *"where there was not work or food for them"* [45] over land, to less affected regions (Love, 1913). Similarly, a battalion of troops was relocated to regions where demand was lower[28]. In addition to food, the demand for water was also high and emergency engineering, such as the construction of temporary cisterns, was proposed by the Madras Engineering department[46].

Charity played an important role in the relief efforts during this crisis; donations were received from both Indian and European citizens for the general purchase and distribution of grain and also for the support of the relocation efforts described above (Love, 1913). At the close of the famine, a building (dubbed the Monegar Choultry) that had acted as temporary accommodation and a distribution centre for food to those in need, was donated to the government for use in future crises (Ahuja, 2002a; Dalyell, 1867). The agricultural output of the regions under British control was greatly reduced, during and after the immediate period of famine. For example, in Tanjore in the years 1781 and 1782 the annual output of grain was less than 20% of that reaped in 1780 and the harvest had still not recovered to pre-famine quantities by the end of the century. The Christian missionary Christian Friedrich Schwartz blamed the cause of prolonged agricultural stress on the depopulation of the region from war and the enfeeblement of the people through hunger and malnutrition (Hemmingway 1906). In October of 1782, Macartney

---

[42] The Gentleman's magazine and historical chronicle, vol 53. 1874.

[43] The Scots Magazine, vol 45. April 1783.

[44] Mack Gen 68 – Extracts from engineers, extract 16. 17th October 1782

[45] The Scots Magazine, vol 45. June 1783 pp 300

[46] Mack Gen 68 – Extracts from engineers, extract 17. 1782

wrote of the bleak prospects for the region, *"The re-establishment of peace, whenever it may happen, will therefore only give us the possession of a desolate and depopulated country, without the means of cultivation and, of course, without the capacity of yielding much revenue for many years to come."*[47]

The next famine occurred in 1806 and extended into 1807. The immediate cause of the famine was attributed by the Indian Famine Commission to the widespread failure of the monsoon rains across the eastern coast of peninsular India[48] (Indian Famine Commission, 1880; Garstin, 1878). During this event, the government was divided about the most effective measures for famine relief. The *laissez-faire* policy of non-intervention in the grain market as a method of famine management was gathering momentum in Anglo-Indian politics (Ambirajan, 1978) and the Board of Revenue were in support of these measures declaring in 1806 that:

> *"Convinced by observation and experience of the impolicy of the measures usually resorted to on the occurrence of the calamity of dearth, or famine and that any restrictions on the freedom of the grain market, whether by enforcing sale, limiting the price, or other direct interference with the speculations of private grain dealers are more calculated to aggravate than diminish the sufferings of the people."*[49]

From the outset, the government agreed to proceed with these principles. They expressed their reluctance to interfere with the grain market by any means, this included, fixing grain prices, prohibiting exportation and government importation and refusing payment in grain from public work schemes (Dalyell, 1867). However, the deterioration of the conditions in the Carnatic region prompted some late action by the government[50], who *"conceived it necessary to purchase* [grain] *guaranteeing a minimum price to importers"* (Indian Famine Commission, 1880) and proceeded to import *"large quantities of grain into the district for distribution"* (Garstin 1878: 195).

A grain committee was established to manage the grain market. Distribution of the government stockpile was withheld until the stores of the private traders dropped sufficiently low to drive the price up to a position when the government could profit from the sale of its own supply[51]. At this point, grain was distributed to the interior districts that had also been affected by the scarcity. Each of the districts in receipt of a supply were informed that grain was to be sold at

[47] Lord McCartney, to England. *Public Correspondence,* vol. cxxviii. Quoted in: *The Vestiges of Old Madras.* vol 3 pp. 235 (Love 1913).

[48] IOR/F/206 – Scarcity of Grain throughout the Madras Presidency owing to the failure of monsoon rains. 18th January 1807.

[49] Board of Revenue to the Governor 29 November 1806 *Madras Board of Revenue Proceedings.* Quoted in: Ambirajan, 1978 pp. 66.

[50] The Literary Panorama, vol 3. January 1808, pp. 846.

[51] IOR/F/4/207 – Proceedings regarding the management of grain supplies at Madras during the famine 1795-1807. 14th June 1807, pp. 239.

the same price as it was at Fort St. George[52]. At the close of the famine, from good rains during the northeast monsoon in 1807 (Chapter 3, Figure 3.7), they were left with a large stock, which ultimately had to be disposed of at a loss (Indian Famine Commission 1880).

Again, charity played an important role in the relief of the starving people. Subscriptions were sought from the public for the poor fund in support of grain distributions from the Monegar Choultry. In the apprehension of a severe scarcity, the committee declared that the primary application of the charity funds would be the supply of food[53]. Large numbers of famine victims migrated towards Madras town for support but many died on this journey[54]. In February 1807, the government established a scheme of relief works throughout the districts that were affected by famine. These works employed those who were able bodied and not otherwise able to find a means of income. The remittance for this labour was low, intended to be used exclusively for subsistence. The rationale for this low pay was to prevent those who could obtain food by any other means from attending the public works. After the establishment of the public works across the Presidency, the Monegar Choultry and the associated poor fund supplied only those who could not work, for reasons of *"infancy or extreme age, from infirmity, sickness, on any other cause, were unable to minister to their own wants"*[55]. The operation of these public works feature, to various extents, in every subsequent famine in the Madras Presidency.

5.2.3 *East India Company Rule: 1807-1858*

Following the substantial increase in British territory in Southern India, the period between 1807 and 1858 saw the East India Company ruling over a comparatively static territorial extent in the regions comprising modern day Kerala and Tamil Nadu. The period ends with the transfer of administrative and military powers to the British Crown following the Indian Rebellion of 1857. During this period, a further two famines are recorded and, on both occasions, government relief policies followed the *laissez-faire* tactics that were proposed by the Board of Revenue in the famine of 1806-1807.

In 1811 the northeast monsoon arrived late and was poor in some districts[56] (Dalyell, 1867). The northeast monsoon of 1812 was also scanty, and the *Government Gazette* reported that the supply of water held in the tanks was not sufficient for the annual usage, *"nor sufficient to render* [the inhabitants] *independent of supplies from quarters where grain may be abundant"*.[57] The Southern districts were particularly affected by the scarcity, and in 1812, the

[52] IOR/F/4/207 – Proceedings regarding the management of grain supplies at Madras during the famine 1795-1807. 23rd July 1807, pp.15; IOR/F/206 – Scarcity of Grain throughout the Madras Presidency owing to the failure of monsoon rains. 18th January 1807.

[53] The Asiatic annual register, or, a view of the history of the Hindustan, and of the politics, commerce and literature of Asia, vol. 10. (1808)

[54] The Literary panorama vol 3. January 1808.

[55] The Asiatic annual register or, a view of the history of the Hindustan, and of the politics, commerce and literature of Asia, vol. 10. (1808) pp. 311

[56] Government Gazette. 12th November 1812

[57] Government Gazette. 10th December 1812.

tax collector for Madura made a formal request to the board for the commencement of public works *"to give employment to those which may be in the state of distress"*[58]. During this famine, public works and remissions of duty on the import of grain were to be the only permitted methods of famine management. Dalyell (1867) reports that the collector[59] of the Canara district *"sent in proposals to store grain on account of the government, in order to provide against scarcities in future. His proposal did not however meet with the approval of Government"* (Dalyell 1867: 26).

The famine persisted into 1813 in the Southern Districts; the northeast monsoon again commenced later than average, but the quantity of rainfall was sufficient to allow cultivators to commence operations (Chapter 3, Figure 3.7). However, there followed a scarcity of rain for the month of October that *"raised the very general apprehension that the monsoon would fail altogether; and under that impression the shops in Tinnevelly are reported to have been shut for two days and grain only sold privately"* [60]. Conditions were similar in Madura, where little rain had fallen. A petition for a further scheme of relief works was made by the collector in order to prevent the emigration of the inhabitants[61]. In April 1814, the collector of Tinnevelly forwarded a request to import grain supplies from the neighbouring districts on the company's account, *"owing to merchants not bringing that supply which is necessary to markets"*[62]. Whether the request was met with approval is not reported.

The next major subsistence crisis occurred in 1833. *The Examiner*[63] and the *Madras Journal of Literature and Science* (Harriott, 1834) both list the immediate cause as the failure of the monsoon rains. The epicentre of the crisis was Guntoor (Indian Famine Commission 1880), which is located in the Northern districts of the Madras Presidency (Chapter 2, Figure 2.9). Despite this, there is evidence that scarcity extended further South into the region of Madras Town: "*Let it be remembered that the famine of 1833 was by no means confined to the Guntoor district. Many must have a lively recollection of its disastrous effects in other parts of the presidency, as well as of the multitudes that came in search of food to Madras itself, where some measure of relief was afforded to them"* (The Madras Journal of Literature and Science, 1844. P.188). On this occasion, the Indian Famine Commission state that the British Officials of the Madras Presidency were caught off guard, and they did little to alleviate the distress felt by the Indian population, except for organising provision of cooked food in relief houses (Indian Famine commission, 1880). In Guntoor, where the worst of the famine was felt, there were reports of substantial outward migration to regions that were better supplied. Migration to the town of Madras was so great that, in an attempt to control the spread of disease, the government requested that collectors forbid migration to the town, declaring that people should be fed in their local district (Dalyell, 1876). The price of rice was reported by *The Examiner* to

---

[58] IOR/F/505 – Boards Collections, extract 13, pp.12175

[59] Each district within the Madras Presidency was appointed a Collector who oversaw its administration.

[60] IOR/F/4/505 - Boards Collections, extract no. 9.

[61] IOR/F/4/505 – Board's collections, extract no. 3

[62] IOR/F/4/505 – Board's collections, extract no. 13 pp.12176.

[63] Examiner, issue 1352. 29th December 1833.

be very high in affected districts and the government, as was now customary, had applied no cap on grain prices. On the 19th of August 1833, discontent culminated in grain riots[64]. It is estimated that in Guntoor alone 150,000-200,000[65] people died from famine along with over half of the cattle, both working and dairy, and more than two thirds of the sheep and goats. The loss of the grazing animals was exacerbated by wildfires in the region (Harriott, 1844). As was the practice for the previous two famines, the Government forbade the importation of grain on the Company's account (Dalyell, 1876) and focused on providing employment in relief works and charitable distributions of food to the starving people.

The condition of the irrigation channels and their dependent tanks that supplied the region was reported to have been in *"utter decay and disuse"* prior to the Guntoor famine. Following the crisis *"the question of constructing [irrigation] works, with the view principally to the prevention of a similar occurrence for the future began to be seriously considered."*[48]. The reopening of both channels was completed in 1837 and 1838, and further works widening the channel – and construction of a new anicut[66] in the Kistna river with two new irrigation channels – was completed in 1855[67].

5.2.4 *Crown rule: 1858-1920*

This period begins with the transfer of administrative and military power to the British Crown and ends in 1920, with the end of the years consulted in this study. As in the previous period of Company rule, the British Territories in Southern India remained largely stable in extent. Three famines are recorded during this period, the first two of which largely followed the same *laissez-faire* principles as those in place during Company rule. The third fell after the introduction of the Indian Famine Commission and the establishment of new 'famine codes'.

In 1865 the southwest monsoon failed on the east coast of India, as it had the previous year in the Madras Presidency, causing widespread drought (Bellew, 1885). In 1865, this was exacerbated by a deficient northeast monsoon (Indian Famine Commission, 1880), which led to a severe famine in the North Indian territories of Orissa, Ganjam and lower Bengal. As early as 1865, the Madras police noted an increase in the number of suicides, which they claim was *"due in part perhaps to better observation, but chiefly to increased destitution"*[68]. In the first half of 1866, conditions deteriorated in the Southeast of the peninsula. In Coimbatore, North and South Arcot and Salem, the condition of those on a low income was reported as 'urgent'[69] and the starving were reported to have been foraging for sustenance (Dalyell, 1867). In Coimbatore, reports stated that some men *"were so weak that when they first come to the Public*

---

[64] Examiner, issue 1352. 29th December 1833.

[65] 150,000 is estimated by The Madras Journal of Literature and Science, 1844 and 200,000 by the irrigation department in IOR/C/141 - Report on irrigation works in India for the year 1875-76

[66] A dam made in a river, which feeds irrigation channels.

[67] IOR/C/141 - Report on irrigation works in India for the year 1875-76 pp. 33-34.

[68] IOR/V/24/3129 – Report on the administration of the Madras Police. 1865, pp.17

[69] IOR/V/26/295 – Selections from Despatches to India. 1867, pp.317

Works Department for work they have to be fed before they can be worked at all"[70]. A relief fund for the starving people in Madras town who were unable to work was established and public subscriptions were sought to increase the relief effort. As the famine increased in severity, the Madras Government sanctioned a payment to the charitable fund[53] (Dalyell, 1867). In spite of the crisis, the Revenue Committee declared that this charitable relief be limited wherever possible and that employment in public works should be the preferred avenue of aid[53], the payment for which during the 1865-1866 famine was *"unusually high"* (Indian Famine commission, 1880: pp. 12)

Rainfall was late and deficient in 1866 (Famine Commission, 1880) and grain maintained a very high price across the Presidency; in December 1866, the Madras Revenue department expressed concerns of the exhaustion of grain supplies in Arcot (Chapter 2, Figure 2.9) and the damage caused by famine prices[71]. In those nearby districts where stock was comparatively high, heavy grain exportation prevented the price from falling[72]. Emigration to regions better supplied with work and sustenance occurred, cattle were distressed, cholera outbreaks were prevalent in famine-stricken regions and grain riots occurred by those who were priced out of reach[53]. Remissions of revenue were granted to those affected by the famine, and duties on import and transportation of grain were removed to encourage the movement of grain (Dalyell 1867). However, the government stayed firm its intention to remain independent of the grain trade, and took no part in the importation of grain[73].

It should be noted that the distress during the famine of 1865-1867 was felt most significantly by those with a low income who were dependent on the grain market for food supplies (Bellew, 1885). During this famine, relief, in the form of food distribution, was restricted "*to the poor, who may, by age, sickness or other cause be unable to earn their subsistence by labour"*[74]. Further discussion in British Parliament suggested that in Coimbatore, some farmers had managed to profit from the prevailing period of drought:

> *"the high prices obtained for cotton and all kinds of agricultural produce within the last three years, has meant the ryots[75] (a large portion of them at least) have made considerable profits and been enabled to lay up money; so that if grain is to be had, they will be able to tide over the trying period before them. But the poorer ryots, and the classes dependent on daily wages, are likely to be great sufferers, as they look to the markets for their supplies. But, granted that the markets are well supplied, the failure of the rain has thrown many of the labouring people out of work, and thereby deprived them greatly of the means of purchasing food."* [76]

---

[70] Parliamentary Papers Vol 52, 1867, pp.35

[71] IOR/L/E/3/753 – Madras Revenue Department. 1867, no.13

[72] Parliamentary Papers Vol 52, 1867.

[73] Parliamentary Papers Vol 52, 1867. pp. 109

[74] Parliamentary Papers Vol 52, 1867. Pp. 62

[75] Peasant or tenant farmer. Subject to taxation.

[76] Parliamentary Papers Vol 52, 1867 p. 52

The second famine during this period occurred between 1876 and 1878. It was a devastating event that affected both Bombay and Madras (Stahl, 2016). The Madras Government attributed the immediate cause of this famine to the failure of the rains[77] (Indian Famine Commission 1880). Singh *et al.* (2018) have recently demonstrated that this famine fell within a period of multi-year drought that also prevailed elsewhere in Asia, Brazil and Africa and was concurrent with a strong El Niño, positive Indian Ocean Dipole and high tropical Pacific SSTs (Singh *et al.*, 2018). In India, this cocktail of climatic conditions, combined with political and economic failures, led to a humanitarian disaster on an enormous scale with loss of life in India alone estimated at 5.25 million people (Danvers, 1886). Both monsoons during 1875 were scanty and not widespread across the Madras Presidency; in some regions, such as North and South Arcot, Cuddapah and Bellary, the supply was poor enough to cause the failure of those crops not grown under irrigation[78] (Garstin, 1878). In 1876 the southwest monsoon, upon which the dry crop depended[79], also partially or completely failed over the Madras Presidency (Digby 1878). Prior to the northeast monsoon of the same year, small local relief works were established, but a petition from the Madras Government for the construction of a railway from Bellary to Gudunk to be undertaken as a large-scale relief work was declined by the president of the council of India. They cited their concern that the Madras Government had not sufficiently regarded their prior injunctions regarding the management of the famine event.

At the failure of the northeast monsoon, grain prices rapidly increased to famine levels (Digby 1878). Demand for food was very high, driving even wealthier individuals into relief works (Anon, 1877). In Madras, Bellew (1885: 44) recounts that, *"The only cheap food of an animal kind has been beef, and this has been cheap solely on account of the mortality amongst cattle, and the deficient supplies of fodder to keep them alive"*. There was substantial migration to larger towns where major food markets existed and relief measures were in operation. In the town of Madras, additional relief works were established to cope with the demand (Digby 1878). During the height of the famine, applications for subscription to relief works were exceptionally high and the provision of work and the project management of the schemes was in many cases, insufficient for such numbers[61] (Digby 1878; Bellew 1885). In an attempt to control the numbers employed in public work schemes, remuneration was cut from a fixed price to a variable level that intended to reflect the prevailing grain prices. However, the scheme received widespread criticism, with numerous opponents expressing concerns that the rate of remuneration fell below a subsistence rate and as such the scheme was abandoned three months after its introduction (Indian Famine Commission, 1880). In addition, poor sanitation and overcrowding contributed to severe outbreaks of cholera[60] and fevers (Digby 1878; Dyson 1991). The severity and length of the drought affected even well-irrigated districts that were thought to be immune to drought: *"Such a universal drying up of the tanks, for which the*

[77] IOR/V/6/304 – Selections from Despatches to India. 31st July 1876

[78] IOR/F86/179 – Report on the 1877 famine, 1877.

[79] IOR/V/6/304 – Selections from Despatches to India. 1876

districts below the Ghat mountains are so celebrated, has hardly been witnessed within the memory of living men." [80]

In light of the crisis, the Madras Government began to purchase grain. The course of action was in conflict with the Council of India who were conclusively against such actions. Despite this, the Madras Government stated their concern for the continual supply of food, at an accessible price, for those dependent upon relief works for their subsistence (Digby 1878). The newly appointed Viceroy of India, Lord Lytton, was a passionate advocate of the *laissez-faire* approach to famine management[81] (Davies, 2002). He condemned the Madras Government for this early activity by stating in a telegram to the Council of India that: "*we have instructed the Government to abandon this policy, and shall take means to make publicly known intention to leave trade unfettered"*[82]. Forbidden from further interference, grain supplies in the Madras presidency were dependent solely on private importation by rail and sea, driven by high famine prices[83]. Indeed, larger, well-connected, towns were supplied with adequate grain[84]; however, the prices to the consumer were exceptionally high and, with the private trade unchecked, the exportation of food grain out of India persisted, largely to Europe and China (Indian Famine Commission, 1880) despite widespread suffering and starvation.

As with previous famines in the nineteenth century, charity played a large role in the alleviation of distress. In the early stages of the famine, in 1866, private charity prevailed, despite pressure on the government to begin an organised scheme of relief (Digby, 1878). As the scarcity deepened in the Madras presidency, the Viceroy of India declared that the government could not, or would not cope with the financial demand of supporting the Indian population. In a telegram to the Council of India Lord Lytton states: *"Considering that the revenues are barely sufficient to meet the ordinary expenditure and heavy additional taxation, both financially and politically impossible, the task of dealing with famines and saving life, irrespective of cost, is beyond the power of the government"*[85].

Early recovery efforts during the northeast monsoon of 1877 were hindered by the lack of agricultural machinery, including bullocks, available to farmers. Added to this, the poorer farmers struggled to purchase the necessary seeds (Digby 1878). Much of what did grow suffered from blight, plagues of locusts and irregular and damagingly heavy rains[86]. As a result, Southern India was on the brink of descending into a further period of crisis in late 1877. Despite a below average harvest (Indian Famine Commission 1880) the relief effort was scaled

[80] IOR/C/140 - Memoranda and papers laid before the Council of India 19 Oct 1876- 8 Mar 1878 pp.167

[81] IOR/C/140 – Minute by His Excellency the Viceroy. 12th august 1877.

[82] IOR/C/140 - Memoranda and papers laid before the Council of India 19 Oct 1876- 8 Mar 1878 pp.373

[83] The Times of India. 21st November 1877.

[84] IOR/C/140 - Memoranda and papers laid before the Council of India 19 Oct 1876- 8 Mar 1878

[85] IOR/C/140 p. 5- Memoranda and papers laid before the Council of India 19 Oct 1876- 8 Mar 1878, pp. 5.

[86] The Times of India, 11th December 1877. IOR/C/140 p. 5- Memoranda and papers laid before the Council of India 19 Oct 1876- 8 Mar 1878

back; the number of people on relief works or receiving gratuitous relief reduced from 2,332,112 in September 1877 to 483,755 at the end of December 1877 (Digby 1878).

Despite the extent and severity of the famine event, the government expenditure on famine relief per capita was lower than the preceding famine of 1873-1874. The famine of 1873-1847 affected the Northern territories of Behar and Orissa and reportedly affected 17 million people. Extensive relief efforts were put in place to preserve life, amounting to 6.5 million pounds. Following the 1873-1874 famine, the Council of India declared that measures should be taken to provide for famine relief within the ordinary expenditures of the country and that the expenditure associated with famine relief *"should no longer be permitted to add to the permanent debt of the country"* (Indian Famine Commission, 1880: 32). The 1876-1878 famine of Southern India 1876-1878 was estimated to have affected 36.4 million people, and the relief effort incurred an expenditure approaching 8 million pounds (Indian Famine Commission, 1880). Using these statistics, the total expenditure on famine relief per capita during the 1876-1878 event was 42% less than during 1873-1874.

Following the disastrous famine of 1876-1878 the Indian Famine Commission was established in order to *"collect with the utmost care all information which may assist future administrators in the task of limiting the range or mitigating the intensity of these calamities"* (Famine Commission, 1880: 1). The provincial famine codes were generated as a result of this endeavour; they instructed the respective governments in the best practice for the mitigation of the effects of famine and were followed for subsequent famine events[87]. In Madras, the codes stipulated that the major method of relief was to remain the operation of famine relief works, with relief kitchens distributing cooked food to those who could not work. A special request was to be required for any gratuitous relief measures where food was provided directly to the houses of the poor.

The famine codes were employed in 1891, the next famine event reported in the region. The famine prevailed in the Madras Presidency, predominantly felt in the central Carnatic districts (Indian Famine Commission 1898). Both English and Tamil language newspapers, including *The Times of India* and *The Vettikkodiyon*, attributed the irregular rains of the northeast monsoon of 1890 as the cause. The northeast monsoon began exceptionally heavy in October before becoming dry for the remainder of the season. There was a poor harvest, which extended into irrigated regions[88]. Prices rose and there were reports of migration from rural villages to larger towns with a better supply of imported grains, or further, to countries such as Sri Lanka and Singapore[89]. The southwest monsoon of 1891 was late, intensifying the subsistence crisis in the central districts (Famine Commission, 1898). The northeast monsoon rains of 1891 were also poorly timed for cultivation[90] and the prevailing scarcity deepened. High grain prices prevailed until April 1892 when good rainfall alleviated the distress (Indian Famine

[87] IOR/V/27/831/40 – Madras Revenue Department, Famine code, madras Presidency 1883.

[88] IOR/L/R/5/106 – Newspaper reports 1891-96. 10th January 1891. Translated by the Madras Government.

[89] IOR/L/R/5/106 – Newspaper reports 1891-96 10th February 1891. Translated by the Madras Government.

[90] IOR/L/R/5/106 – Newspaper reports 1891-96. 13th December 1891. Translated by the Madras Government.

Commission 1898). In June and July of 1891 there are reports of wildfires north of Madras town, and in Coimbatore there were reports of a growing scarcity of drinking water that forced local people to travel up to a mile and a half for the next supply[91]. The scarcity of food-grains drove some individuals within the poorer classes on to a diet of non-nutritious and foraged foods[92].

Relief works were established in the most affected regions. The highest number of applications for work were received in Chingleput and North Arcot. Relief kitchens were also established; however, their usefulness was publicly questioned a number of times in local newspapers, which suggested that they were of little use to those in remote villages and that the funds involved in operating the kitchens could be better spent by providing grain at low prices directly to the people[93]. The relief works attracted less labour than anticipated by the government; this was attributed to high levels of outward migration to less-affected districts, low subsistence wages within the relief works and better preparation for agricultural stress by local people (Indian Famine Commission, 1898). However, an excerpt from the Tamil newspaper, the *Swadesamitran,* expresses concerns that the relief works were not operated as they once were, focusing on smaller operations and drawing attention to the difficulty in obtaining work[92].

During the scarcity of 1891, there are multiple reports of the burden of high taxes on the farmers. In Chingleput, tax was not remitted and those who could not pay had "*their cattle, cooking utensils and even the doors of their dwelling houses … distrained for arrears of revenue*"[94]. In January 1891, a translated newspaper excerpt reports that in Pollachi, near Coimbatore, *"there is now a dearth of food grains and fodder for cattle in these parts; and in consequence people are obliged to sell their cattle in the local fairs at very low prices for maintaining themselves. Besides many of the ryots [are] trying to abscond in order to escape the payment of the government kist[95]"* [96]. In November 1891, an excerpt from a translated Tamil newspaper, *the Swadesamitran* noted, *"Merciless officials have let loose on society inhuman maniyamdars[97] for the purpose of ringing out the kist from people, who, misled by the recent scanty rains, sold their cattle for using the proceeds in the purchase of agricultural implements"* [98].

5.3 Evolution of the key government response methods to famine

Throughout the study period, numerous changes occurred in the political and social structures in southern India. Some of them were large, such as the militarisation of the East India Company and the subsequent conquest of Indian territories; 1767-1799 saw vigorous fighting in the region and large transitions in power. In addition, there were some more protracted

---

[91] IOR/L/R/5/106 – Newspaper reports 1891-96. 1st July 1891. Translated by the Madras Government.

[92] IOR/L/R/5/106 – Newspaper reports 1891-96. 15th June 1891. Translated by the Madras Government.

[93] IOR/L/R/5/106 – Newspaper reports 1891-96. 1st January 1892. Translated by the Madras Government.

[94] IOR/L/R/5/106 – Newspaper reports 1891-96. 17th July 1891. Translated by the Madras Government.

[95] Fixed price for government land rent

[96] IOR/L/R/5/106 – Newspaper reports 1891-96. 2nd January 1891, pp.8. Translated by the Madras Government.

[97] These were village management fees.

[98] IOR/L/R/5/106 – Newspaper reports 1891-96. 20th November 1891. Translated by the Madras Government.

changes, such as the evolution of the hierarchy of British Indian governance. The political responses during famine events varies considerably throughout this period. From the discourse that was analysed for this research, the primary political responses fell into two groups, a) trade and distribution of food grains, b) relief works and charitable efforts. The contribution of each group to policy and procedure is different for each famine event; however, some broad trajectories can be noted within the archival data.

5.3.1 *Trade and distribution of food grains*

Government presence in the grain market was far more prevalent in the eighteenth and early nineteenth century, prior to and during the first major colonial expansion in Southern India. This earlier approach of government activity largely mimicked those practices of the previous native rulers (Sarada, 1941). Evidence of market manipulation measures from this research included reducing or eliminating duties on importation of food grains, fixing grain prices, price manipulation through sale of private stockpiles, and the active prevention of grain stockpiling by traders. In 1774, during a period of scarcity, a great dispute erupted between the Nawab of Tanjore and the British Government, following a request made by the British for a cap on grain price and assistance from the Nabob's grain stores[99]. These actions during a period of scarcity are a marked contrast to later proclamations of the value of *laissez-faire* principles, which were more commonplace in nineteenth century politics. Ahuja (2002a) suggests that this tendency towards interference may have been encouraged, to some extent, by a sense of responsibility to those in British settlements and the need to maintain a living standard sufficient to encourage a viable workforce. Evidence of this demand for a sufficient workforce in the early period was found in the archival materials, for example, taxes were lowered substantially in Fort St. David to encourage the settlement of skilled labourers who were sparse in the region of town[100]. However, this 'interference' was also largely an artefact of the government's own speculation in the grain market. A popular quote from the collector of Tanjore, written in 1807 reads, "*the grain market has never been free for many years. The Sircar[101] has always had grain of its own in the store and constrained the market*" (Ambirajan, 1978 p.67, Raju, 1941, p.248). Speculation in the grain market by governments was commonplace in the early period[102]; as a result, the government acted as a dual force, both in a political and private entity. In contrast to the famine events of the nineteenth and twentieth centuries, the government openly acted as an opponent to grain merchants during this early period, chiefly to check market control and the high prices of grain[103].

Significant political reform occurred at the turn of the nineteenth century, following the rapid acquisition of territory and protected states (Love, 1913; Muir, 1917). A full exploration of the

---

[99] MSS EUR E379/8 – Patterson's Diary

[100] IOR/G/18/4 – Fort St. David Consultations 1733. 13th November 1733; Records of Fort St. George: Diary and Consultation book 1759. Reprinted 1953

[101] The term Sircar is used to represent the government or ruling power.

[102] IOR/G/18/5 – Fort St. David Consultations. December 1743

[103] IOR/G/18/5 – Fort St David Consultations. December 1743; Diary and Consultation book. January 1736. Madras Records Office (1736)

reform is beyond the scope of this thesis; however, during this time considerable changes in the political approach to famine management occurred. Chief among these changes was condemnation of interference in the grain market by government officials, who claimed that such practices only exacerbated scarcity. L*aissez-faire* was founded on the belief that private trade was best placed to import large quantities of grain, and that government importation monopolised the means of conveyance, thus limiting the power of those private traders. The Madras Board of Revenue, who were vehement and early supporters of the principles of *laissez-faire*, went so far as to declare government interference in the grain trade a *"restriction on natural liberty… and an infraction of public justice"* (Ambirajan 1978: 66). Despite these proclamations, the withdrawal of government support was not immediate; the famine of 1806-1807 was the final example where government policy had not abolished interference in the grain trade. Following this change in procedure, the role of the government was relegated primarily to relief operations and the assistance of private trade. However, the removal of taxes on the importation of grain remained common practice throughout the study period, as did the reduction or the temporary removal of land taxes on the agriculturalists. During the 1876-1878 famine, Lytton and Richard Temple outlined the scope of the government actions during periods of famine:

> *"early and correct information as to process and means of carriage should be published. The carrying power of railways and canals leading into the famine tracts, should be reinforced; tolls and other restraints on free intercommunication should be removed; roads into the interior should be improved and kept in order; rates of railway or other carriage might be reduced; and, in cases of extreme necessity, temporary railways or tramways might be laid into populous tracts, whereto means of communication failed, or were insufficient"* [104].

The rapid increase in the price of grain during times of hardship was almost ubiquitous throughout the famine history, although the extent of these price increases were not consistently quantified and so it is challenging to detect more subtle changes in the influence of famine policy on the price of grain. However, during the 1876-1878 famine Lytton supported these high grain prices, suggesting that they acted as a natural rationing force to "curtail consumption"[105]. However, during this crisis, these uncontrolled grain prices were reported to have climbed to four or five times that of normal rates[106], and they caused substantial suffering to those dependent on the grain market, particularly those living hand-to-mouth. Similar difficulty was described regularly throughout the study period, for example, in 1838, an excerpt from a letter written by Julia Maitland, the wife of a British Civil servant in the Madras Presidency, reads: *"They are so screwed by high taxes, higher than the land will fairly bear, that they never have a farthing in hand"* (Maitland, 1846: 109).

---

[104] IOR/C/140 – Minute by His Excellency the Viceroy. 12th August 1877. pp. 6

[105] IOR/C/140 – Famine telegrams to and from India. 16th January 1877. Pp. 5

[106] IOR/C/140 – Minute by His Excellency the Viceroy. 12th august 1877.

Frequent references to the influence of the grain traders on the price of rice were made throughout the study period, for example, in 1890; local newspapers complained that *"the grain dealers aggravate*[d] *the situation by taking advantage of the distress and selling grain at high prices"*[107]. Similarly, in the famine of 1865-1867, the Madras Revenue Department reported that merchants had been purchasing grain at wholesale prices in order to command the market during the coming scarcity. In 1833 *"exorbitant prices"* of rice, which British journalists declared to be the result of collusion by the grain merchants, were said to have fuelled grain riots in the markets, which were plundered for their stock[108]. Similar accusations were also made against local government prior to the adoption of *laissez faire* principles. In 1733, Benjamin Schultze accused the authorities of hoarding grain; *"There is therefore great dearth; for at such times those in authority store the grain to sell it as dear as they can. They see many dying from hunger but their hearts are not softened into pity for the poor"*[109]. To what extent these accusations against grain traders are true is not clear from the archival material.

5.3.2 *Relief works and charitable efforts*

As the government withdrew their support for the interference in the grain trade as a means of famine management, relief operations in the form of employment on public works became more common, targeted at the most vulnerable poor. This approach to famine management was first used by the British government in the Madras Presidency in 1792, during a famine that prevailed in Ganjam (Chapter 2, Figure 2.9) (Indian Famine Commission, 1880; Danvers, 1886). Following this, government managed relief works were used in every subsequent famine that affected the Tamil Nadu region in this study period. Applications for employment on public works were received from those whose means of obtaining subsistence were eliminated during time of social or climatic stress. According to British Parliamentary reports in 1866, this was largely comprised of the landless labouring classes, particularly agricultural labourers, whose means of earning a living stalled as agricultural operations and employment opportunities reduced in time of hardship[110]. The most effective structure of relief works, based on cost of operation against the benefit of the starving people, was a frequent object of discussion between government officials (Indian Famine Commission, 1880), and one that appeared to undergo considerable changes based on the political structure of the time. For example, during the famine of 1866-1867 the government advocated the use of numerous smaller relief operations, distributed throughout the most affected districts stating that *"it is advisable to avoid as much as possible the collection of large bodies of labourers [and] it is not desirable that they should be required to leave their homes"*[111]. Yet in the following famine

[107] L/R/5/106 - Newspaper reports 1891-96. August 8th 1891.

[108] The Examiner 1833. December 29, pp. 824

[109] Observation from the diary of Benjamin Schultze, reprinted in: Notices of Madras and Cuddalore in the last century. Published 1858

[110] Parliamentary papers vol. 52 - Papers relating to the Famine in Madras and Orissa. August 1866.

[111] Parliamentary papers vol. 52 - Papers relating to the Famine in Madras and Orissa. 25th July 1866. pp.35

of 1876-1878, Lytton disapproved of the operation of smaller works, particularly during the early stages of a famine, in favour of fewer, larger relief operations[112]

Similarly, the rate of remuneration for work was often the subject of debate. The most well documented example of this occurred during the 1876-1878 famine, during which controversial experimentation with reduced subsistence wages is thought to have resulted in increased mortality and chronic health conditions (see Hall-Matthews (2008) for a comprehensive summary of the dispute). A standard rate for payment was not established in policy until the first report of the Indian Famine Commission in 1880 in which the minimum amount of food required to sustain the life of a working male was deduced to be 1.5 pounds of flour. Payment, in coin, was recommended to be sufficient to provide for this quantity, in addition to enabling the purchase of essential sundries, such as salt, pepper and firewood.

Government operated relief works were subsidised by charitable efforts to relieve the suffering of the starving poor. Until the latter half of the nineteenth century, charitable relief efforts were both funded by native officials and the public[113]. The first example of governmental contribution to charity in this study came during the famine of 1866-1867, when a payment was sanctioned to assist an existing charitable fund. In the following famine of 1876-1878, pressure was placed on the government to provide correct and proper guidance to the public and local governments for the distribution of charitable funds to those who could not work[92]. Lytton, cautioned against heavy expenditure on charitable relief efforts, citing fears of indiscriminate governmental charity adding to the financial burdens of the country[114]. However, Government charity did occur during the famines of 1876-1878 and 1891 and took two forms; the first, was the distribution of food grains to housebound inhabitants, and the second the provision of cooked food at relief camps or poor houses.

5.4 Famine and drought

The political and social crisis of famine occurred frequently within the 191-year study period. In the Tamil Nadu region alone, eleven events are sufficiently well documented within the archives to provide evidence of some impacts on society and the primary colonial responses. This list is not exhaustive, as there are a further three years in which a famine is recorded in historical documents, but with insufficient detail to confirm the extent, severity or social impacts of the event. This section discusses the relationship between these famine events and drought, specifically the relationship as presumed by colonial voices. Chapter 6, Section 6.2.2, goes on to expand this argument by using the new documentary reconstruction to investigate the relationship between northeast monsoon rainfall and famine. Together these sections address the final question of this research.

[112] IOR/C/140 – Minute by his excellency the Viceroy. 12th August 1877. pp.2

[113] IOR/C/140 – Charitable Contributions from the Public for the Relief of the Famine-Stricken Poor. W. Muir, 28th March 1877

[114] IOR/C/140 – Famine telegrams to and from India. 21st January 1877.

The primary colonial narrative recorded in conjunction with each famine event throughout the study period was that these devastating periods of social crisis were caused by failures in monsoon rainfall, both in magnitude and timeliness. In eleven of the fourteen famine years captured in the documentary sources, failure of monsoon rainfall is directly referred to as the cause of the prevailing famine and in the remaining three insufficient rainfall is lamented. In 1878, the Indian Famine Commission was established. In its introductory passage is a statement of intent to protect the people of India *"from the effects of the uncertainty of seasons"* (Indian Famine Commission, 1880: 1). Similarly, the "*periodical scourge of famine*"[115] was seen by numerous colonial actors as an unfortunate but natural aspect of the unique monsoon climate. This belief that droughts cause famines was perhaps so pervasive because of the sensible connection between the two. A successful growing season was largely dependent on sufficient rainfall; this was exacerbated for the dry crops - those that are not grown under irrigation. Comments on the sight of crops "*withering*" in a dry season[116] or those that were parched or dried up for want of rain[117] are prevalent. Equally so, are the accounts of the effect of good rains and concurrent plentiful crops[118]. At the close of the 1812-1813 famine, it was "*the ... rains [that] brought sufficient grain into market*"[119] – not the traders, the government or the farmers, but the rains themselves.

By reinforcing this causal link between meteorology and famine, the East Indian government naturalised famine events and sidestepped the responsibility to take action to prevent famines (Davis, 2002; Hardiman, 1996; Mahony & Endfield, 2018). An excerpt from *The Bombay Times and the Journal of Commerce* encapsulates this argument: *"can the Governor and council command the clouds of heaven that they shall pour down showers on the Earth, when He who alone can give the early and the latter rain"*[120]. Furthermore, where natural forces are to blame for the cause of suffering, the efforts of the government could be portrayed to the public in both India and Britain as heroic in their philanthropic efforts to reduce the suffering of the people in the face of such natural disasters (Ahuja, 2002a). For example in 1808, the British newspaper, *The Literary Panorama*, reported to the British Public that in the response to the famine in the Madras Presidency, *"Lord Bentinck ... is doing everything in his power to alleviate the miseries of the wretched sufferers*"[121].

This deterministic narrative dominates in the colonial documents considered for this research. However, as was also found by Major (2019), there is a significant collection of records in which contemporary voices criticise the government's lack of foresight, citing factors beyond drought that influence the severity and extent of famine events. These were largely recorded

---

115 Bombay Times and the Journal of Commerce. 7th October 1846. pp 702.

116 IOR/F/4/505 – Boards collections. Extract 3. 23rd December 1813; The Times of India. 23rd November 1897.

117 Benjamin Schultze in *Notices of Madras and Cuddalore in the last century.* 20th December 1733; The Diary of Ananda Ranga Pillai vol. 3. 10th January 1747. Translated by Henry Dowdwell.

118 Report of the administration of the police. Madras police department; Government Gazette. 26th November 1812.

119 IOR/F/4/505 – Boards collections. Extract 9. November 1813. pp. 12175.

120 Bombay Times and the Journal of Commerce. 5th of October 1836.

121 The Literary Panorama, vol 3, January 1808. pp.846

in the nineteenth and early twentieth centuries as the Indian nationalist movement gathered momentum (Haridmann 2002; Hall-Matthews 2008; Major, 2019; Suntharalingam, 1974). Prominent campaigners from this period included Romesh Dutt, Wlliam Digby and Charles Bradlaugh. Within this research, the most significant topics were the government's failure to maintain adequate irrigation or water storage systems, as in *The Argosy*: *"the remedy for such deep and wide-spread distress is perfectly plain ... works of irrigation are not only indispensable to the welfare of the people of India, but they are enormously profitable when constructed"*[122]. The second being heavy tax burden on those with a low income, which impoverished Indian farmers, leaving them vulnerable to high grain prices during famines, as reported in the *Times of India: "the people in India are grievously oppressed and wretchedly poor. This is to be traced to the enormous taxation of the East India Company"*[123].

In addition to critique of the government's assertions of a causal connection between drought and famine, its famine-policy was also a topic of debate. As described in Section 5.3, following the 1806-1807 famine the government adopted a *laissez-faire* approach to famine management; it relied on private trade to supply famine demand, and placed its own resources into famine relief. However, the ability of private trade to effectively meet the demand of the famine stricken regions was questioned repeatedly (Ambirajan, 1978; Hall-Matthews, 2008; Stahl, 2016), not least due to the high mortality that persisted during Indian famine events despite the adoption of *laissez-faire* techniques (Dasgupta, 1993). Such critique was most prominent in the mid-late 19th century, as famines across India became increasingly regular (Mishra, 2013). In this research, dissent from the government's famine policy was frequently found in English language newspapers. For example, in 1846, an excerpt from the *Bombay Times and the Journal of Commerce,* written by a correspondent reads: "*But the fact is that in most parts of the country there is abundance of grain during the worst famines. It is not that the grain is consumed, but it is because it is not available to the poorer portions of the population, that the people starve*"[124]. While this is short of blaming the government for the existence of famine, it does imply that the non-intervention of government in the grain trade exacerbates severity of the event.

Criticism of hard-line *laissez-faire* politicians such as Lord Lytton, Richard Temple and John Strachey became most prominent at the end of the nineteenth century famine (Davis, 2002; Stahl, 2016; Suntharalingam, 1974; Washbrook, 2004). At this time, a number of politicians and civil rights activists lobbied parliament in both Britain and India for better famine policies with which to protect the people of India from famine, in addition to the relaxation of *laissez-faire* policies (Digby, 1878; Dutt, 1901; Bradlaugh, 1890). Similarly, during the disastrous 1876-1878 famine, the Governor of Madras, in contempt of policy, imported grain supplies to the Presidency[125] (Davies, 2002; Stahle, 2016). Despite this activism, the Indian Famine Commission, and the subsequent famine codes, detailed a famine management policy which was largely rooted in *laissez-faire* principles (Indian Famine Commission 1880;1898).

[122] The Argosy: a magazine of tales, essays and poems. 1866, volume 2 issue 12.

[123] The Times of India. 17th December 1904. pp. 9.

[124] Bombay Times and the Journal of Commerce, October 7th 1846 pp. 702

[125] IOR/C/140 - Memoranda and papers laid before the Council of India 19 Oct 1876- 8 Mar 1878 pp.373

5.5 Summary

This chapter presents an account of eleven famine events that affected past societies within the region of contemporary Tamil Nadu between 1730 and 1920: 1733-1736, 1746, 1755, 1759; 1781-1782, 1806-1807, 1812-1813, 1833, 1865-1867, 1876-1878, 1891. The data for each instance of famine are taken from the physical and digital archives described in Chapter 2. There was a paucity of information about non-European individuals and communities, which was a result of the bias within the English language colonial documents towards governmental records; however, good information concerning the primary political responses to famine was available. The details of each instance of famine, as described in the archives, are provided alongside the primary government responses. While it is difficult to establish an accurate indicator of the severity of each event because of changes in famine management and reporting, the severity of the 1876-1878 famine and its exceptionally high death toll was pivotal in Indian famine politics, after which the Indian Famine Commission was established.

The most substantial changes in the government's approach to the mitigation of famine events occurred at the turn of the nineteenth century during which time the territories and political influence of the East India Company expanded considerably. In the eighteenth century, the primary mitigation measures included the reduction or elimination of the import tax, fixing of grain prices, maintaining emergency stockpiles and market manipulation, which included the prevention of stockpiling by private grain merchants. Evidence suggests that these policies largely imitated those of the local Mughal and Maratha rulers. Furthermore, during this early period a scarcity of labour within the British territories drove considerable governmental efforts to increase the immigration of skilled labourers to the regions, in addition to a number of policies that sought to retain inhabitants during subsistence crises.

The assimilation of several districts into British control in the early nineteenth century resulted in substantial changes in the political structure of the Indian rural countryside and the land tax regime. The concept of the *laissez-faire* policy of non-interference in the grain trade became prevalent within governmental discourse. *Laissez-faire* was centred on the logic that in times of scarcity, increased prices would lead to greater importation of grain from regions better supplied by private merchants. Under this principle, any governmental presence in the market, by means of grain supply, price caps or the prevention of exportation, would act as a deterrent for private importation. The famine of 1806-1807 was the first example during which famine mitigation relied on *laissez-faire* principles. However, as the famine deepened, the government reverted to its original practices, leading to a large surplus of stock and political embarrassment. Despite the consistent failure of the *laissez-faire* policy to prevent mass mortality during famine events in the Tamil Nadu region, the concept remained at the heart of famine mitigation measures until the end of the study period.

Following their use by the Madras government in the famine of 1792, relief works became ubiquitous in the Tamil Nadu region. The scope of these works and their management underwent numerous changes throughout the study period that appear to have been dependent on the ideology of the senior political powers. For example, the preference for smaller, local relief works over larger schemes reverses over the course of a single famine event. Similarly, regular reassessments of what constituted a sufficient subsistence wage were made throughout the study period. The minimum amount of food required to sustain life was not fixed until the Indian Famine Commission report of 1880; the variable price of grain and other sundries that were to be included in the remuneration (such as salt, pepper and firewood) still left room for fluctuation in the wage. In the latter half of the nineteenth century the government acknowledged its responsibility for those starving people who could not work. This led to the establishment of a scheme of charitable relief, including distribution of food to housebound individuals and cooked food within relief camps and poor houses. These government-funded charitable efforts were only seen in the famines of 1876-1878 and 1891.

Throughout the study period, the concept that droughts were responsible for famine is often repeated and is most prevalent within governmental documents. However, despite the greater volume of documents that reinforce this concept, there is also a smaller body of transcriptions that critique this deterministic attitude. These documents cite political failure as a means of causing or contributing to the severity of famine events. Section 5.4 focused on the portrayal of this relationship within the transcriptions. The following chapter will build upon this, using the new reconstruction of northeast monsoon magnitude along with the famine history created here to investigate the influence of both socio-political and monsoon failures on the manifestation and magnitude of famine events.

Chapter 6: Discussion

This research has explored the capacity of colonial documents to improve the knowledge of historical monsoon magnitude in southern India, and the relationship between drought, famine and colonial responses as told through these documents. This chapter brings together the main findings from each of three main components of this research: the terrestrial documentary reconstruction of the northeast monsoon over modern day Tamil Nadu, the seasonal monsoon reconstructions over both Kerala and Tamil Nadu and finally, the famine history of Tamil Nadu. This chapter will demonstrate how historical climatology, which weaves together the physical and social sciences (Allan *et al.*, 2016; Pfister, 2010), can be used to further the understanding of past interactions between climate and society.

6.1 Reconstructing the monsoon

The first aim of this thesis was to explore the possibility of reconstructing historical monsoon magnitude using two distinct forms of documentary data: wind data from within ships' logbooks and the qualitative and early instrumental data within colonial texts. This section discusses the key findings that became apparent while pursuing this aim.

6.1.1 *Terrestrial documentary reconstruction methods*

Chapter 3 sought to answer the first research question by investigating whether the data contained within documentary records is sufficient to reconstruct the northeast monsoon magnitude over Tamil Nadu. The reconstruction is the first of its kind for the state and only the second performed in India, the first being Adamson and Nash's (2014) reconstruction of the southwest monsoon over western India. Exploratory archival work was performed to determine the viability of the reconstruction based on the number of records that contained information about historical monsoon activity. Despite being limited to documents written in the English language, considerable data was found to be extant through having been preserved in physical and digital archives. Fort St. George, whose construction began in 1639, was one of the earliest trading outposts of the East India Company in modern India. As a result, some of the earliest examples of administrative documents and accounts can be found for this region. Due to time constraints, this research consulted documents from 1730 onwards; by this point, both Forts St George and St David were well established. However, serial government documents exist prior to this date, particularly, *letters to (from) Fort St. George* and *The Diary and Consultation Book.* Documents such as these offer the potential to extend the historical reconstruction into the seventeenth century.

The calibration and five-point index scale (Chapter 3, Section 3.3.1) used to translate the archival data into a reconstruction of monsoon magnitude largely followed that of Adamson and Nash (2014). This was to ensure that this new reconstruction remained comparable with their series for the southwest monsoon in Western India. Together, these reconstructions partially alleviate the dearth of information regarding past monsoon variability in India, however, despite these studies, there is still considerable work to be done. Historical climate reconstruction efforts in tropical regions are still under-developed in relation to equivalent studies in Europe, the Americas and China (Grab & Nash, 2010; Nash & Adamson, 2014). In order to increase the understanding of past monsoon rainfall over all India, a greater spatial coverage in the reconstructions is required. Happily, throughout the course of the historical data collection, good resources were found for numerous regions across India, for example, from the Bengal Presidency, which became the centre of British political power in India. Records from other regions that had colonial interests, such as Myanmar and Malaysia, also had a strong archival presence. The Madras Presidency itself has also not been exhausted; due to both time and financial constraints, this research neglected archives in India that contain British-era documents that were not transmitted to the London East India Offices. Furthermore, the region focused on here was contemporary Tamil Nadu. From the nineteenth century onwards, the Madras Presidency extended into the modern states of Kerala, Andhra Pradesh and Hyderabad (Chapter 2, Figure 2.1). Additional information from these regions could improve the understanding of past all-India rainfall and the wider dynamics of the Indian monsoon.

While the reconstruction method used in this thesis remained close to that of Adamson and Nash (2014), two additional procedures were included in order to increase the reliability of the reconstruction. These were researcher agreement testing (Chapter 3, Section 3.3.1) and the application of confidence values (Chapter 3, Section 3.3.4), both procedures being presently underutilised in historical climatology. Both methods seek to prevent the transfer of errors from studies that use historical documents into future work. For example, Garrison *et al.* (2018) have recently suggested that an erroneous diary account may have led to the misattribution of strong volcanic activity in 1831 to Babuyan Claro. The first of these methods, researcher agreement testing, is an additional step during the calibration period. It seeks to improve continuity with wider historical climate studies by identifying poorly aligned calibration codes. Following Nash *et al.* (2016), multiple researchers who are familiar with the field independently classify a sample of transcriptions that have been randomly selected from the database. The calibration codes are readdressed as necessary following the results of the procedure. Researcher agreement testing is a simple but valuable procedure that can increase the overall quality and reliability of the indexing procedure. In this research for example, the consistent under-evaluation of extremely wet years led to the amendment of the calibration codes. Secondly, the application of confidence values to the reconstructed seasons is an effective method for identifying those data points that have a higher chance of being correct (and conversely those that are based on limited or lower quality data). This is determined based on the apparent limitations of the raw data, which may be temporally or spatially isolated, or may originate within sources that have recognised problems associated with them. In the case of this research, personal correspondence was found to have an increased potential for exaggeration. This simple confidence scale balances the demand for longer, more complete records of past monsoon variability and the quality and quantity of the data available to achieve this (Kelso and Vogel, 2007). These values are becoming increased better utilised in a number of tropical historical climatology studies, most notably for southern Africa (Grab and Nash, 2010; Kelso and Vogel, 2007; Nash *et al.*, 2016, 2019).

6.1.2 *Logbook reconstruction methods*

Chapter 4 focused on the second research question by investigating the potential to use historical records of wind strength and direction contained within ships' logbooks to reconstruct northeast monsoon magnitude. The reconstruction process used two statistical methods that are widely employed in climate reconstructions: composite plus scale (CPS) and principal component regression (PCR) (Ho *et al.*, 2015b; Jones *et al.*, 2009; Neukom *et al.*, 2011). Barrett *et al.* (2017) employed CPS for the first time with regard to logbook reconstructions and found it to be an effective method in those years with a reduced spatial field and reduced temporal availability compared to PCR. These findings are supported by this research, where the PCR method failed to produce a reconstruction that was better than the climatology.

The models for both statistical techniques were developed in the modern period between 10m u and v wind components from the ERA-Interim reanalysis data set (regridded to a coarser resolution suitable for use with logbook data) and modern instrumental rainfall from both Kerala and Tamil Nadu. This method is often used when insufficient data exist in the early period for an adequate calibration of the predictor series (Barrett *et al.*, 2018b; Hannaford *et al.*, 2015a). The ERA-Interim dataset and the modern instrumental data share a 36-year overlap, which creates a short calibration period. Following Jones and Widmann (2003) and Schmith and Hansen (2003), in order to maximise the number of years that could be included in this calibration, a verification period was not segregated; instead, the cross validation technique was performed to determine the fit of the model (Chapter 4, Section 4.3.1). However, while the crossover period (1871-1920) between logbooks and instrumental rainfall was insufficient for calibration, it did provide a valuable opportunity to validate the models by analysing the fit between each state's rainfall and the logbook-derived rainfall reconstruction. An important finding that resulted from this opportunity was that the cross-validation technique was not a good indicator of the overall success of the final model. In the calibration period, the CPS model fitted to the northeast monsoon for Kerala was the most successful with an r^2 value of 0.74, however, when applied to the logbook data, it failed to yield a reconstruction that was better than climatology. This suggests that the cross-validation technique may not be an effective measure of the model's ability to transfer the relationship between modern wind and rainfall data to the historical logbook series.

This research has performed the first exploratory test of reconstructing Indian monsoon rainfall using both wind speed and direction derived from ships' logbooks. Therefore, comprehensive threshold testing was carried out in order to determine the minimum number of logbooks per grid box per season required to make a reliable reconstruction. There is currently no standard threshold for this figure, which varies depending on the regional climate under reconstruction. Previous examples ranged from 3 data days per grid per season (Küttel *et al.*, 2010; Neukom *et al.*, 2014) to 10% of the target season length (Hannaford *et al.*, 2015a). As far as we are aware, no threshold testing was used in these previous studies. Following Barrett *et al.* (2018) the fitting and reconstruction process was performed using randomly selected daily wind data from ERA-Interim at sample sizes ranging from one day to a complete season. The fitting and reconstruction were performed 100 times at each sample size and validation statistics performed on the results. The number of data days required per grid box was taken as the minimum number of days required to produce a significant correlation with rainfall and to generate an ensemble mean RE score greater than zero; indicating a reconstruction that performs as well as or better than the climatology. Despite the mean RE score being in excess of 0, the variability within the ensembles was exceptionally high, for example, for Tamil Nadu, reconstructed using CPS, applied to u winds, the RE scores at mean 0 ranged between ~ +/- 0.5 (Chapter 4, Figure 4.16). This variability indicates that, despite meeting the threshold minimum for data days, there is still a possibility of error. The cumulative density function of the ensemble RE scores for the threshold minimum for the above model states that there is a 24% chance that it will be below zero. The chance of a spurious reconstruction increases at half of this threshold minimum; with a 54% chance of an RE score below zero. Despite the increase in the probability of spurious reconstruction, the possibility of a skilful reconstruction still exists. To reflect this possibility, and to maximise the number of years captured in the reconstruction, the threshold minimum values were converted to confidence values, with the lower confidence reflecting the increased probability of a spurious reconstruction.

6.1.3 *Comparing the terrestrial and marine documentary reconstructions*

The characteristic wind patterns associated with monsoon systems, coupled with active shipping routes, makes them a desirable target for logbook reconstruction techniques (Gallego *et al.*, 2017; Vega *et al.*, 2018). The semi-instrumental data within ships' logbooks is independent of the terrestrial sources used in this thesis and the second research question of this thesis sought to evaluate the potential of reconstructing monsoon magnitude from this new source. However, as also found by Ordonez *et al.* (2016), a long-term pre-instrumental reconstruction was not possible. The documentary reconstruction correlated with monsoon rainfall between 1871-1920 at 0.74, statistically significant at $p<0.05$. The logbook reconstruction of the northeast monsoon season, created using the CPS method, also correlated significantly ($p<0.05$) at 0.36 over the same period.

A number of elements within the reconstruction may have led to the reduction in skill of the logbook-derived data at capturing historical northeast monsoon rainfall. The first and most prevalent is the change in the temporal and spatial domain of the raw logbook-derived data. As mentioned above, due to data availability, both the PCR and CPS models used in this reconstruction are fitted in the modern period under ideal circumstances of a complete spatial and temporal domain - this was rarely the case with the logbook data. It was hoped, as with Hannaford et al. (2015), that the use of seasonal means in both the calibration and reconstruction periods would reduce the impact of substantial changes in the wind field. Figure 6.1 shows two examples, just 30 years apart, which demonstrate the variability in data availability. In the first example (1916), a number of ships traverse the study area, and only one day of 92 is without data. In the second example (1876), the data input is sparse, comprised of just two ships, which travelled through the region in November. In this instance, the former is more likely to capture intraseasonal changes than the latter due the improved data availability.

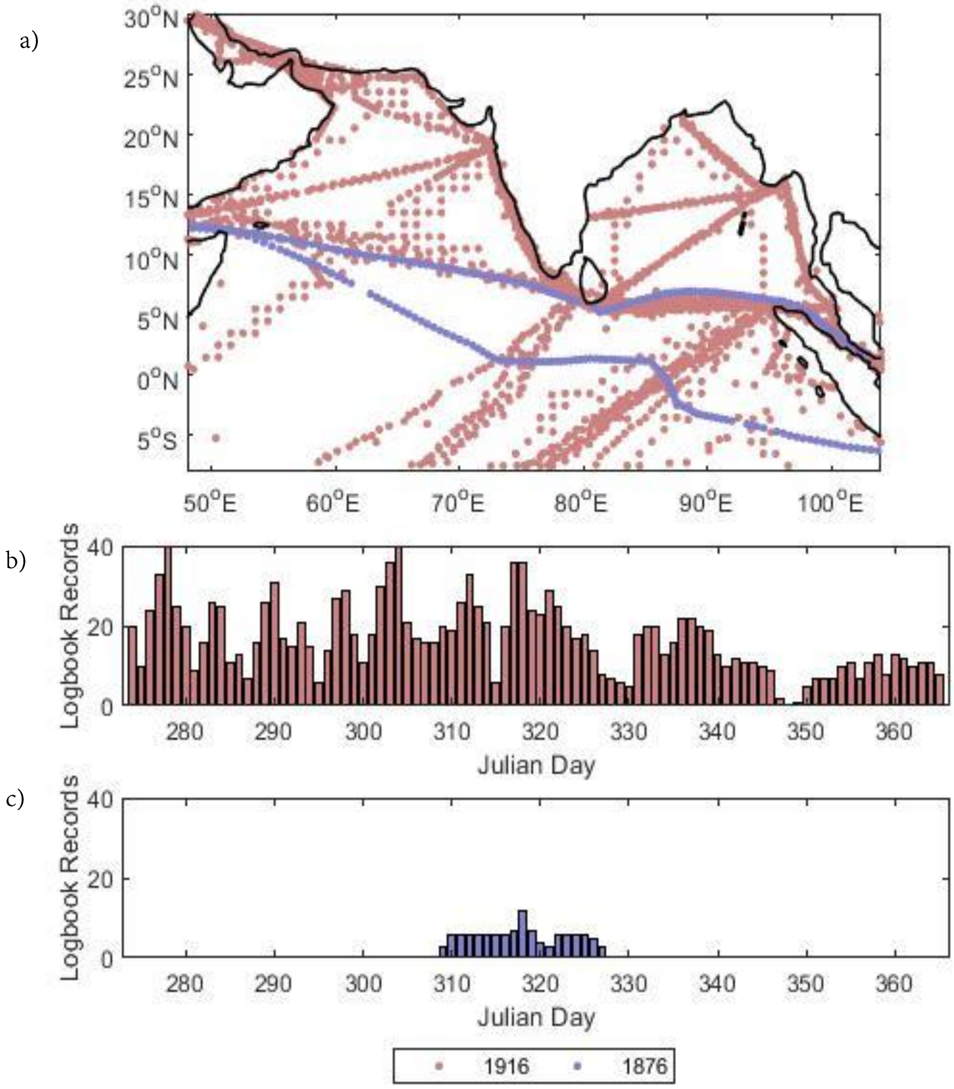

Figure 6.1 - a) distribution of logbook data during the northeast monsoon seasons of 1916 and 1876, b and c) represent the temporal distribution of logbook records for the same years respectively.

According to the threshold testing procedure employed in this research, the data demand is high. This is likely caused by the need to adequately capture the intraseasonal variation displayed in active and break cycles, characteristic of the Indian monsoon season. Figure 6.2 compares the mean and standard deviation of daily rainfall over Tamil Nadu between 1981-2010 during the northeast monsoon with the summer rainfall zone of South Africa during November-March and the North Atlantic region 40W-50E and 20N -70N in all four seasons; Winter (December –February), Spring (March-May), Summer (June-August) and Autumn (September-November). Both of these regions have been the targets of skilful logbook reconstructions by Hannaford *et al. (2015)* and Küttel *et al.* (2010) respectively. The data for Figure 6.2 was derived from *CPC Global Unified Precipitation data (*https://www.esrl.noaa.gov/psd/*)*. The variability in daily rainfall over Tamil Nadu during the northeast monsoon season is indicative of the challenge of creating a reliable seasonal mean with fewer data days aver the season.

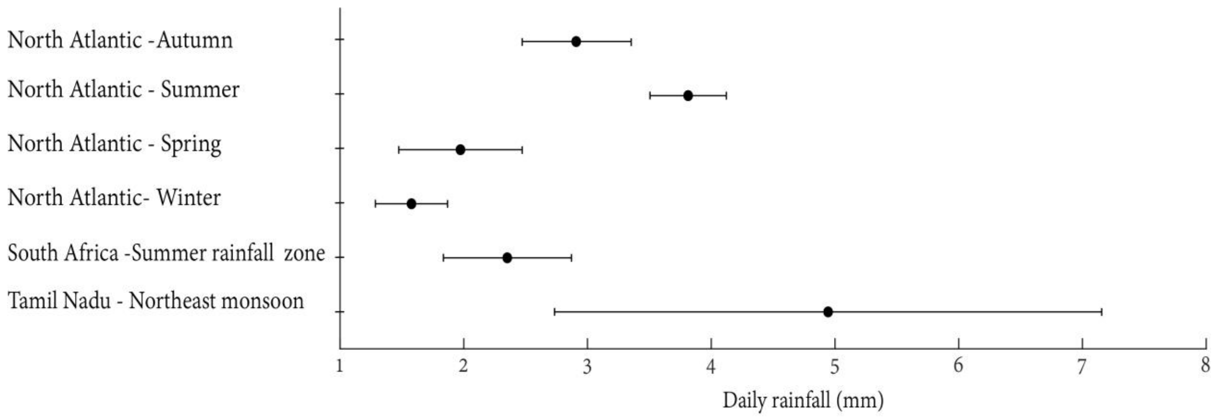

Figure 6.2 - The mean daily rainfall (shown as a dot) and +/-1 standard deviations (shown as tails) for seasonal north Atlantic rainfall, summer rainfall in the summer rainfall zone of South Africa and northeast monsoon rainfall over Tamil Nadu. Daily rainfall data derived from gridded CPC Global Unified Precipitation data (*https://www.esrl.noaa.gov/psd/*).

Historic spatial and temporal variability is not unique to logbook derived data: the terrestrial documentary data analysed in Chapter 3 is subject to the geographical biases expressed in colonial settlement patterns (Fenby & Gergis, 2013; Prieto & García Herrera, 2009). Prior to the nineteenth century, British settlements were a component of the East India trade, located on the coast; chief among these were Fort St. David and Fort St. George. As the British presence in India grew, the area covered by the documentary records also expands. However, as discussed in Chapter 5, the British population in India remained small. Much of the archival data collected for this research maintained a bias towards major British forts and trading towns, particularly Madras town. This bias is unavoidable, particularly when dealing with data of a colonial origin (Fenby and Gergis, 2013); however, as in previous studies that have faced similar challenges, such as Kelso and Vogel (2007) and Grab and Nash (2010), cases of spatially isolated raw data are evidenced by lower confidence values.

The terrestrial reconstruction appears to be more effective at handling these spatial differences, perhaps due to the detailed investigation of the annual evidence for each season. This can be demonstrated using the examples from Figure 6.1 of the years 1916 and 1876. When degraded into index values, the reconstructed rainfall for 1916 is classified as normal, matching both the modern instrumental data and documentary reconstruction. However, the reconstructed value for 1876 suggests a normal year with an index value of 0, whereas, both the modern instrumental and the documentary reconstruction suggest an extremely deficient year (-2). Interestingly, the logbook data was recorded in November, during which time the documentary data reports isolated rainfall on the southeast coast of Madras and over Sri Lanka[126]. The easterly path of the two ships traverses this region at this time (Figure 6.1). Therefore, it is likely that this reconstruction is biased towards this localised rainfall, whereas widespread

[126] IOR/V/24/231 – Report on the meteorology of India. Henry F Blandford. Written in 1878.

deficiency of rain was reported across the Presidency for October and December and the season was described as a failure, so acute that the chief food crops failed[127].

The demand for high data inputs is acknowledged by others who have studied monsoon regions (Gomez-Delgado *et al.*, 2019; Vega *et al.*, 2018). Despite this, data availability and distribution cannot be solely responsible for the issues with the logbook reconstruction for the Indian monsoon region. For example, during the fitting and verification period performed between spatially and temporally complete ERA wind data and modern instrumental rainfall data from Tamil Nadu, the residual variability from both the CPS and the PCR models was high (62% and 68% respectively). This suggests that while seasonal reversals in wind direction are characteristic of the monsoon, more detailed intraseasonal changes such as the frequency or magnitude of active and break cycles may be poorly captured at the spatial and temporal resolution that the logbook data demands. The use of logbook data in monsoonal regions is still a new field and this study has demonstrated that traditional reconstruction techniques (Barrett *et al.*, 2018b; Hannaford *et al.*, 2015a; Jones & Salmon, 2005; Küttel *et al.*, 2010; Neukom *et al.*, 2014) may be less effective for reconstructing the Indian monsoon. In light of this finding, caution is advised when performing logbook reconstructions in climates with a high intraseasonal variability. However, as a greater volume of logbook data is transcribed and assimilated into ICOADS, experimentation with higher spatial and temporal resolutions would be of great interest.

6.1.4 *Extending the understanding of northeast monsoon magnitude*

The terrestrial documentary reconstruction of northeast monsoon magnitude is the first of its kind for South Peninsular India, therefore, obtaining equivalent series for comparison was challenging; this was exacerbated by the failure of the logbook reconstructions explored in Chapter 4. Walsh *et al.* (1999) used sources independent of this reconstruction to create a chronology of heavy rainfall, drought, floods and cyclones for 29 years. There was 64% agreement for high and low rainfall years between the documentary reconstruction and that of Walsh; the most common disagreement was a record of heavy rainfall in the Walsh *et al.* (1999) chronology that corresponded to normal rainfall in the present reconstructed northeast monsoon, for example in 1735, 1747, 1776, and 1794. Despite evidence of good agreement between the two series, the reconstruction created in this research handled documentary data in a very different manner to Walsh *et al.* (1999) who presented a chronology, exclusively comprised of extreme events as reported in historical documents.

The longest instrumental rainfall series for south India within peer-reviewed literature covers 1813-2005 (Sontakke *et al.*, 2008). However, this series combines both Kerala and Tamil Nadu – each with different rainfall regimes – before resolving the dataset annually, obscuring the contribution of the northeast monsoon contribution over Tamil Nadu. It is therefore not suitable for comparison. Similar challenges were faced when attempting to compare the new reconstruction with dendroclimatic reconstructions. Dendroclimatology in tropical regions is

[127] IOR/C/140 - Memoranda and papers laid before the Council of India 19 Oct 1876- 8Mar 1878

challenging and the process is still in its infancy in peninsular India (Bhattacharyya *et al.*, 2007; Borgaonkar *et al.*, 2010; Ram *et al.*, 2011; Sengupta *et al.*, 2018). There are no independent dendroclimatic reconstructions of the climate of Tamil Nadu available to researchers, neither are there any assimilated into the gridded Monsoon Asia Drought Atlas (Cook *et al.*, 2010).

This inability to verify the new reconstruction against an independent long-term data set is a limitation for this study; however, the dearth of appropriate seasonally resolved rainfall reconstructions available for Tamil Nadu highlights the value of this new reconstruction. Similar difficulties were experienced when attempting to investigate historical northeast monsoon variability in relation to past ENSO dynamics. A number of attempts have been made to reconstruct past ENSO variability; two were chosen for comparison with the documentary reconstruction of northeast monsoon magnitude in Chapter 3, Section 3.5.3; Emile-Geay (2013) and Wilson *et al.* (2010). Each of the ENSO reconstructions chosen were calibrated to SSTs from the Niño 3.4 region. Central Pacific ENSO has been shown to correlate more strongly with northeast monsoon variability (Nair *et al.*, 2018). Both reconstructions had a limited latitudinal extent, +/- 35° from the equator, however, Wilson *et al.* (2010) focused exclusively on proxy data from the Tropical Pacific Ocean. There was no long-term relationship between either ENSO series and the reconstructed northeast monsoon magnitude. However, there was some evidence of a cyclical pattern in the strength and direction of the trend between the monsoon magnitude and ENSO phase, which has been previously detected (Adamson & Nash, 2014; Maraun & Kurths, 2005; Torrence & Webster, 1998). This cyclical relationship was most prominent between the new northeast monsoon reconstruction and the Wilson *et al.* (2010) ENSO reconstruction, suggesting that the Tropical Pacific proxies used in their study were the most effective at capturing monsoon teleconnections. However, the trend was only significant at the 0.05 threshold during three short periods of positive correlation; 1767-1773, 1959-1971 and 1966-1981.

6.2 The monsoon and society

The famine history of contemporary Tamil Nadu presented in Chapter 5 addresses this research's third research question and summarises eleven episodes of famine between 1730 and 1920. During periods of social crisis such as warfare and/or famine, data availability within historical documents is perceptibly higher; this is likely to be a consequence of their longevity and financial burden when compared to other disasters such as floods. This section summarises the empirical information that was collected from the archives during historical famine events and discusses the complex, and often contentious, relationship between drought and famine (Akerkar, 2015; Damodaran *et al.*, 2019; Slavin, 2016) from the perspective of this interdisciplinary study.

6.2.1 *A famine history*

Each of the eleven famine events described in Chapter 5 present a unique profile of society in crisis. A detailed understanding of the social dynamics is encumbered by the colonial origin of the documents consulted for this work. However, the data collected and described in this study responds to the demand for more empirical data concerning social responses to climate extremes (Bavel *et al.*, 2019; Carey, 2012; Nash *et al.*, 2018). Furthermore, it contributes to a greater understanding of historic famine events in eighteenth- and nineteenth-century Tamil Nadu, which have attracted less scholarly attention than their Bengali counterparts (Ahuja, 2002a). The data form a platform from which a more comprehensive understanding can be built as additional data from more diverse perspectives are sought out in future research. Table 6.1 provides a simple and concise summary of the direct social and political impacts and responses during each famine event that were explicitly reported within the historical documents consulted in this research. In each case, simple descriptors are used to identify responses and impacts. The political responses to famine are well discussed in Chapter 5 and do not require further elaboration here. However, brief details of each of the categories used in Table 6.1 are provided in i-vii; some categories are grouped for ease of the narrative.

i) Death – Disease - Urban Disease Outbreaks

Reports of death, either from starvation or *disease* during famine events, were prevalent but not ubiquitous throughout the record; they became remarkably more common during the nineteenth century famine events. In these later cases the government's efforts to quantify the effects of Indian famine events led to an increase in the number of attempts to estimate famine death tolls (Mitra, 2012). Here, the term *estimation* should be emphasised: death tolls reported in official documents were often unreliable, failing to capture the deaths that occurred in rural areas, or of those who perished migrating from region to region (Hall-Matthews, 2005). Similarly, reporting deaths from starvation were compounded by the relationship between acute malnutrition and the consequent susceptibility to disease (Davis, 2002). Frequent references to the effect of over-crowding on the spread of contagious diseases in urban areas during famine times is summarised in Table 6.1 as urban disease outbreak.

ii) Migration to Less Affected Regions - Migration to Urban Regions - Urban Crowding

Migration, as a response to famine is recurrent throughout history and across the world (Sadliwala, 2019). Dyson (1991) describes it as a routine response to South Asian famines. Hall-Matthews (2005) and Adamson (2014) both report widespread migration as a response to famine in Western India. Similarly, Ahuja (2002a) found it to be one of two of the most prevalent responses to famines in the latter half of the eighteenth century in Tamil Nadu. Famine-induced migration is reported in eight of the eleven famines described in Chapter 5. The response is not consistent in each event but can be grouped into three categories: a) short-term outmigration from rural areas to better supplied urban regions; b) permanent or long-term outmigration to areas less affected by famine; and c) governmentally subsidised outmigration to less affected areas. Of the three categories, the last is least prominent, with only one record in the archival documents, occurring in 1782. Typically, short-term migration to urban areas is more prevalent than long distance migration to less affected regions (Maharatna, 2014). The recurring records of urban crowding due to increased population density during times of famine suggests that the pattern of South Indian famine-induced migration largely conforms to this generalisation.

iii) Rural Depopulation - Death of Livestock and Working Cattle

Rural depopulation is a broad category that is largely a response to the two former categories. It is explicitly referred to in the historical record in those cases where significant mortality or outmigration has occurred in rural regions. This includes people driven from their homes in times of war. Within the historical record, rural depopulation is often attributed to a reduction in agricultural activities, and in 1781-1782, depopulation and increased sickness was thought responsible for the slow recovery to pre-famine harvest levels (Pearson, 1835: 224).

iv) High grain prices - Grain Riots - Foraged Diets.

Reports of rapid increases in grain price of and high grain prices are almost ubiquitous in the nineteenth-century famines in Tamil Nadu where the prices of grain and market speculation were both unregulated by government. These price shocks are characteristic of numerous Indian famines of the *laissez faire* era of famine management (Adamson, 2014; Hall-Matthews, 2005; Stahl, 2016). Civil discontent during times of scarcity or unaffordable grain could culminate in grain riots where the public seized and removed grain supplies. Furthermore, faced with scarcity, multiple references are made to poor communities turning to a foraged diet. Foraged foods, such as the fruits of wild cacti, often offered a low nutritional value, and some were even indigestible or mildly poisonous (Gupta & Kanodia, 1968).

v) Debt Bondage

A person could sell themselves or their children to a creditor during times of famine in return for supplies and financial support. This was to be returned by the close of the season, and the individuals were not permitted to leave the bounds of their creditor until all debts were paid. Despite the prevalence of debt bondage in historical Tamil Nadu (Ahuja, 2002a, 2002b; Carswell & De Neve, 2013), this research only found evidence of the practice during one famine event (1733-1736). This may be an artefact of the inherent colonial bias of the documents, where community scale responses such as these are often poorly represented.

vi) Private Charity

Acts of private charity are well described in Chapter 5; they often played a large role in the mitigation of suffering and mortality during famine events throughout the study period. The most prominent scheme of organised private charity described within the archival material was the poor fund, which supported the distribution of food supplies and the provision of shelter from the Monegar Choultry. Petitions for public support for charitable efforts were made both in India and Europe. Digby (1878) also describe wealthy merchants or nobles feeding impoverished people from their own stocks. Acts of charity such as these also occurred alongside smaller scale familial and social support networks, however, these community scale responses are poorly represented in the archival material. Table 6.1 refers to all charitable efforts outside of state-relief.

vii) Limited Access to Drinking Water

Limited access to drinking water refers to a decline in the availability of essential drinking water during famine episodes. This includes the necessity for long distance travel to a clean water source or overcrowding at local wells or tanks. Colonial texts, including those written retrospectively, focused more heavily on food availability, impacts on agricultural practices and the financial expenditure during famine events; there are relatively few references to the challenge of accessing clean drinking water during a famine event.

Table 6.1 - The social and political impacts and responses recorded during historical famine events in Tamil Nadu between 1730 and 1920

Famine Years	Social impacts	Social responses	Political responses	
1733-1736	High grain prices	Debt bondage	Importation of grain	
	Death	Migration to urban areas		
1746	Rural depopulation	Migration to less affected regions	-	
1755	-	-	Importation of grain	
1759	Rural depopulation		Importation of grain	Government distributed grain rations
	High grain prices		Import duties removed from grain	Regulation of private grain trade
1781-1782	Rural depopulation	Private charity	Importation of grain	Price cap on grain
			Grain committee	Government led emigration
1806-1807		Migration to urban areas	Importation of grain	Relief works
		Private charity	Grain committee	
1812-1813	High grain prices		Relief works	Import duties removed from grain
1833	Death	Migration to urban areas	Provision of cooked food	Relief works
	Urban crowding	Grain riots	Migration to Madras prohibited	
	Death of livestock and working cattle	Migration to less affected regions		
	High grain prices			
	Urban disease outbreak			
1865-1867	Death	Migration to less affected regions	Relief works	Import duties removed from grain
	Disease outbreak	Grain riots	Remission of taxes	
	High grain prices	Private charity		
		Foraged diet		
1876-1878	Death	Urban disease outbreak	Relief works	The creation of the Indian Famine Commission
	Death of livestock and working cattle	Private charity		
	High grain prices		Importation of Grain	
	Urban crowding			
1890-1891	High grain prices	Foraged diet	Relief works	Provision of cooked food
	Limited access to drinking water	Migration to less affected regions		
		Migration to urban areas		

6.2.2 *Monsoon failure and famine*

Chapter 5, Section 5.4 discussed stance of the East India Company who defended concept that famines were caused by failures in the monsoon rainfall and subsequent agricultural deficits. Despite an overall increase in irrigated agricultural land during the study period (Ludden 1979; Hardiman, 2002), rain fed agriculture was, and still remains, an important industry on which many people in Tamil Nadu depended for income, employment and resources (Akerkar, 2015; Kumar & Parikh, 2001). As discussed in Chapter 5, Section 5.3, the sensitivity of agricultural output to changes in rainfall was sufficiently compelling for many in the East India Company to declare famines a natural disaster. For example, in 1880, the Indian Famine Commission (p. 27) wrote:

> *"In Madras and Mysore, if the crops grown under the south-western monsoon are lost, much may be retrieved if the N.E monsoon is good and fills the tanks and river, so that a large area of rice land can be artificially irrigated; if this too fails, no crop will come in materially to assist the people till the succeeding autumn. Experience shows that extreme pressure does not arise till local have been somewhat reduced, and famine is thus hardly known to begin, as a consequence of a failure of the south-west monsoon, before the month of November."*

The new long-term reconstruction of northeast monsoon magnitude created in Chapter 3 demonstrates that all famine events detected in the historical records coincided with at least one year of below average northeast monsoon rainfall (Figure 6.3). However, neither extremely deficient northeast monsoon rainfall nor recurring deficiencies were certain to occasion a famine event. Interestingly, examples of famine events that occur in conjunction with extremely deficient years appear to reduce over time. Between 1730 and 1800, six of the seven documented famine events coincide with an extremely deficient monsoon in their first or only year (Figure 6.3). However, in the period between 1800 and 1920, the same is only true for four of the seven famine events, despite there being a further five northeast monsoon seasons classified as extremely deficient. In this latter period, it was more common for a famine to occur during or following successive drought years, as was the case for five out seven famine events. Cumulatively, reduced northeast monsoon rainfall prevailed during the first or only year of famine in twelve of the fourteen famine events during the study period, the two exceptions being the famines of 1781-1782 and 1865-1867, which each commenced during a season of average or above average rainfall (Figure 6.3).

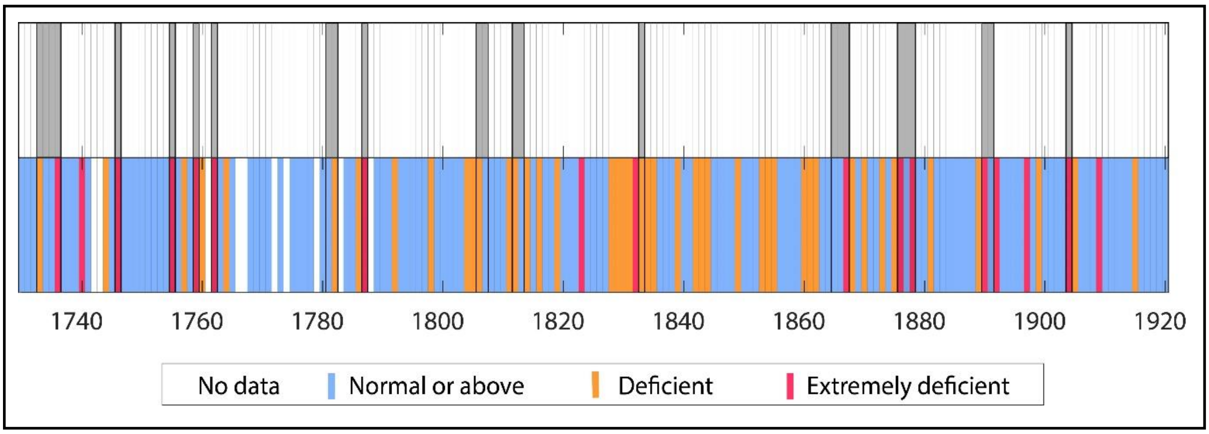

Figure 6.3 – The relationship between low rainfall and famine in the region of contemporary Tamil Nadu between 1730 and 1920. Deficient and extremely deficient northeast monsoon seasons, classified as -1 and -2 in the reconstruction are represented as orange and red bars respectively. Normal, above average and excess rainfall are all shown in blue. Famine events detected in the literature are outlined on the series in grey, and shown above for clarity.

The first of these exceptions, the famine of 1781-1782 occurred during a period of warfare between the East India Company and the Kingdom of Mysore (Chapter 2, Section 2.4.1), during which the Mysore battle tactics focused on intercepting supplies, destroying stocks and reducing agricultural capabilities. Scarcity of food was exacerbated by the demand of feeding a large army[128]. A deficient the northeast monsoon in the subsequent year apparently heightened the deficit of food and water[129].

During the famine of 1865-1867, neither of the first two northeast monsoon seasons were reconstructed as deficient. However, the Indian Famine Commission stated that it was the lateness of the monsoon rains that caused the distress, particularly so in 1866 (Indian Famine Commission, 1880). Chapter 5, Section 5.2, presented evidence from the documentary material that described the detrimental effect of poorly timed rainfall on agricultural output, both during this famine and during others within the study period, such as 1812-1813 and 1891[130]. The seasonal resolution of the northeast monsoon reconstruction can obscure this intraseasonal variability. However, in this case, the early instrumental data, collected from the Madras Observatory (Chapter 3, Section 3.3.2) can be used to investigate distribution of rainfall.

Figure 6.4, shows the weekly rainfall anomaly at Madras between 1865 and 1867 relative to the 1861-1890 mean. In 1865 the rainfall was below average throughout October, suggesting a late northeast monsoon onset. In 1866 following a dry southwest monsoon, the northeast monsoon was timely, but was followed by below average conditions in November. In both years, high

[128] The Gentleman's magazine and historical chronicle, vol. 53. 1874.

[129] Mack Gen 68 – Extracts from engineers, extract 17. 1782

[130] IOR/L/R/5/106 – Newspaper reports 1891-96. 13th December 1891. Translated by the Madras Government.; Government Gazette. 12th November 1812

rainfall anomalies occurred in December. Both monsoon seasons of 1867 were below the average, with the departures from the mean most severe during the northeast monsoon. This concurs with the manifestation of the famine event decribed in the archives, where distress amoung the poor was reported as early as 1865[131], but increased in severity quite rapidly in 1866, where foraged diets were reported along with accounts of severly malnourished individuals reporting to relief works[132]. The famine was already fully manifested by 1867 when the reconstruction records the first deficient monsoon. This suggests that, as stated by the Indian Famine Commission, poorly timed rainfall is likley to have contributed to famine during this period.

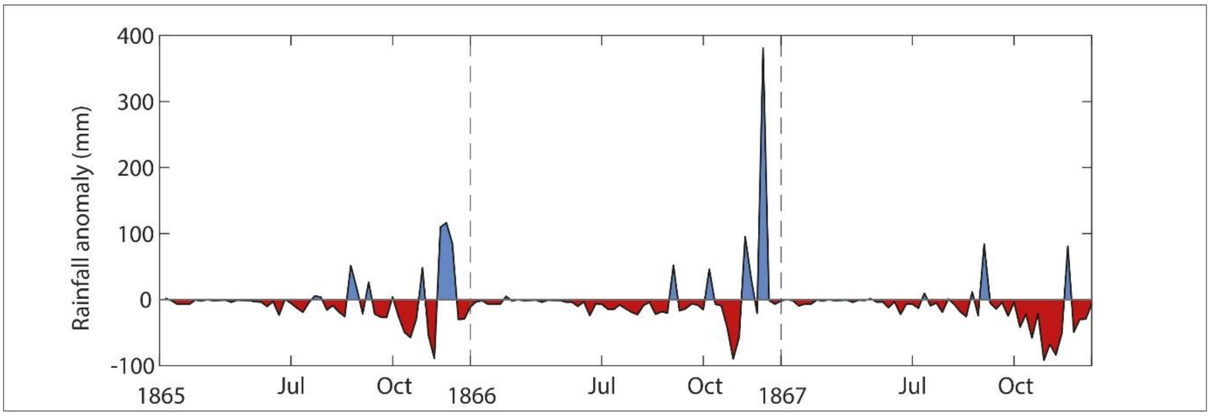

Figure 6.4 - Weekly rainfall anomaly for Madras town, relative to the 1861-1890 mean. Data transcribed from the Madras Observatory.

Despite the prevalence of deficient or poorly timed monsoon rainfall at the time of famine events, it does not necessarily imply that this is the proximate cause (Damodaran, Hamilton and Allan, 2019); there are a further 44 northeast monsoon seasons that are categorised as below average or deficient where no record of famine was found. Therefore, the manifestation of famine is not a ubiquitous consequence of poor monsoon rainfall, suggesting that other factors must also be in effect on those 14 occasions where famine conditions develop. This finding is in agreement with a number of studies addressing the famine / drought relationship India (Adamson, 2016; Hall-Matthews, 2005; Hardiman, 1996; Bhatia 1967; Davies, 2002), in each of these studies, the importance of non-meteorological conditions on the manifestation and severity of famines are addressed. Indeed, evidence from documentary material suggests that a more accurate immediate cause of eight out of the eleven famines described in Chapter 5, Section 5.2, was a substantial increase in the price of grain.

Increase in grain price may indeed have been a result of a reduced harvest due to rainfall deficiencies or poorly timed rainfall as purported by the East India Company and the British Government (Indian Famine Commission, 1880), however, evidence from the archives also demonstrates that these may have also been compounded multiple other factors. For example, warfare, during the famines of 1746-1748 and 1781 -1782 both reduced agricultural output and

---

[131] IOR/V/24/3129 – Report on the administration of the Madras Police. 1865, pp.17

[132] Parliamentary Papers Vol 52, 1867, pp.35

increased demand. Heavy outmigration from Guntoor to Madras town in 1833 caused a rapid increase in the population and the subsequent demand on Madras' food supplies, which drew famine conditions further south[133]. During the famines of 1865-1867 and 1876-1878, under *laissez-faire* governance uncontrolled grain exportation affected the price of grain. In the former, grain markets in those districts with good harvests suffered significant increases in grain prices as grain supplies were exported to meet the demands of the neighbouring districts[134], widening the region affected by famines. In the latter, export of rice from India to Europe and China persisted (Indian Famine Commission, 1880; Digby, 1878a), decreasing the supplies available to famine regions. Finally, Chapter 5, Section 5.3.1, discussed the role of grain traders in the famines of 1733, 1833, 1865-1867 and 1890, during which they were accused of artificially inflating the price of grain.

Finally, this linear connection between rainfall deficiency, harvest reduction and famine overlooks the disproportionate impact on those with lower entitlements (Sen, 1981; Thomas et al., 2019). While the data collected for this study were not sufficient to investigate this in detail, throughout the body of this research, there are no reports of any British individual or family suffering severe adverse effects during a famine event, including hunger. This differential vulnerability has been identified in previous studies of colonial Indian famines, for example, Adamson (2016) and Ahuja (2002a) where British citizens were largely unaffected by famine. Sporadic records of exportation of food grains out of India during periods of famine (Indian Famine Commission, 1880) support the findings of Ghose (2014) and Stahl (2016), who state that agricultural productivity in the country was not critically low during nineteenth century Indian famines, instead poor grain management prevented those in need from accessing sufficient supplies. Similarly, reports of increased poverty within the historical record, often written of in connection with high taxes (Maitland, 1846; Bellew 188), is said to have placed more at the mercy of grain prices[135]. The colonial government's public work schemes, offering wages sufficient only to maintain life, in reward for hard labour, was open to those whose normal streams of income were disrupted by famine. How appropriate this colonial relief system was for addressing famine conditions in India is too great of a topic to debate here, however, further details can be found in a range of sources (Hall-Matthews, 2005, 2008; Major, 2019; Sen, 1981).

To conclude this section, the prevalence of drought conditions prior to and during famine events suggests that the two are connected. However, even within the colonially-biased data collected for this study, there is evidence of multiple human and social interactions that manifest themselves during drought conditions and serve to exacerbate physical stressors. Studies are increasingly showing that the deterministic connection between rainfall and famine should be re-examined (Akerkar, 2015; Davis, 2002; Hall-Matthews, 2005; Mitra, 2012; Slavin, 2016; Slettebak, 2012). However, like Endfield (2007; 2012), it is possible to conclude that the role of drought should not be dismissed; instead, it is likely that drought conditions serve as a trigger for a network of social-political feedbacks that can culminate in famine. Furthermore, it should be remembered that

---

[133] The Madras Journal of Literature and Science. 1844, Anon.

[134] Parliamentary Papers vol. 52. August 1867.

[135] IOR/L/R/5/106 – Newspaper reports 1891-96. Written on 11th September 1891. Translated by the Madras Government.

famine is not ubiquitous following drought conditions, which has important methodological considerations for historical climatology. Records of famine should not be used as an indicator for deficient rainfall nor vice versa. Moreover, the existence of famine in a drought year cannot be used as an assessment of the magnitude of a drought as this research has shown that socio-political forces can exacerbate or distribute famine conditions.

6.3 Chapter summary

This chapter has drawn together the three distinct aspects of this research addressed in Chapters 3, 4 and 5 - the terrestrial documentary and ships' logbook reconstructions of monsoon variability and the famine history of Madras. The chapter began by summarising the methods used in both reconstructions. For the terrestrial reconstruction it highlighted the value of employing underutilised methods, specifically, the inclusion of confidence values and the use of researcher agreement testing during the calibration stage. These methods aim to increase the reliability of the reconstruction while providing some evidence of the quality of each data point, which reduces the likelihood of errors being incorporated into future studies. It went on to detail the challenges faced in the logbook reconstruction, specifically potential causes of the poor reconstruction skill. It is assumed that the poor reconstruction skill was largely a result of insufficient data, which was not at a sufficient temporal or spatial resolution to capture intraseasonal variability. It also highlighted that the cross validation technique used to maximise the number of years available to the calibration process, was not indicative of the skill of the final models when they were applied to historical logbook data. Finally, the only reconstruction that correlated significantly with modern instrumental rainfall data and performed better than the climatology was created using the simpler, composite plus scaling technique.

The chapter then went on to discuss the improved skill of the terrestrial documentary reconstruction over the logbook reconstruction. It suggested that while both data sources are liable to temporal and spatial variability, terrestrial documentary data is more apt to handle them. This improved skill may largely be a result of the lower data demand, when compared with the logbook reconstruction, in addition, the reconstruction method for the terrestrial documentary data requires detailed analysis of each quotation. Section 6.1 concluded by discussing the dearth of long-term northeast monsoon datasets with which to compare the new reconstructions, highlighting the value of this research and identifying a demand for future reconstructions.

Finally, Section 6.2 began by broadly summarising the direct socio-political impacts and responses that were identified in the historical documents, the impacts included, death of both humans and cattle, disease, increases in grain prices, urban crowding and limited access to drinking water. The primary responses detected in the archival material were migration and private charity, also noted were foraged diets, debt bondage and grain rioting. It then went on to investigate causal statements made by East India Company officials, namely that famines are a result of poor northeast monsoon rainfall. By using the new northeast monsoon rainfall reconstruction created in Chapter 3, it was possible to compare the rainfall deficiencies between 1730 and 1920 with the famine accounts described in Chapter 4. Each famine event occurs in conjunction with at least one year of below average northeast monsoon rainfall; however, the occurrence of famine in deficient northeast monsoon years is not ubiquitous. This suggests that while monsoon deficiencies contribute to the manifestation of famine, they are not the sole cause. Identifying the cause of the asymmetric development of famines in poor rainfall years using the archival material collected for this research was challenging, because of the bias towards documents authored by the British Government. Despite this bias, the impact of high grain prices on those with lower entitlements was prominent. There was evidence that these price increases could be caused or exacerbated by more factors other than just deficient or poorly timed rainfall, such as; warfare, unregulated exportation of grain supplies and high levels of migration to urban regions.

Chapter 7: Conclusions and further work

7.1.1 *Conclusions*

At the time of writing, India is the second most populous country in the world after China. Its major climate system, the Indian monsoon, is still not completely understood (Fletcher *et al.*, 2019; Seth *et al.*, 2019). Crucially, it is poorly represented in climate models which inhibits the understanding of how modern climate change may affect the monsoon and in consequence, those societies dependent upon it (Biasutti *et al.*, 2018; Rakesh *et al.*, 2015). The restrictive length of available instrumental data sets, which fail to capture long-term cycles, inhibits present understanding of monsoon variability (Adamson and Nash, 2014; Sengupta *et al.*, 2018). The main aim of this thesis was explore the information contained within historical documents, of both terrestrial and marine origin, and determine to what extent they can be used to strengthen and deepen the modern understanding of historical monsoon variability and the socio-political response to famine in southern India. The following research questions were addressed:

i. Can qualitative and quantitative data, contained within documentary records be used to reconstruct historical monsoon magnitude and to identify prominent trends and/or teleconnections with large scale climate drivers, such as the IOD and ENSO?

ii. Can semi-quantitative wind data, contained within the logbooks of ships' captains be used to reconstruct historical monsoon rainfall and are the resulting reconstructions sufficient to explore trends and/or teleconnections with large scale climate drivers, such as the IOD and ENSO?

iii. What were the political and social responses to historical famines, as reported in the historical documents?

iv. Is there evidence, within the documentary sources, of a connection between historical famine events and northeast monsoon rainfall?

In answering the first question, both qualitative information and early instrumental records were transcribed from archival sources; a particular focus was placed on extracting data from the region of modern day Tamil Nadu. This region was chosen as it was an active and longstanding centre of British colonial administration in India, and so therefore had a high data density and longevity. The main rainfall season in Tamil Nadu is the northeast monsoon, which at present is critically understudied in comparison with its southwestern counterpart. Modern historical climatology techniques were applied to the transcriptions in order to convert the qualitative and early instrumental data into a 5-point index series of northeast monsoon magnitude, calibrated to modern instrumental data. The resulting reconstruction between the years 1730 to 1920 is presented in Chapter 3, correlated with modern instrumental rainfall data at a value of 0.74, statistically significant at the 0.05 threshold. Both the long timescale of this statistically robust reconstruction, when coupled with the use of confidence values, makes the series a valuable addition to the current understanding of the northeast monsoon.

The reconstruction was extended from 1730-present using degraded modern instrumental data. Northeast monsoon magnitude demonstrated persistence in the cyclic pattern of positive and negative rainfall trend in rainfall. Periods of prolonged increased rainfall occur approximately every 20-50 years. There was no long term increasing or decreasing trend over the full 285, years, however, as noted by Kumar *et al.* (2010) there was a significant negative trend in monsoon magnitude prior to 1910, which does not persist into the 20th century. It is worth noting that the extended northeast monsoon magnitude series correlated poorly with reconstructed ENSO and IOD over the study period. There was some evidence of a cyclic relationship between the ENSO and northeast monsoon magnitude, however, this was only the case when correlated with Wilson *et al.'s* (2010) reconstruction of ENSO, which only uses proxies from the Tropical Pacific region. When considering only El Niño/La Niña and strongly positive/negative IOD events, there is a good relationship between above and below average northeast monsoon rainfall.

In addressing the second question, Chapter 4 dealt with the reconstruction of monsoon rainfall using the data contained within ships' logbooks. The marine reconstruction was substantially less successful than its terrestrial counterpart. A total of 16 reconstructions were trialled, one for each of the four seasons, as manifest over both Kerala and Tamil Nadu. Each instance was reconstructed using both the CPS and PCR technique. Of these 16 reconstructions, one performed better than the climatology, which was the northeast monsoon over Tamil Nadu, reconstructed using the CPS technique. This reconstruction correlated with modern instrumental data at 0.36 (significant at $p<0.05$). Chapter 6 proposed that the high intraseasonal variability of monsoon rainfall, made the demand for historic logbook data too high for the present availability. Furthermore, at present, the number of available logbook data varies considerably, both spatially and temporally which may contribute to the poor reconstruction skill. An investigation into the trends and teleconnections were not attempted due to the poor quality of the reconstruction; it was determined that, when compounded with challenges faced in Chapter 3, no meaningful results could be achieved.

In answering the third question, information pertaining to past societies was transcribed from archival data sources. Chapter 5 uses this information to examine periods of famine that affected the region of modern day Tamil Nadu. Fourteen famine events are reported in the transcriptions, eleven of which contained details of socio-political impacts of, and responses to, the famine event; each of these were summarised in Chapter 6. The British colonial authorship of the studied documents created a considerable bias within the discourse that favoured the exploration of political responses to crises as opposed to detailed information about social vulnerability and resilience. The most significant change in the British/East India Company's management of famine events occurred at the turn of the nineteenth century with the rapid acquisition of land area and taxation rights. At this time, the economic system of *laissez faire* gained momentum and dominated the political response until the end of the study period. Under these principles, the government withdrew from interference in the grain market, focusing instead on mitigation and relief, offering schemes of relief work, relief kitchens and the assistance of private trade, largely in the form of remissions on import taxes.

The suitability of these principles of famine management began to be questioned more vociferously during the nineteenth century, where discontent with the mortality experienced during Indian famine events, was given voice, predominantly through newspapers and magazines, but also in acclaimed literary works and prominent campaigns within parliament. Despite this, the governments of the East India Company, and later the Crown maintained that famines were natural crises, and the prevention of mortality was beyond the control of the government. This claim was investigated in Chapter 6, where, in answer to the fourth research question, the meteorological and social information gathered throughout this thesis were both used to demonstrate that drought likely plays a role in the development of famine events, but that it is not the sole cause. Other factors, social, or environmental, must also affect societies in order for famine conditions to develop.

7.1.2 *Further work*

As is often repeated in studies of past climates and societies, more data would strengthen this research. For the documentary reconstruction, data is biased towards larger colonial towns and factories, namely Madras Town; this is particularly prominent prior to the Mysore Wars, when East India Company landholdings were limited. Increased data would not only offer the opportunity to increase the applicability of the reconstruction to changes in statewide rainfall, it may also offer the opportunity to create reconstructions for smaller climatic zones within the state. This would provide a higher resolution with which to investigate regional monsoon changes. Moreover, by focussing on infilling gaps in the time series a more comprehensive reconstruction of seasonal and intraseasonal variability could be achieved. The value of a sub-seasonal resolution is demonstrated in Chapter 6, where weekly rainfall anomalies from Madras Town during the northeast monsoon seasons of 1865 to 1867 demonstrate the irregular distribution of rainfall. Similarly, the logbook reconstruction may be improved considerably with increased data. Only a fraction of the world's logbooks have been transcribed, yet with rapid strides being made to transcribe these, it is plausible that reconstructing the monsoon using the data from within ships' logbooks may indeed become more fruitful. Improved data availability may increase the skill of reconstructions, furthermore, it would offer the opportunity to fit models directly between wind data from logbooks and historical rainfall.

This research has discussed the dearth of historical climate studies in India, which stands peculiarly at odds with the data availability. With the addition of further reconstructions from key regions such as, Kerala, West Bengal and the northwest Indo/Pakistan border a greater understanding of the manifestation, magnitude and progress of both the southwest and northeast monsoons over all-India could be achieved. Presently, the southwest and northeast monsoon reconstructions, created for western India and Tamil Nadu respectively, are insufficient for this purpose.

It is hypothesised in this research that the methods used in the logbook reconstruction require further adaptation to suit the Indian monsoon system. This research experimented with surrogate data fields and flexible models which were fitted to the spatial availability of the historical data (not shown), however neither exhibited consistent improvement in the final reconstruction skill. Time constraints limited further exploration of logbook data transformation methods and pre-processing tools, specifically, different grid sizes and improved extremes analysis. In addition, there was not time for a more comprehensive exploration of various fitting techniques, for example, the regularized expectation maximisation technique (Mann *et al.*, 2008).

This research was unable to identify a clear relationship with large-scale climate mechanisms, such as ENSO and the IOD. Presently, there are multiple reconstructions of historic ENSO activity, yet there is no clear evidence as to which is most applicable to the Indian region. Furthermore, prior to the year 1800, the ENSO/northeast monsoon relationship was largely obscured by the compound errors in the two reconstructions. As new insights into historic IOD and ENSO variability are found, testing these relationships should be a priority.

The most prevalent concern within the study of the socio-political impacts of famine was the colonial bias inherent within the data. This research chose to focus more attention on the political responses to famines in order to avoid making assumptions about human-environment pathways, which were poorly constrained in the data. However, in doing so it neglects the role of society in famine management. The data for this research will be freely available, hosted on The University of Sheffield's Online Research Data (ORDA) portal (DOI: doi.org/10.15131/shef.data.11925381), it is hoped that future researchers will be able to build upon the information digitised in the course of this work, with a particular focus on procuring documents written in the Dravidian languages. Together this information could provide a deeper understanding of the historical trajectories of social vulnerability to climatic extremes such as drought within India. It could also be used to investigate further the successes and failures of past political actions in the face of famine, with a substantial reduction in the colonial bias.

References

Abram, N. J., Gagan, M. K., Cole, J. E., Hantoro, W. S., & Mudelsee, M. (2008). Recent intensification of tropical climate variability in the Indian Ocean. *Nature Geoscience*, **1**(12), 849–853.

Abram, N. J., Mulvaney, R., Vimeux, F., Phipps, S. J., Turner, J., & England, M. H. (2014). Evolution of the Southern Annular Mode during the past millennium. *Nature Climate Change*, **4**(7), 564–569.

Acharya, N., Kar, S. C., Kulkarni, M. A., Mohanty, U. C., & Sahoo, L. N. (2011). Multi-model ensemble schemes for predicting northeast monsoon rainfall over peninsular India. *Journal of Earth System Science*, **120**(5), 795–805.

Adamson, G. (2016). “The Most horrible of Evils”: Social Responses to Drought and Famine in the Bombay Presidency, 1782-1857. In G. Bankoff & J. Christensen, eds., *Natural Hazards and Peoples in the Indian Ocean World. bordering on Danger*, pp. 79–104.

Adamson, G. C. D. (2014). Institutional and community adaptation from the archives: A study of drought in western India, 1790-1860. *Geoforum*, **55**, 110–119.

Adamson, G. C. D., Hannaford, M. J., & Rohland, E. J. (2018). Re-thinking the present: The role of a historical focus in climate change adaptation research. *Global Environmental Change*, **48**, 195–205.

Adamson, G. C. D., & Nash, D. J. (2013). Long-term variability in the date of monsoon onset over western India. *Climate Dynamics*, **40**(11–12), 2589–2603.

Adamson, G. C. D., & Nash, D. J. (2014). Documentary reconstruction of monsoon rainfall variability over western India, 1781-1860. *Climate Dynamics*. doi:10.1007/s00382-013-1825-6

Ahuja, R. (2002a). Labour relations in an early colonial context: Madras, c. 1750-1800. *Modern Asian Studies*, **36**(4), 793–826.

Ahuja, R. (2002b). State formation and “famine policy” in early colonial south India. *Indian Economic and Social History Review*, **39**(4), 351–380.

Akerkar, S. (2015). Development of a normative framework for disaster relief: Learning from colonial famine histories in India. *Disasters*, **39**, s219–s243.

Allan, R., Endfield, G., Damodaran, V., Adamson, G., Hannaford, M., Carroll, F., Macdonald, N., Groom, N., Jones, J., Williamson, F., Hendy, E., Holper, P., Arroyo-Mora, P., Hughes, L., Bickers, R., Bliuc, A. M. (2016). Toward integrated historical climate research: The example of Atmospheric Circulation Reconstructions over the Earth. *Wiley Interdisciplinary Reviews: Climate Change*. doi:10.1002/wcc.379

Allan, R. J., Reason, C. J. C., Carroll, P., & Jones, P. D. (2002). A reconstruction of Madras (Chennai) mean sea-level pressure using instrumental records from the late 18th and early 19th centuries. *International Journal of Climatology*. doi:10.1002/joc.678

Ambirajan, S. (1978). *Classical political economy and British policy in India*, Cambridge:

Cambridge University Press.

Annamalai, H., & Slingo, J. M. (2001). Active /break cycles: diagnosis of the intraseasonal variability of the Asian Summer Monsoon. *Climate Dynamics*, **18**, 85–102.

Ashok, K., Feba, F., & Tejavath, C. T. (2019). The Indian summer monsoon rainfall and ENSO. *Mausam*, **70**(3), 443–452.

Ashok, K., Guan, Z., Saji, N. H., & Yamagata, T. (2004). Individual and combined influences of ENSO and the Indian Ocean Dipole on the Indian summer monsoon. *Journal of Climate*, **17**(16), 3141–3155.

Ashok, K., & Saji, N. H. (2007). On the impacts of ENSO and Indian Ocean dipole events on sub-regional Indian summer monsoon rainfall. *Natural Hazards*. doi:10.1007/s11069-006-9091-0

Auffhammer, M., Ramanathan, V., & Vincent, J. R. (2012). Climate change, the monsoon, and rice yield in India. *Climatic Change*. doi:10.1007/s10584-011-0208-4

Balachandran, S., Asokan, R., & Sridharan, S. (2006). Global surface temperature in relation to Northeast Monsoon Rainfall over Tamil Nadu. *Journal of Earth System Science*, **115**(3), 349–362.

Barrett, H. G. (2017). El Niño Southern Oscillation from the pre-instrumental era : development of logbook-based reconstructions ; and evaluation of multi-proxy reconstructions and climate model simulations, (August).

Barrett, H. G., Jones, J. M., & Bigg, G. R. (2018a). Reconstructing El Niño Southern Oscillation using data from ships' logbooks, 1815–1854. Part II: Comparisons with existing ENSO reconstructions and implications for reconstructing ENSO diversity. *Climate Dynamics*, **50**(9–10), 3131–3152.

Barrett, H. G., Jones, J. M., & Bigg, G. R. (2018b). Reconstructing El Niño Southern Oscillation using data from ships' logbooks, 1815–1854. Part I: methodology and evaluation. *Climate Dynamics*, **50**(3–4), 845–862.

Barriopedro, D., Gallego, D., Alvarez-Castro, M. C., García-Herrera, R., Wheeler, D., Peña-Ortiz, C., & Barbosa, S. M. (2014). Witnessing North Atlantic westerlies variability from ships' logbooks (1685-2008). *Climate Dynamics*, **43**(3–4), 939–955.

Barry, R. & Chorley, R., 2010. *Atmosphere, weather and climate (9th edition). London, Routeledge.*

Barua, P. P. (2011). Maritime Trade, Seapower, and the Anglo-Mysore Wars, 1767-1799. *Historian*, **73**(1), 22–40.

Bavel, B. J. P., Curtis, D. R., Hannaford, M. J., Moatsos, M., Roosen, J., & Soens, T. (2019). Climate and society in long-term perspective: Opportunities and pitfalls in the use of historical datasets. *Wiley Interdisciplinary Reviews: Climate Change*, (January), 1–18.

Berland, A. J., Metcalfe, S. E., & Endfield, G. H. (2013). Documentary-derived chronologies of rainfall variability in Antigua, Lesser Antilles. *Climate of the Past*, **9**(3), 1331–1343.

Berry, G., & Reeder, M. J. (2014). Objective identification of the intertropical convergence Zone: Climatology and trends from the ERA-Interim. *Journal of Climate*, **27**(5), 1894–1909.

Bhanu Kumar, O. S. R. U., Naidu, C. V., Rao, S. R. L., & Rao, B. R. S. (2004). Prediction of southern Indian winter monsoon rainfall from September local upper-air temperatures. *Meteorological Applications*, **11**(3), 189–199.

Bhatia, B. M. (1967). *Famines in India*, London: Asia Publishing House.

Bhattacharyya, A., Eckstein, D., Shah, S. K., & Chaudhary, V. (2007). Analyses of climatic changes around Perambikulum, South India, based on early wood mean vessel area of teak. *Current Science*, **93**(8), 1159–1164.

Biasutti, M., Voigt, A., Boos, W. R., Barconnot, P., Hargreaves, J. C., Harrison, S. P., Kang, S. M., Mapes, B. E., Scheff, J., Schumacher, C., Sobel, A. H., Xie, S-P.. (2018). Global energetics and local physis as drivers of past present and future monsoons. *Nature Geoscience*, **11**(June). doi:10.1038/s41561-018-0137-1

Böhm, R., Jones, P. D., Hiebl, J., Frank, D., Brunetti, M., & Maugeri, M. (2010). The early instrumental warm-bias: A solution for long central European temperature series 1760-2007. *Climatic Change*, **101**(1), 41–67.

Bollasina, M., & Nigam, S. (2011). The summertime “heat” low over Pakistan/northwestern India: evolution and origin. *Climate Dynamics*, **37**(5–6), 957–970.

Boos, W. R., & Kuang, Z. (2010). Dominant control of the South Asian monsoon by orographic insulation versus plateau heating. *Nature*, **463**(7278), 218–222.

Bordoni, S., & Schneider, T. (2008). Monsoons as eddy-mediated regime transitions of the tropical overturning circulation. *Nature Geoscience*, **1**(8), 515–519.

Borgaonkar, H. P., Sikder, A. B., Ram, S., & Pant, G. B. (2010). El Niño and related monsoon drought signals in 523-year-long ring width records of teak (Tectona grandis L.F.) trees from south India. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **285**(1–2), 74–84.

Bradlaugh, C. (1890). *Speeches by Charles Bradlaugh*, London: Freethought Publishing Company.

Brázdil, R., Dobrovolný, P., Luterbacher, J., Moberg, A., Pfister, C., Wheeler, D., Zorita, E. (2010). European climate of the past 500 years: New challenges for historical climatology. *Climatic Change*. doi:10.1007/s10584-009-9783-z

Brázdil, R., Dobrovolný, P., Trnka, M., Kotyza, O., Řezníčková, L., Valášek, H., Zahradníček, P. Val Štěpánek, P. (2013). Droughts in the Czech Lands, 1090-2012 AD. *Climate of the Past*, **9**(4), 1985–2002.

Brázdil, R., Dobrovolný, P., Trnka, M., Buntgen, U., Řezníčková, L., Kotyza, O., Valášek, H., Štěpánek, P. (2016). Documentary and instrumental-based drought indices for the Czech Lands back to AD 1501. *Climate Research*, **70**(2–3), 103–117.

Brázdil, R., Pfister, C., Wanner, H., Von Storch, H., & Luterbacher, J. (2005). Historical climatology in Europe - The state of the art. *Climatic Change*. doi:10.1007/s10584-005-5924-1

Brohan, P., Allan, R., Freeman, E., Wheeler, D., Wilkinson, C., & Williamson, F. (2012). Constraining the temperature history of the past millennium using early instrumental observations. *Climate of the Past*, **8**(5), 1551–1563.

Brohan, P., Allan, R., Freeman, J. E., Waple, A. M., Wheeler, D., Wilkinson, C., & Woodruff, S. (2009). Marine observations of old weather. *Bulletin of the American Meteorological Society*, **90**(2), 219–230.

Brugere, C., & Lingard, J. (2003). Irrigation deficits and farmers' vulnerability in Southern India. *Agricultural Systems*, **77**(1), 65–88.

Brugnara, Y., Auchmann, R., Brönnimann, S., Allan, R. J., Auer, I., Barriendos, M., Bergström, H., Bhend, J., Brázdil, R., Compo, G. P., Cornes, R. C., Dominguez-Castro, F., Van Engelen, A. F. V., Filipiak, J., Holopainen, J., Jourdain, S., Kunz, M., Luterbacher, J., et al. (2015). A collection of sub-daily pressure and temperature observations for the early instrumental period with a focus on the "year without a summer" 1816. *Climate of the Past*, **11**(8), 1027–1047.

Bryant, G. J. (2004). British logistics and the conduct of the Carnatic wars. In *War in History*, Vol. 11, pp. 278–306.

Bryant, G.J. (2012) *The War in the Carnatic*, in Danley, M.H., Speelman, P.J. (ed.) *The Seven Years War.* Brill, Leiden pp 73-106

Busby, J., Smith, T. G., Krishnan, N., Wight, C., & Vallejo-Gutierrez, S. (2018). In harm's way: Climate security vulnerability in Asia. *World Development*, **112**, 88–118.

Camuffo, D., & Bertolin, C. (2012). Recovery of the early period of long instrumental time series of air temperature in Padua, Italy (1716-2007). *Physics and Chemistry of the Earth*, **40**–**41**, 23–31.

Camuffo, D., Bertolin, C., Barriendos, M., Dominguez-Castro, F., Cocheo, C., Enzi, S., Sghedoni, M., della Valle, A., Garnier, E., Alcoforado, M. J., Xoplaki, E., Luterbacher, J., Diodato, N., Maugeri, M., Nunes, M. F., & Rodriguez, R. (2010). 500-Year temperature reconstruction in the Mediterranean Basin by means of documentary data and instrumental observations. *Climatic Change*, **101**(1), 169–199.

Camuffo, D., Cocheo, C., & Sturaro, G. (2006). Corrections of systematic errors, data homogenisation and climatic analysis of the Padova pressure series (1725-1999). *Climatic Change*, **78**(2–4), 493–514.

Carey, M. (2012). Climate and history: A critical review of historical climatology and climate change historiography. *Wiley Interdisciplinary Reviews: Climate Change*. doi:10.1002/wcc.171

Carswell, G., & De Neve, G. (2013). From field to factory: Tracing transformations in bonded labour in the Tiruppur region, Tamil Nadu. *Economy and Society*, **42**(3), 430–454.

Cherchi, A., Gualdi, S., Behera, S., Luo, J. J., Masson, S., Yamagata, T., & Navarra, A. (2007). The influence of tropical Indian Ocean SST on the Indian summer monsoon. *Journal of Climate*, **20**(13), 3083–3105.

Christiansen, B., Schmith, T., & Thejll, P. (2009). A surrogate ensemble study of climate reconstruction methods: Stochasticity and robustness. *Journal of Climate*, **22**(4), 951–976.

Compo, G. P., Whitaker, J. S., Sardeshmukh, P. D., Matsui, N., Allan, R. J., Yin, X., Gleason, B. E., Vose, R. S., Rutledge, G., Bessemoulin, P., Brönnimann, S., Brunet, M., Crouthamel, R. I., Grant, A. N., Groisman, P. Y., Jones, P. D., Kruk, M. C., Kruger, A. C., et al. (2011). The Twentieth Century Reanalysis Project. *Quarterly Journal of the Royal Meteorological Society*, **137**(654), 1–28.

Commonwealth of Australia (2013) *Indian Ocean influence on Austalian Cliamte:* Positive IOD. Viewed 14th January 2020, http://www.bom.gov.au/climate/iod/

Cook, E., Briffa, K., Jones, P. (1994) Spatial regression methods in dendrclimatology: A review and comparison of two techniques. *International Journal of Climatology*. **14**(4), 379-402

Cook, E. R., Anchukaitis, K. J., Buckley, B. M., D'Arrigo, R. D., Jacoby, G. C., & Wright, W. E. (2010). Asian monsoon failure and megadrought during the last millennium. *Science (New York, N.Y.)*, **328**(5977), 486–9.

Coombes, P., & Barber, K. (2005). Environmental determinism in Holocene research: causality or coincidence? *Area*, **373**(37), 303–311.

Cornes, R. (2014). Historic storms of the northeast Atlantic since circa 1700: a brief review of recent research. *Weather*, **1588**, 121–125.

Dai, A. (2011). Drought under global warming: A review. *Wiley Interdisciplinary Reviews: Climate Change*, **2**(1), 45–65.

Damodaran, V., Hamilton, J., & Allan, R. (2019). Climate signals, environment and livelihoods in the long seventeenth century in India. *A Cultural History of Famine: Food Security and the Environment in India and Britain*, (July), 52–70.

Daniels, S., & Endfield, G. H. (2009). Narratives of climate change: introduction. *Journal of Historical Geography*, **35**(2), 215–222.

Das, P. K., Dutta, D., Sharma, J. R., & Dadhwal, V. K. (2016). Trends and behaviour of meteorological drought (1901-2008) over Indian region using standardized precipitation-evapotranspiration index. *International Journal of Climatology*, **36**(2), 909–916.

Dasgupta, A. (1993). *A history of Indian Economic thought*, London: Routledge.

Dash, S. K., Saraswat, V., Panda, S. K., & Sharma, N. (2013). A study of changes in rainfall and temperature patterns at four cities and corresponding meteorological subdivisions over coastal regions of India. *Global and Planetary Change*, **108**, 175–194.

Davis, M. (2002). *Late Victorian holocausts: El Nino famines and the making of the third world*, London: Verso.

Debrett, J., Cadell, T. and Davies, W. (1802) *The Asiatic Annual Register or, A view of the history of Hindustan, and the Politics, commerce and literature of Asia for the year 1801.* Wilson and Co. Oriental Press, London.

de Kraker, A. M. J. (2006). Historical climatology, 1950-2006. *Belgeo*, **3**(3), 307–338.

Degroot, D. (2014). “Never such weather known in these seas”: Climatic Fluctuations and the Anglo-Dutch Wars of the Seventeenth Century, 1652-1674. *Environment and History*, **20**(2), 239–273.

Degroot, D. (2018). Climate change and society in the 15th to 18th centuries, (October 2017), 1–20.

Digby, W. (1878). *The Famine campaign in Southern India. Vol. 1*, London: Longmans, Green & Co.

Dimri, A. P., Niyogi, D., Barros, A. P., Ridley, J., Mohanty, U. C., Yasunari, T., & Sikka, D. R. (2015). Reviews of Geophysics Western Disturbances: A review. *Reviews of Geophysics*, **53**, 225–246.

Dobrovolný, P., Moberg, A., Brázdil, R., Pfister, C., Glaser, R., Wilson, R., van Engelen, A., Limanówka, D., Kiss, A., Halíčková, M., Macková, J., Riemann, D., Luterbacher, J., & Böhm, R. (2010). Monthly, seasonal and annual temperature reconstructions for Central Europe derived from documentary evidence and instrumental records since AD 1500. *Climatic Change*, **101**(1), 69–107.

Dowdwell H. H. (1929) *The Cambridge History of India. Vol 5. British India.* Cambridge, University Press.

Druckenbrod, D. L., Mann, M. E., Stahle, D. W., Cleveland, M. K., Therrell, M. D., & Shugart, H. H. (2003). Late-eighteenth-century precipitation reconstructions from James Madison’s Montpelier plantation. *Bulletin of the American Meteorological Society*. doi:10.1175/BAMS-84-1-57

Duan, K., Yao, T., & Thompson, L. G. (2004). Low-frequency of southern Asian monsoon variability using a 295-year record from the Dasuopu ice core in the central Himalayas. *Geophysical Research Letters*, **31**(16), 28–31.

Dwivedi, S., Goswami, B. N., & Kucharski, F. (2015). Unraveling the missing link of ENSO control over the Indian monsoon rainfall. *Geophysical Research Letters*, **42**(19), 8201–8207.

Dwivedi, S., Mittal, A. K., & Goswami, B. N. (2006). An empirical rule for extended range prediction of duration of Indian summer monsoon breaks. *Geophysical Research Letters*, **33**(18), 1–5.

Dyson, T. (1991). On the Demography of South Asian Famines : Part I. *Population Studies*, **45**(1), 5–25.

Eacott, J. P. (2012). Making an Imperial Compromise: The Calico Acts, the Atlantic Colonies, and the Structure of the British Empire. *Omohundro Institute of Early American History* *and Culture*, **69**(4), 731–762.

Emile-Geay, J., Cobb, K. M., Mann, M. E., & Wittenberg, A. T. (2013). Estimating central equatorial pacific SST variability over the past millennium. part II: Reconstructions and implications. *Journal of Climate*, **26**(7), 2329–2352.

Endfield, G. H. (2007). Archival explorations of climate variability and social vulnerability in colonial Mexico. *Climatic Change*, **83**(1–2), 9–38.

Endfield, G. H. (2012). The resilience and adaptive capacity of social-environmental systems in colonial Mexico. *Proceedings of the National Academy of Sciences*, **109**(10), 3676–3681.

Farrington, A (2002) Trading places, the east India Company and Asia. *History today.* 52 (5) pp.40-41.

Felsenstein, D., & Lichter, M. (2014). Social and economic vulnerability of coastal communities to sea-level rise and extreme flooding. *Natural Hazards*, **71**(1), 463–491.

Felton, C. S., Subrahmanyam, B., & Murty, V. S. N. (2013). ENSO-modulated cyclogenesis over the Bay of Bengal. *Journal of Climate*, **26**(24), 9806–9818.

Fenby, C., & Gergis, J. (2013). Rainfall variations in south-eastern Australia part 1: Consolidating evidence from pre-instrumental documentary sources, 1788-1860. *International Journal of Climatology*, **33**(14), 2956–2972.

Fernández-Fernández, M. I., Gallego, M. C., Domínguez-Castro, F., Trigo, R. M., & Vaquero, J. M. (2017). The climate in Zafra from 1750 to 1840: temperature indexes from documentary sources. *Climatic Change*, **141**(4), 671–684.

Flatau, M. K., Flatau, P. J., & Rudnick, D. (2001). The dynamics of double monsoon onsets. *Journal of Climate*, **14**(21), 4130–4146.

Fletcher, J. K., Parker, D. J., Turner, A. G., Menon, A., Martin, G. M., Birch, C. E., Mitra, A. K., Mrudula, G., Hunt, K. M. R., Taylor, C. M., Houze, R. A., Brodzik, S. R., & Bhat, G. S. (2019). The dynamic and thermodynamic structure of the monsoon over southern India: New observations from the INCOMPASS IOP. *Quarterly Journal of the Royal Meteorological Society*, (August), 1–24.

Formetta, G., & Feyen, L. (2019). Empirical evidence of declining global vulnerability to climate-related hazards. *Global Environmental Change*, **57**(May), 101920.

Fraser, E. D. G. (2007). Travelling in antique lands: Using past famines to develop an adaptability/resilience framework to identify food systems vulnerable to climate change. *Climatic Change*, **83**(4), 495–514.

Freeman, E., Woodruff, S. D., Worley, S. J., Lubker, S. J., Kent, E. C., Angel, W. E., Berry, D. I., Brohan, P., Eastman, R., Gates, L., Gloeden, W., Ji, Z., Lawrimore, J., Rayner, N. A., Rosenhagen, G., & Smith, S. R. (2017). ICOADS Release 3.0: a major update to the historical marine climate record. *International Journal of Climatology*, **37**(5), 2211–2232.

Freeman, J. E., Freeman, J. E., Carolina, N., Anderson, H., Carolina, N., & Seiderman, M. (2016). Noaa ' S Climate Database Modernization, (December).

Gadgil, S. (2003). The Indian monsoon and its variability. *Annu. Rev. Earth Planet. Sci*, **31**, 429–67.

Gadgil, S. (2018). The monsoon system: Land–sea breeze or the ITCZ? *Journal of Earth System Science*, **127**(1), 1–29.

Gadgil, S., & Joseph, P. V. (2003). On breaks of the Indian monsoon. *Proceedings of the Indian Academy of Sciences, Earth and Planetary Sciences*, **112**(4), 529–558.

Gallego, D., García-Herrera, R., Peña-Ortiz, C., & Ribera, P. (2017). The steady enhancement of the Australian Summer Monsoon in the last 200 years. *Scientific Reports*, **7**(1), 1–7.

Galvin, J. F. P., & Jones, C. D. (2009). The weather and climate of the tropics: Part 10 - Tropical agriculture. *Weather*, **64**(6), 156–161.

García-Herrera, R., Barriopedro, D., Gallego, D., Mellado-Cano, J., Wheeler, D., & Wilkinson, C. (2018). Understanding weather and climate of the last 300 years from ships' logbooks. *Wiley Interdisciplinary Reviews: Climate Change*, **9**(6), 1–18.

Garcia-Herrera, R., Diaz, H. F., Garcia, R. R., Prieto, M. R., Barriopedro, D., Moyano, R., & Hernández, E. (2008). A chronology of El Niño events from primary documentary sources in northern Peru. *Journal of Climate*, **21**(9), 1948–1962.

García-Herrera, R., Können, G. P., Wheeler, D. A., Prieto, M. R., Jones, P. D., & Koek, F. B. (2005). CLIWOC: A climatological database for the world's oceans 1750-1854. *Climatic Change*. doi:10.1007/s10584-005-6952-6

Garrison, C. S., Kilburn, C. R. J., & Edwards, S. J. (2018). The 1831 eruption of Babuyan Claro that never happened: Has the source of the one of the largest volcanic climate forcing events of the nineteenth century been misattributed? *Journal of Applied Volcanology*, **7**(1). doi:10.1186/s13617-018-0078-9

Garstin, J., H. (1878) *Manual of the South Arcot District.* Madras, Lawrence Asylum Press.

Ge, Q. S., Zheng, J. Y., Hao, Z. X., Zhang, P. Y., & Wang, W. C. (2005). Reconstruction of historical climate in China. *Bulletin of the American Meteorological Society*, **86**(5), 671–679.

Gergis, J., & Ashcroft, L. (2013). Rainfall variations in south-eastern Australia part 2: A comparison of documentary, early instrumental and palaeoclimate records, 1788-2008. *International Journal of Climatology*, **33**(14), 2973–2987.

Gergis, J. L., & Fowler, A. M. (2009). A history of ENSO events since A.D. 1525: Implications for future climate change. *Climatic Change*. doi:10.1007/s10584-008-9476-z

Gergis, L. L. E., Braganza, K., Fowler, A., Mooney, S., & Risbey, J. (2006). Reconstructing El Nino - Southern oscillation (ENSO) from high-resolution palaeoarchives. *Journal of Quaternary Science*, **21**(7), 707–722.

Ghose, A. K. (2014). Food Supply and Starvation : A Study of Famines with Reference to the Indian Sub-Continent Author (s): Ajit Kumar Ghose Source : Oxford Economic Papers , New Series , Vol . 34 , No . 2 (Jul ., 1982), pp . 368-389 *Oxford Economic Papers*, **34**(2), 368–389.

Gilady, L., & Mackay, J. (2015). Bringing the insurgents back in: Early wars in British India. *Terrorism and Political Violence*, **27**(5), 797–817.

Gomez-Delgado, F. de P., Gallego, D., Peña-Ortiz, C., Vega, I., Ribera, P., & Garcia-Herrera, R. (2019). Long term variability of the northerly winds over the Eastern Mediterranean as seen from historical wind observations. *Global and Planetary Change*, **172**(October 2018), 355–364.

Gomez-Navarro, J., Werner, J. P., Wagner, S., Luterbacher, J. (2015) Establishing the skill of climate field reconstruction techniques for precipitation with pseudoproxy experiments. *Climate Dynamics*. **45** (5-6), 1395-1413

Goswami, B. N. (2006). The Asian monsoon: Interdecadal variability. In *The Asian Monsoon*, Springer Berlin Heidelberg, pp. 295–327.

Goswami, B. N., & Ajaya Mohan, R. S. (2000). A common spatial mode for intra-seasonal and inter-annual variation and predictability of the Indian summer monsoon. *Current Science*, **79**(8), 1106–1111.

Government of Kerala. (2011). Response to Climate Change: Strategy and Action Kerala State Action Plan on Climate Change.

Grab, S. W., & Nash, D. J. (2010). Documentary evidence of climate variability during cold seasons in Lesotho, Southern Africa, 1833-1900. *Climate Dynamics*, **34**(4), 473–499.

Guhathakurta, P., Rajeevan, M., Sikka, D. R., & Tyagi, A. (2015). Observed changes in southwest monsoon rainfall over India during 1901-2011. *International Journal of Climatology*, **35**(8), 1881–1898.

Gupta, P. (2012). Monsoon fever. *Social Dynamics*, **38**(3), 516–527.

Gupta, R. K., & Kanodia, K. C. (1968). Plants used during scarcity and famine periods in the dry regions of India. *Journal d'agriculture Tropicale et de Botanique Appliquée*, **15**(7), 265–285.

Hall-Matthews, D. (2002). Famine Process and Famine Policy : A Case Study of Ahmednagar District , Bombay Presidency ,.

Hall-Matthews, D. (2005). *Peasants, Famine and the State in Colonial Western India*, Basingstoke: Palgrave Macmillan.

Hall-Matthews, D. (2008). Inaccurate conceptions: Disputed measures of nutritional needs and famine deaths in colonial India. *Modern Asian Studies*, **42**(6), 1189–1212.

Halley, E. (1686). An historical account of the trade winds and monsoons observable in the seas between and near the tropics with an attempt to assign a physical cause of the said winds. *Phillosophical Transactions*, **16**(1), 153–168.

Hannaford, M. J. (2015). The consequences of past climate change for state formation and security in southern Africa PhD Thesis, (March).

Hannaford, M. J., Bigg, G. R., Jones, J. M., Phimister, I., & Staub, M. (2014). Climate variability and societal dynamics in pre-colonial Southern African history (AD 900-1840): A synthesis and critique. *Environment and History*. doi:10.3197/096734014X14031694156484

Hannaford, M. J., Jones, J. M., & Bigg, G. R. (2015a). Early-nineteenth-century southern African precipitation reconstructions from ships' logbooks. *Holocene,* **25**(2), 379–390.

Hannaford, M. J., Jones, J. M., & Bigg, G. R. (2015b). Early-nineteenth-century southern African precipitation reconstructions from ships' logbooks. *The Holocene,* **25**(2), 379–390.

Hannaford, M. J., & Nash, D. J. (2016a). Climate, history, society over the last millennium in southeast Africa. *Wiley Interdisciplinary Reviews: Climate Change*. doi:10.1002/wcc.389

Hannaford, M. J., & Nash, D. J. (2016b). Climate, history, society over the last millennium in southeast Africa. *Wiley Interdisciplinary Reviews: Climate Change,* **7**(3), 370–392.

Hardiman, D. (1996). Usury , Dearth and Famine in Western India. *The Past and Present Society,* **152**, 113–156.

Hardiman, D. (2002). The politics of water in colonial India. *South Asia: Journal of South Asia Studies*, **25**(2), 111–120.

Harriott, H. (1834) A new system of supplying tanks with water. *Madras Journal of Literature and Science,* vol 1, pp. 111-113

Hayavadana Rao, C. (1948) *History of Mysore (1399-1799 A.D).* Karnataka, Superintendent Government Press.

Heim, R. R. J. (2002). A review of twentieth-century drought indices used in the United States. *Bulletin of the American Meteorological Society,* (August).

Hemmingway, F. R. (1906) *Madras district gazetteers. Tanjore.* Madras, Government Press

Hill, S. A. (2019). Theories for Past and Future Monsoon Rainfall Changes. *Current Climate Change Reports,* **5**, 160–171.

Hlaing, Z. C., Teplyakov, V. K., & Thant, N. M. L. (2014). Influence of climate factors on tree-ring growth in teak (Tectona grandis L. f.) plantations in the Bago Yoma Range, Myanmar. *Forest Science and Technology,* **10**(1), 40–45.

Ho, M., Kiem, A. S., & Verdon-Kidd, D. C. (2015a). A paleoclimate rainfall reconstruction in the Murray-Darling Basin (MDB), Australia: 2. Assessing hydroclimatic risk using paleoclimate records of wet and dry epochs. *Water Resources Research,* **51**(10), 8380–8396.

Ho, M., Kiem, A. S., & Verdon-Kidd, D. C. (2015b). A paleoclimate rainfall reconstruction in the Murray- Darling Basin MDB, Australia: 1. Evaluation of different paleoclimate archives, rainfall networks, and reconstruction techniques. *Water Resources Research,* **51**(10), 8362–8379.

Howe, P. (2018). Famine systems: A new model for understanding the development of famines.

World Development, **105**, 144–155.

Hsieh, H. F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research*, **15**(9), 1277–1288.

Huang, R., Chen, J., Wang, L., & Lin, Z. (2012). Characteristics, processes, and causes of the spatio-temporal variabilities of the East Asian monsoon system. *Advances in Atmospheric Sciences*, **29**(5), 910–942.

Hulme, M. (2015). Climate and its changes: a cultural appraisal. *Geo: Geography and Environment*, **2**(1), 1–11.

Hunt, K. M. R., Turner, A. G., & Shaffrey, L. C. (2018). The evolution, seasonality and impacts of western disturbances. *Quarterly Journal of the Royal Meteorological Society*, **144**(710), 278–290.

Hussain, H., & Sarwar, F. H. (2012). A Comparative Study of Zamindari, Raiyatwari and Mahalwari Land Revenue Settlements: The Colonial Mechanisms of Surplus Extraction in 19 th Century British India. *IOSR Journal of Humanities and Social Science*, **2**(4), 16–2

Ihara, C., Kushnir, Y., Cane, M. A., & De La Pena, V. H. (2007a). Ocean circulation: Thermohaline circulation. *International Journal of Climatology*, **27**, 179–187.

Ihara, C., Kushnir, Y., Cane, M. A., & De la Peña, V. H. (2007b). Indian summer monsoon rainfall and its link with ENSO and Indian Ocean climate indices. *International Journal of Climatology*. doi:10.1002/joc.1394

Indian Famine Commission (1880) *Report of the Indian Famine Commission, 1880-1885.* London, Her Majesty's Stationery Office

Indian Famine Commission (1898) *Report of the Indian Famine Commission, 1898. Presented to both Houses of Parliament by command of her Majesty.* London, Darling and Son.

Indian Meterological department (2015) *monsoon.* Last accessed 02 January 2017 at http://www.imd.gov.in/pages/monsoon_main.php?adta=ONSET&adtb=&adtc=&adtd=onset

Jasanoff, S. (2010). A new climate for society. *Theory, Culture and Society*, **27**(2), 233–253.

Jones, J. M., & Widmann, M. (2003). Instrument- and tree-ring-based estimates of the Antarctic oscillation. *Journal of Climate*, **16**(21), 3511–3524.

Jones, P. (2008). Historical climatology - A state of the art review. *Weather*. doi:10.1002/wea.245

Jones, P. D., Briffa, K. R., Osborn, T. J., Lough, J. M., Ommen, T. D. Van, Vinther, B. M., Luterbacher, J., Wahl, E. R., Zwiers, F. W., Mann, M. E., Schmidt, G. A., Ammann, C. M., Buckley, B. M., Cobb, K. M., Esper, J., Goosse, H., Graham, N., Jansen, E., et al. (2009). The Holocene High-resolution palaeoclimatology of the last millennium: a review of current. *Library*, **1**, 3–49.

Jones, P. D., Jonsson, T., & Wheeler, D. (1997). Extension to the North Atlantic oscillation using early instrumental pressure observations from Gibraltar and south-west Iceland. *International Journal of Climatology*, **17**(13), 1433–1450.

Jones, P. D., & Salmon, M. (2005). Preliminary reconstructions of the North Atlantic Oscillation and the Southern Oscillation Index from measures of wind strength and direction taken during the CLIWOC period. *Climatic Change*, **73**(1–2), 131–154.

Joppen, Charles (1907) *Historical Atlas of India. For the use of high schools, colleges and private students.* London, Longmans and Green

Kelso, C., & Vogel, C. (2007). The climate of Namaqualand in the nineteenth century. *Climatic Change*. doi:10.1007/s10584-007-9264-1

Kochhar, R. (2002). Madras and Kodaikanal Observatories : A Brief History, (August), 16–28.

Kothawale, D. R., & Rajeevan, M. (2017). Monthly , Seasonal and Annual Rainfall Time Series for All-India , Homogeneous Regions and Meteorological Subdivisions : 1871-2016. *Indian Institute of Tropical Meteorology*.

Kothawale, D. R., Revadekar, J. V., & Kumar, K. R. (2010). Recent trends in pre-monsoon daily temperature extremes over India. *Journal of Earth System Science*, **119**(1), 51–65.

Kripalani, R. H., & Kumar, P. (2004). Northeast monsoon rainfall variability over south peninsular India vis-à-vis the Indian Ocean dipole mode. *International Journal of Climatology*, **24**(10), 1267–1282.

Krishna Kumar, K., Rupa Kumar, K., Ashrit, R. G., Deshpande, N. R., & Hansen, J. W. (2004). Climate impacts on Indian agriculture. *International Journal of Climatology*. doi:10.1002/joc.1081

Krishnakumar, K. N., Prasada Rao, G. S. L. H. V., & Gopakumar, C. S. (2009). Rainfall trends in twentieth century over Kerala, India. *Atmospheric Environment*, **43**(11), 1940–1944.

Krishnamurthy, V., & Goswami, B. N. (2000). Indian monsoon-ENSO relationship on interdecadal timescale. *Journal of Climate*, **13**(3), 579–595.

Krishnamurthy, V., & Shukla, J. (2000). Intraseasonal and interannual variability of rainfall over India. *Journal of Climate*, **13**(24), 4366–4377.

Kumar, K. K., Rajagopalan, B., & Cane, M. A. (1999). On the weakening relationship between the indian monsoon and ENSO. *Science*, **284**(5423), 2156–2159.

Kumar, K. S., & Parikh, J. (2001). Indian Agriculture and Climate Sensitivity. *Global Environmental Change*, **11**, 147–154.

Kumar, P., Rupa Kumar, K., Rajeevan, M., & Sahai, A. K. (2007). On the recent strengthening of the relationship between ENSO and northeast monsoon rainfall over South Asia. *Climate Dynamics*, **28**(6), 649–660.

Kumar, V., Jain, S. K., & Singh, Y. (2010). Analysis of long-term rainfall trends in India. *Hydrological Sciences Journal*, **55**(4), 484–496.

Kumar, V., Satya Kumar, M., & Hosalikar, K. S. (2018). Forecasting rainfall trend over Tamil Nadu during northeast monsoon. *The Journal of Indian Geophysical Union*, **22**(1), 79–89.

Küttel, M., Xoplaki, E., Gallego, D., Luterbacher, J., García-Herrera, R., Allan, R., Barriendos, M., Jones, P. D., Wheeler, D., & Wanner, H. (2010). The importance of ship log data: Reconstructing North Atlantic, European and Mediterranean sea level pressure fields back to 1750. *Climate Dynamics*, **34**(7), 1115–1128.

Lawson, P. (1993). *The East india Company*, London: Longman.

Leijonhufvud, L., Wilson, R., Moberg, A., Söderberg, J., Retsö, D., & Söderlind, U. (2010). Five centuries of Stockholm winter/spring temperatures reconstructed from documentary evidence and instrumental observations. *Climatic Change*, **101**(1), 109–141.

Liu, K.-B., Shen, C., & Louie, K.-S. (2001). A 1,000-Year History of Typhoon Landfalls in Guangdong, Southern China, Reconstructed from Chinese Historical Documentary Records. *Source: Annals of the Association of American Geographers*, **91**(3), 453–464.

Liu, Y., Wu, G., Hong, J., Dong, B., Duan, A., Bao, Q., & Zhou, L. (2012). Revisiting Asian monsoon formation and change associated with Tibetan Plateau forcing: II. Change. *Climate Dynamics*, **39**(5), 1183–1195.

Llasat, M. C., Barriendos, M., Barrera, A., & Rigo, T. (2005). Floods in Catalonia (NE Spain) since the 14th century. Climatological and meteorological aspects from historical documentary sources and old instrumental records. *Journal of Hydrology*, **313**(1–2), 32–47.

Love, H. D. (1913) *Vestiges of old Madras 1640-1800 (*vols 1-3). London, John Murray.

Lu, B., Ren, H. L., Scaife, A. A., Wu, J., Dunstone, N., Smith, D., Wan, J., Eade, R., MacLachlan, C., Gordon, M. (2018). An extreme negative Indian Ocean Dipole event in 2016: dynamics and predictability. *Climate Dynamics*, **51**(1–2), 89–100.

Luterbacher, J., & Pfister, C. (2015). The year without a summer. *Nature Geoscience*, **8**, 246–248.

Luterbacher, J., Xoplaki, E., Dietrich, D., Rickli, R., Jacobeit, J., Beck, C., Gyalistras, D., Schmutz, C., & Wanner, H. (2002). Reconstruction of sea level pressure fields over the Eastern North Atlantic and Europe back to 1500. *Climate Dynamics*, **18**(7), 545–561.

Machado, M. J., Benito, G., Barriendos, M., & Rodrigo, F. S. (2011). 500 Years of rainfall variability and extreme hydrological events in southeastern Spain drylands. *Journal of Arid Environments*, **75**(12), 1244–1253.

Madras Presidency (1885) *Manual of the Madras Presidency, in illustration of the records of government and the yearly administration reports* (vol 2). Madras, Government press.

Maharatna, A. (2014). Food scarcity and migration: An overview. *Social Research*, **81**(2), 277–298.

Mahony, M., & Endfield, G. (2018). Climate and colonialism. *Wiley Interdisciplinary Reviews: Climate Change*, **9**(2), 1–16.

Maiti, S., Jha, S. K., Garai, S., Nag, A., Chakravarty, R., Kadian, K. S., Chandel, B. S., Datta, K. K., & Upadhyay, R. C. (2015). Assessment of social vulnerability to climate change in the eastern coast of India. *Climatic Change*, **131**(2). doi:10.1007/s10584-015-1379-1

Maitland, J. C. (1846) *Letters from Madras during the years 1836-1839.* London, John Murray, Albemarle Street.

Major, A. (2019). British Humanitarian Political Economy and Famine in India, 1838-42. *Journal of British Studies*.

Mallya, G., Mishra, V., Niyogi, D., Tripathi, S., & Govindaraju, R. S. (2015). Trends and variability of droughts over the Indian monsoon region. *Weather and Climate Extremes*, **12**, 43–68.

Managave, S. R., Sheshshayee, M. S., Ramesh, R., Borgaonkar, H. P., Shah, S. K., & Bhattacharyya, A. (2011). Response of cellulose oxygen isotope values of teak trees in differing monsoon environments to monsoon rainfall. *Dendrochronologia*, **29**(2), 89–97.

Mann, M. E., Bradley, R. S., & Hughes, M. K. (2010). Long-Term Variability in the El Niño/Southern Oscillation and Associated Teleconnections. *El Nino and the Southern Oscillation*, (2), 357–410.

ann, M. E., Keimig, F. T., Hughes, M. K., Gross, W., Gille, E., Bradley, R. S., & Overpeck, J. (2000). Global Temperature Patterns in Past Centuries: An Interactive Presentation. *Earth Interactions*, **4**(4), 1–29Mann, M. E., Rutherford, S., Wahl, E., & Ammann, C. (2007). Robustness of proxy-based climate field reconstruction methods. *Journal of Geophysical Research Atmospheres*, **112**(12), 1–18.

Mann, M. E., Zhang, Z., Hughes, M. K., Bradley, R. S., Miller, S. K., Rutherford, S., & Ni, F. (2008a). Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia. *Proceedings of the National Academy of Sciences of the United States of America*, **105**(36), 13252–7.

Maraun, D., & Kurths, J. (2005). Epochs of phase coherence between El Nino/Southern Oscillation and Indian monsoon. *Geophysical Research Letters*, **32**(15), 2–6.

Marshman, J. C. (1905) *Abridgement of the history of India from the earliest period to the present time*. Edinburgh and London, William Blackwood and Sons.

McCarroll, D., Young, G. H. F., & Loader, N. J. (2015). Measuring the skill of variance-scaled climate reconstructions and a test for the capture of extremes. *Holocene*, **25**(4), 618–626.

McGregor, G., & Nieuwold, S. (1998). *Tropical Climatology*, 2nd Editio, Chichester: John Wiley & Sons.

Mcgregor, S., Timmermann, A., & Timm, O. (2010). Climate of the Past A unified proxy for ENSO and PDO variability since 1650. *Clim. Past*, **6**, 1–17.

McMichael, A. J. (2013). Globalization, Climate Change, and Human Health. *New England Journal of Medicine*, **368**(14), 1335–1343.

Mehta, S. K., Ojha, D., Mehta, S., Anand, D., Rao, D. N., Annamalai, V., Ananthavel, A., & Ali, S. (2017). Thermodynamic structure of the convective boundary layer (CBL) over the Indian monsoon region during CAIPEEX campaigns. *Annales Geophysicae*, **35**(6), 1361–1379.

Messerli, B., Grosjean, M., Hofer, T., Núñez, L., & Pfister, C. (2000). From nature-dominated to human-dominated environmental changes. *Quaternary Science Reviews*, **19**(1–5), 459–479.

Mikami, T. (2008). Climatic variations in Japan reconstructed from historical documents. *Weather*. doi:10.1002/wea.281

Mishra, A. K., & Singh, V. P. (2010). A review of drought concepts. *Journal of Hydrology*, **391**(1–2), 202–216.

Mishra, S. (2013). Cattle, dearth, and the colonial state: Famines and livestock in Colonial India, 1896-1900. *Journal of Social History*, **46**(4), 989–1012.

Mishra, V., Tiwari, A. D., Aadhar, S., Shah, R., Xiao, M., Pai, D. S., & Lettenmaier, D. (2019). Drought and Famine in India, 1870–2016. *Geophysical Research Letters*, **46**(4), 2075–2083.

Mitra, R. (2012). The Famine in British India: Quantification Rhetoric and Colonial Disaster Management. *Journal of Creative Communications*, **7**(1–2), 153–174.

Mooley, D. A., Parthasarathy, B., Rupa Kumar, K., Sontakke, N. A., Munot, A. A., & Kothawale, D. R. (2016). IITM Indian regional/subdivisional Monthly Rainfall data set (IITM-IMR). *Indian Institute of Tropical Meteorology*. Retrieved from https://www.tropmet.res.in/Data Archival-51-Page

Mudelsee, M. (2012). A proxy record of winter temperatures since 1836 from ice freeze-up/breakup in lake Näsijärvi, Finland. *Climate Dynamics*, **38**(7–8), 1413–1420.

Muir, R. (1917) *The Making of British India*. Manchester, The university press.

Mustafa, M. (2007). The shaping of land revenue policy in Madras Presidency: Revenue experiments - The case of Chittoor District. *Indian Economic and Social History Review*, **44**(2), 213–236.

Governmernt of Tamil Nadu (2013). *State Action Plan on Climate Change*. Online: http://moef.gov.in/wp-content/uploads/2018/01/States-SAPCC-tamilnadu.pdf

Naidu, C. V., Satyanarayana, G. C., Durgalakshmi, K., Malleswara Rao, L., & Nagaratna, K. (2010). Is winter monsoon rainfall over South Peninsular India increasing in global warming era? *Global and Planetary Change*, **72**(1–2), 69–72.

Nair, A., Acharya, N., Singh, A., Mohanty, U. C., & Panda, T. C. (2013). On the Predictability of Northeast Monsoon Rainfall over South Peninsular India in General Circulation Models. *Pure and Applied Geophysics*, **170**(11), 1945–1967.

Nair, A., Ajith Joseph, K., & Nair, K. S. (2014). Spatio-temporal analysis of rainfall trends over a maritime state (Kerala) of India during the last 100 years. *Atmospheric Environment*, **88**. doi:10.1016/j.atmosenv.2014.01.061

Nair, P. J., Chakraborty, A., Varikoden, H., Francis, P. A., & Kuttippurath, J. (2018). The local and global climate forcings induced inhomogeneity of Indian rainfall. *Scientific Reports*, **8**(1), 1–12.

Nash, D. J., & Adamson, G. C. D. (2014). Recent advances in the historical climatology of the tropics and subtropics. *Bulletin of the American Meteorological Society*. doi:10.1175/BAMS-D-12-00030.1

Nash, D. J., & Endfield, G. H. (2002). A 19th century climate chronology for the Kalahari region of central southern Africa derived from missionary correspondence. *International Journal of Climatology*. doi:10.1002/joc.753

Nash, D. J., & Grab, S. W. (2010). “A sky of brass and burning winds”: Documentary evidence of rainfall variability in the Kingdom of Lesotho, Southern Africa, 1824-1900. *Climatic Change*. doi:10.1007/s10584-009-9707-y

Nash, D. J., Klein, J., Endfield, G. H., Pribyl, K., Adamson, G. C. D., & Grab, S. W. (2019). Narratives of nineteenth century drought in southern Africa in different historical source types. *Climatic Change*. doi:10.1007/s10584-018-2352-6

Nash, D. J., Pribyl, K., Endfield, G. H., Klein, J., & Adamson, G. C. D. (2018). Rainfall variability over Malawi during the late 19th century. *International Journal of Climatology*, **38**(January), e629–e642.

Nash, D. J., Pribyl, K., Klein, J., Neukom, R., Endfield, G. H., Adamson, G. C. D., & Kniveton, D. R. (2016). Seasonal rainfall variability in southeast Africa during the nineteenth century reconstructed from documentary sources. *Climatic Change*. doi:10.1007/s10584-015-1550-8

Neukom, R., Luterbacher, J., Villalba, R., Küttel, M., Frank, D., Jones, P. D., Grosjean, M., Wanner, H., Aravena, J. C., Black, D. E., Christie, D. A., D’Arrigo, R., Lara, A., Morales, M., Soliz-Gamboa, C., Srur, A., Urrutia, R., & von Gunten, L. (2011). Multiproxy summer and winter surface air temperature field reconstructions for southern South America covering the past centuries. *Climate Dynamics*, **37**(1), 35–51.

Neukom, R., Nash, D. J., Endfield, G. H., Grab, S. W., Grove, C. A., Kelso, C., Vogel, C. H., & Zinke, J. (2014). Multi-proxy summer and winter precipitation reconstruction for southern Africa over the last 200 years. *Climate Dynamics*, **42**(9–10). doi:10.1007/s00382-013-1886-6

Neukom, R., Prieto, M. D. R., Moyano, R., Luterbacher, J., Pfister, C., Villalba, R., Jones, P. D., & Wanner, H. (2009). An extended network of documentary data from South America and its potential for quantitative precipitation reconstructions back to the 16th century. *Geophysical Research Letters*, **36**(12), 1–5.

Nicholson, S. E., Klotter, D., & Dezfuli, A. K. (2012). Spatial reconstruction of semi-quantitative precipitation fields over Africa during the nineteenth century from documentary evidence and gauge data. *Quaternary Research (United States)*, **78**(1), 13–23.

Niranjan Kumar, K., Rajeevan, M., Pai, D. S., Srivastava, A. K., & Preethi, B. (2013). On the observed variability of monsoon droughts over India. *Weather and Climate Extremes*, **1**, 42–50.

Nirmala, M., & Sundaram, S. M. (2010). A Seasonal Arima Model for Forecasting Monthly Rainfall in Tamilnadu. *National Journal on Advances in Building Sciences and Mechanics*, **1**(2), 43–47.

Norrgård, S. (2015). Practising historical climatology in West Africa: a climatic periodisation 1750–1800. *Climatic Change*. doi:10.1007/s10584-014-1307-9

O'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., Nygaard, L., & West, J. (2004). Mapping vulnerability to multiple stressors: Climate change and globalization in India. *Global Environmental Change*, **14**(4), 303–313.

Ogilvie, A. E. J. (2010). Historical climatology, Climatic Change, and implications for climate science in the twenty-first century. *Climatic Change*. doi:10.1007/s10584-010-9854-1

Ordoñez, P., Gallego, D., Ribera, P., Peña-Ortiz, C., & García-Herrera, R. (2016). Tracking the Indian Summer Monsoon Onset Back to the Preinstrument Period. *Journal of Climate*, **29**(22), 8115–8127.

PAGES 2k. (2013). Continental-scale temperature variability during the past two millennia. *Nature Geoscience*, **6**(5), 339–346.

Pai, D. S., & Rajeevan, M. (2009). Summer monsoon onset over Kerala : *Journal of Earth System Science*, **118**(2), 123–135.

Parker, D. J., Willetts, P., Birch, C., Turner, A. G., Marsham, J. H., Taylor, C. M., Kolusu, S., & Martin, G. M. (2016). The interaction of moist convection and mid-level dry air in the advance of the onset of the Indian monsoon. *Quarterly Journal of the Royal Meteorological Society*, **142**(699), 2256–2272.

Parthasarathy, B., Munot, A. A., & Kothawale, D. R. (1994). All-India monthly and seasonal rainfall series: 1871-1993. *Theoretical and Applied Climatology*, **49**(4), 217–224.

Paschen, J. A., & Ison, R. (2014). Narrative research in climate change adaptation - Exploring a complementary paradigm for research and governance. *Research Policy*, **43**(6), 1083–1092.

Pfister, C. (2010). The vulnerability of past societies to climatic variation: A new focus for historical climatology in the twenty-first century. *Climatic Change*, **100**(1), 25–31.

Pfister, C., Brazdil, R., Glaser, R., Barriendos, M., Camuffo, D., Deutsch, M., Dobrovolný, P., Enzi, S., Guidoboni, E., Kotyza, O., Militzer, S., Racz, L., & Rodrigo, F. S. (1999). Documentary evidence on climate in sixteenth century Europe. *Climatic Change*, **43**, 55–110.

Pillai, A. R. (1904) *The Private Diary of Ananda Ranga Pillai, Dubash to Joseph Francois Dupleix, Knight of the order of St Michael and Governor Pondicherry* (vol 1). Translated from French by Price, F., Achari, K. R. Madras, Government Press.

Pillai, A. R. (1918) *The Private Diary of Ananda Ranga Pillai, Dubash to Joseph Francois Dupleix, Knight of the order of St Michael and Governor Pondicherry* (vol. 6). Translated from French by Dowdwell, H. Madras, Government Press.

Pillai, A. R. (1925) *The Private Diary of Ananda Ranga Pillai, Dubash to Joseph Francois Dupleix, Knight of the order of St Michael and Governor Pondicherry* (vol 10). Translated from French by Dowdwell, H. Madras, Government Press.

Pillai, A. R. (1927) *The Private Diary of Ananda Ranga Pillai, Dubash to Joseph Francois Dupleix, Knight of the order of St Michael and Governor Pondicherry* (vol 11). Translated from French by Dowdwell, H. Madras, Government Press.

Pokhrel, S., Chaudhari, H. S., Saha, S K., Dhakate, A., Yadav, R.k., Salunke, K., Mahapatra, S., Rao, S. A. (2012) ENSO, IOD and Indian Summer Monsoon in NCEP climate forecast system. *Climate Dynamics* **39**, 2143-2165.

Prabhakar, S. V. R. K., & Shaw, R. (2008). Climate change adaptation implications for drought risk mitigation: A perspective for India. *Climatic Change*, **88**(2), 113–130.

Prieto, M. del R., & García Herrera, R. (2009). Documentary sources from South America: Potential for climate reconstruction. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **281**(3–4), 196–209.

Prieto, M. R., Gallego, D., García-Herrera, R., & Calvo, N. (2005). Deriving wind force terms from nautical reports through content analysis. The Spanish and French cases. *Climatic Change*, **73**(1–2), 37–55.

Privé, N. C., & Plumb, R. A. (2007a). Monsoon Dynamics with Interactive Forcing. Part II: Impact of Eddies and Asymmetric Geometries. *Journal of the Atmospheric Sciences*, **64**(5), 1431–1442.

Privé, N. C., & Plumb, R. A. (2007b). Monsoon dynamics with Monsoon Dynamics with Interactive Forcing. Part I: Axisymmetric Studies. *J. Atmos. Sci.*, **64**(1995), 1417–1430.

Queen, S. K. (2015). Idioms , Symbolism and Divisions : Beyond the Black and White Towns in Madras , 1652-1790, (August).

Raj, Y. E. A., & Geetha, B. (2008). Relation between southern oscillation index and Indian northeast monsoon as revealed in antecedent and concurrent modes. *Mausam*, **59**(1), 15–34.

Rajeevan, M., Gadgil, S., Bhate, J. (2010). Active and Break Spells of the Indian Summer Monsoon. NCC Research Report: March 2008. *Journal of Earth System Science*, **119**(3), 229–247.

Rajeevan, M., Pai, D. S., Anil Kumar, R., & Lal, B. (2007). New statistical models for long-range forecasting of southwest monsoon rainfall over India. *Climate Dynamics*, **28**(7–8), 813–828.

Rajeevan, M., Unnikrishnan, C. K., Bhate, J., Niranjan Kumar, K., & Sreekala, P. P. (2012). Northeast monsoon over India: Variability and prediction. *Meteorological Applications*, **19**(2), 226–236.

Raju, A. S. (1941) *Economic Conditions in the Madras Presidency 1800-1850.* PhD thesis. University of Madras.

Raju, P. V. S., & Bhatla, R. (2014). Evolution of withdrawal features of the southwest monsoon over India. *International Journal of Climatology*, **34**, 1860–1872.

Raju, P. V. S., Mohanty, U. C., & Bhatla, R. (2005). Onset characteristics of the southwest monsoon over India. *International Journal of Climatology*, **25**(2), 167–182.

Rakesh, V., Goswami, P., & Prakash, V. S. (2015). Evaluation of high resolution rainfall forecasts over Karnataka for the 2011 southwest and northeast monsoon seasons. *Meteorological Applications*, **22**(1), 37–47.

Ram, N. (1972). Impact of Early Colonisation on Economy of South India. *Social Scientist*, **1**(4), 47–65.

Ram, S., Borgaonkar, H. P., Munot, A. A., & Sikder, A. B. (2011). Tree-ring variation in teak (Tectona grandis L.) from Allapalli, Maharashtra in relation to moisture and Palmer Drought Severity Index, India. *Journal of Earth System Science*, **120**(4), 713–721.

Raman, B. (2012). The duplicity of paper: Counterfeit, discretion, and bureaucratic authority in early colonial madras. *Comparative Studies in Society and History*, **54**(2), 229–250.

Ramanathan, V., Chung, C., Kim, D., Bettge, T., Buja, L., Kiehl, J. T., Washington, W. M., Fu, Q., Sikka, D. R., & Wild, M. (2005). Atmospheric brown clouds: Impacts on South Asian climate and hydrological cycle. *Proceedings of the National Academy of Sciences*, **102**(15), 5326–5333.

Rao, G. N. (1998). Interannual Variations of Monsoon Rainfall in Godavari River Basin — Connections with the Southern Oscillation. *Journal of Climate*, **11**(4), 768–771.

Reddy, D. S. (1988). The Ryotwari Land Revenue Settlements and Peasant Resistance in the “Northern Division of Arcot” of the Madras Presidency during Early British Rule. *Social Scientist*, **16**(6/7), 35.

Retsö, D. (2015). Documentary evidence of historical floods and extreme rainfall events in Sweden 1400-1800. *Hydrology and Earth System Sciences*, **19**(3), 1307–1323.

Ridley, J., Wiltshire, A., & Mathison, C. (2013). More frequent occurrence of westerly disturbances in Karakoram up to 2100. *Science of the Total Environment*, **468–469**(April), S31–S35.

Robins, N. (2002). Loot: In search of the East India Company, the world’s first transnational corporation. *Environment and Urbanization*, **14**(1), 79–88.

Robins, N. (2012). *The Corporation that changed the world*, London: Pluto Press. doi:10.1017/CBO9781107415324.004

Rodrigo, F. S., & Barriendos, M. (2008). Reconstruction of seasonal and annual rainfall variability in the Iberian peninsula (16th-20th centuries) from documentary data. *Global and Planetary Change*, **63**(2–3), 243–257.

Roy Bhowmik, S. K., Sen Roy, S., & Kundu, P. K. (2008). Analysis of large-scale conditions associated with convection over the Indian monsoon region. *International Journal of Climatology*, **28**(6), 797–821.

Roy, I., Tedeschi, R. G., & Collins, M. (2019). ENSO teleconnections to the Indian summer monsoon under changing climate. *International Journal of Climatology*, **39**(6), 3031–3042.

Rutherford, S., Mann, M. E., Delworth, T. L., & Stouffer, R. J. (2003). Climate field reconstruction under stationary and non stationary forcing. *Journal of Climate,* **16**(3), 462–479.

Sadliwala, B. K. (2019). Fleeing Mass Starvation: What we (don't) know about the famine-migration nexus. *Disasters*, (2014), disa.12420.

Sanap, S. D., Priya, P., Sawaisarje, G. K., & Hosalikar, K. S. (2019). Heavy rainfall events over southeast peninsular India during northeast monsoon: Role of El Niño and easterly wave activity. *International Journal of Climatology,* **39**(4), 1954–1968.

Sarada, R. A. (1941) *Economic conditions in the Madras Presidency 1800-1850*. PhD thesis. University of Madras, Madras.

Schmith, T., & Hansen, C. (2003). Fram strait ice export during the nineteenth and twentieth centuries reconstructed from a multiyear sea ice index from southwestern Greenland. *Journal of Climate*, **16**(16), 2782–2791.

Schultze, B. (1858) *Notices of Madras and Cuddalore, in the last century from the journals and letters of the earlier missionaries of the society for promoting Christian knowledge.* London, Longman and Co.

Schulze-Engler, F. (2018). When remembering back is not enough: Provincializing Europe in World War II novels from India and New Zealand. *Memory Studies*, **11**(3), 315–327.

Sen, A. (1981). *Poverty and Famines: An Essay on Entitlement and Deprivation*. *Oxford, Claendon Press*. doi:10.1086/451432

Sengupta, A., & Nigam, S. (2019). The northeast winter monsoon over the Indian subcontinent and Southeast Asia: Evolution, interannual variability, and model simulations. *Journal of Climate*, **32**(1), 231–249.

Sengupta, S., Borgaonkar, H., Joy, R. M., & Ram, S. (2018). Monsoon climate response in Indian teak (Tectona grandis L.f.) along a transect from coast to inland. *Theoretical and Applied Climatology*, **134**(3–4), 1197–1205.

Seth, A., Giannini, A., Rojas, M., Rauscher, S. A., Bordoni, S., Singh, D., & Camargo, S. J. (2019). Monsoon Responses to Climate Changes—Connecting Past, Present and Future. *Current Climate Change Reports*, 63–79.

Shah, S. K., Bhattacharyya, A., & Chaudhary, V. (2007). Reconstruction of June-September precipitation based on tree-ring data of teak (Tectona grandis L.) from Hoshangabad, Madhya Pradesh, India. *Dendrochronologia*, **25**(1), 57–64.

Sharmila, S., Joseph, S., Sahai, A. K., Abhilash, S., & Chattopadhyay, R. (2015). Future projection of Indian summer monsoon variability under climate change scenario: An assessment from CMIP5 climate models. *Global and Planetary Change*, **124**, 62–78.

Shekhar, R., & Boos, W. R. (2016). Improving energy-based estimates of monsoon location in the presence of proximal deserts. *Journal of Climate*, **29**(13), 4741–4761.

Simon, A., & Mohankumar, K. (2004). Spatial variability and rainfall characteristics of Kerala. *Journal of Earth System Science*, **113**(2), 211–221.

Singh, A., & Patwardhan, A. (2012). Spatio-Temporal Distribution of Extreme Weather Events in India. *APCBEE Procedia*, **1**(January), 258–262.

Singh, D., Tsiang, M., Rajaratnam, B., & Diffenbaugh, N. S. (2014). Observed changes in extreme wet and dry spells during the south Asian summer monsoon season. *Nature Climate Change*, **4**(6), 456–461.

Singh, P., Gnanaseelan, C., & Chowdary, J. S. (2017). North-East monsoon rainfall extremes over the southern peninsular India and their association with El Niño. *Dynamics of Atmospheres and Oceans*, **80**, 1–11.

Sinha, A., Berkelhammer, M., Stott, L., Mudelsee, M., Cheng, H., & Biswas, J. (2011a). The leading mode of Indian Summer Monsoon precipitation variability during the last millennium. *Geophysical Research Letters*, **38**(15), 2–6.

Sinha, A., Cannariato, K. G., Stott, L. D., Cheng, H., Edwards, R. L., Yadava, M. G., Ramesh, R., & Singh, I. B. (2007). A 900-year (600 to 1500 A.D.) record of the Indian summer monsoon precipitation from the core monsoon zone of India. *Geophysical Research Letters*, **34**(16), 1–5.

Sinha, A., Stott, L., Berkelhammer, M., Cheng, H., Edwards, R. L., Buckley, B., Aldenderfer, M., & Mudelsee, M. (2011b). A global context for megadroughts in monsoon Asia during the past millennium. *Quaternary Science Reviews*, **30**(1–2), 47–62.

Slavin, P. (2016). Climate and famines : a historical reassessment, **7**(June), 433–447.

Slettebak, R. T. (2012). Don't blame the weather! climate-related natural disasters and civil conflict. *Journal of Peace Research*, **49**(1), 163–176.

Sontakke, N. A., Singh, N., & Singh, H. N. (2008). Instrumental period rainfall series of the Indian region (AD 1813-2005): Revised reconstruction, update and analysis. *Holocene*, **18**(7), 1055–1066.

Sreekala, P. P., Rao, S. V. B., & Rajeevan, M. (2012). Northeast monsoon rainfall variability over south peninsular India and its teleconnections. *Theoretical and Applied Climatology*, **108**(1–2), 73–83.

Stafford, J. (2017). A sea view: perceptions of maritime space and landscape in accounts of nineteenth-century colonial steamship travel. *Journal of Historical Geography*, **55**(November 1857), 69–81.

Stahl, R. M. (2016). The Economics of Starvation: Laissez-Faire Ideology and Famine in Colonial India. In *Intellectual History of Economic Normativities*, New York: Palgrave Macmillan US, pp. 169–184.

Stern, P. C., Ebi, K. L., Leichenko, R., Olson, R. S., Steinbruner, J. D., & Lempert, R. (2013).

Managing risk with climate vulnerability science. *Nature Climate Change*, **3**(7), 607–609.

Stieler, A. (1875) *Stielers Handatlas: Inner-Asien & Indien.* Map, scale, 1:7500000. Justus Perthes, Gotha.

Suntharalingam, R. (1974). *Politics and nationalist awakening in South India, 1852-1891*, Tucson: University of Arizona Press.

Suokhrie, T., Saalim, S. M., Saraswat, R., & Nigam, R. (2018). Indian monsoon variability in the last 2000 years as inferred from benthic foraminifera. *Quaternary International*, **479**, 128–140.

Thomas, J., & Prasannakumar, V. (2016). Temporal analysis of rainfall (1871-2012) and drought characteristics over a tropical monsoon-dominated State (Kerala) of India. *Journal of Hydrology*, **534**, 266–280.

Thomas, P. J. (1924). The beginnings of calico-printing in England. *English Historical Review*, **39**(154), 206–216.

Torrence, C., & Webster, P. J. (1998). The annual cycle of persistence in the El Nino/Southern Oscillation. *Q. J. R. Meteorological Society*, **124**(October 1996), 1985–2004.

Tripati, S., & Raut, L. N. (2006). Monsoon wind and maritime trade : a case study of historical evidence from Orissa , India, **90**(6).

Tudhope, A. W., Lea, D. W., Shimmield, G. B., Chilcott, C. P., & Head, S. (1996). Monsoon climate and Arabian Sea coastal upwelling recorded in massive corals from Southern Oman. *Research Reports*, **11**, 347–361.

Turner, A. G., & Annamalai, H. (2012). Climate change and the South Asian summer monsoon. *Nature Climate Change*, **2**(8), 587–595.

Turner, A. G., & Slingo, J. M. (2009). Uncertainties in future projections of extreme precipitation in the Indian monsoon region. *Atmospheric Science Letters*, **10**, 152–158.

Tyagi, A., Mazumdar, A. B., Khole, M., Gaonkar, S. B., Devi, S., & Ramanathan, R. A. N. (2011). Re-determination of normal dates of onset of southwest monsoon over India. *Mausam*, **62**(3), 321–328.

Vaquero, J. M., García-Herrera, R., Wheeler, D., Chenoweth, M., & Mock, C. J. (2008). A historical analog of 2005 Hurricane Vince. *Bulletin of the American Meteorological Society*, **89**(2), 191–201.

Varadan, R. J., & Kumar, P. (2015). Mapping agricultural vulnerability of Tamil Nadu, India to climate change: a dynamic approach to take forward the vulnerability assessment methodology. *Climatic Change*. doi:10.1007/s10584-015-1327-0

Vartavarian, M. (2014). An open military economy: The british conquest of South India reconsidered, 1780-1799. *Journal of the Economic and Social History of the Orient*, **57**(4), 486–510.

Veena, M. P., Achyuthan, H., Eastoe, C., & Farooqui, A. (2014). A multi-proxy reconstruction of monsoon variability in the late Holocene, South India. *Quaternary International*. doi:10.1016/j.quaint.2013.10.026

Vega, I., Gallego, D., Ribera, P., Gómez-Delgado, F. de P., García-Herrera, R., & Peña-Ortiz, C. (2018). Reconstructing the western North Pacific summer monsoon since the late nineteenth century. *Journal of Climate*, **31**(1), 355–368.

Wallbrink, H., Koek, F., & Brandsma, T. (2009). The US Maury collection Metadata 1796 - 1861.

Walsh, R. P. D., Glaser, R., & Militzer, S. (1999). The climate of madras during the eighteenth century. *International journal of climatology int. J. Climatol*, **19**, 1025–1047.

Wang, B., Xiang, B., Li, J., Webster, P. J., Rajeevan, M. N., Liu, J., & Ha, K. J. (2015). Rethinking Indian monsoon rainfall prediction in the context of recent global warming. *Nature Communications*, **6**(May). doi:10.1038/ncomms8154

Washbrook, D. (2004). South India 1770-1840: The colonial transition. *Transition*, **38**(3), 479–516.

Webster, A. (1990). The political economy of trade liberalization: the East India Company Charter Act of 1813. *The Economic History Review*, **43**(3), 404–419.

Webster, P. J., Magaña, V. O., Palmer, T. N., Shukla, J., Tomas, R. A., Yanai, M., & Yasunari, T. (1998). Monsoons: Processes, predictability, and the prospects for prediction. *Journal of Geophysical Research: Oceans*, **103**(C7), 14451–14510.

Wheeler, J. T. (1861) *Madras in the olden time: being a history of the presidency from the first foundation of Fort St. George.* Madras, Graves and Co.

Wheeler, D. (2004). Understanding seventeenth-century ships' logbooks: An exercise in historical climatology. *Journal for Maritime Research*, **6**(1), 21–36.

Wheeler, D., & García-Herrera, R. (2008). Ships' logbooks in climatological research: Reflections and prospects. *Annals of the New York Academy of Sciences*, **1146**, 1–15.

Wheeler, D., Garcia-Herrera, R., Wilkinson, C. W., & Ward, C. (2010). Atmospheric circulation and storminess derived from Royal Navy logbooks: 1685 to 1750. *Climatic Change*, **101**(1), 257–280.

Wheeler, D., & Wilkinson, C. (2004). From calm to storm: The origins of the beaufort wind scale. *Mariners Mirror*, **90**(2), 187–201.

Wheeler, J. T. (1861) *Madras in the olden time: being a history of the presidency from the first foundation of Fort St. George.* Madras, Graves and Co.

Wilkinson, C., Woodruff, S. D., Brohan, P., Claesson, S., Freeman, E., Koek, F., Lubker, S. J., Marzin, C., & Wheeler, D. (2011). Recovery of logbooks and international marine data: The RECLAIM project. *International Journal of Climatology*. doi:10.1002/joc.2102

Wilson, N. H. (2011). From reflection to refraction: State administration in British India, circa

1770-18551. *American Journal of Sociology*, **116**(5), 1437–1477.

Wilson, R., Cook, E., D'Arrigo, R., Riedwyl, N., Evans, M. N., Tudhope, A., & Allan, R. (2010). Reconstructing ENSO: the influence of method, proxy data, climate forcing and teleconnections. *Journal of Quaternary Science*, **25**(1), 62–78.

Wood, K., & Overland, J. E. (2003). Accounts from 19th-century Canadian Arctic Explorers' Logs Reflect Present Climate Conditions. *Eos*, **84**(40). doi:10.1029/2002JB002077,2003

Woodruff, S. D., Diaz, H. F., Worley, S. J., Reynolds, R. W., & Lubker, S. J. (2005). Early ship observational data and ICOADS. *Climatic Change*, **73**(1–2), 169–194.

Wu, Z., & Yu, L. (2016). Seasonal prediction of the East Asian summer monsoon with a partial-least square model. *Climate Dynamics*, **46**(9–10), 3067–3078.

Xenarios, S., Nemes, A., Sarker, G. W., & Sekhar, N. U. (2016). Assessing vulnerability to climate change: Are communities in flood-prone areas in Bangladesh more vulnerable than those in drought-prone areas? *Water Resources and Rural Development*, **7**, 1–19.

Yadav, R. K. (2012). Why is ENSO influencing Indian northeast monsoon in the recent decades? *International Journal of Climatology*, **32**(14), 2163–2180.

Yadav, R. K. (2013). Emerging role of Indian ocean on Indian northeast monsoon. *Climate Dynamics*, **41**(1), 105–116.

Yancheva, G., Nowaczyk, N. R., Mingram, J., Dulski, P., Schettler, G., Negendank, J. F. W., Liu, J., Sigman, D. M., Peterson, L. C., & Haug, G. H. (2007). Influence of the intertropical convergence zone on the East Asian monsoon. *Nature*, **445**(7123), 74–77.

Yang, A. A. (2007). Bandits and kings: Moral authority and resistance in early colonial India. *Journal of Asian Studies*, **66**(4), 881–896.

Yun, K. S., & Timmermann, A. (2018). Decadal Monsoon-ENSO Relationships Reexamined. *Geophysical Research Letters*, **45**(4), 2014–2021.

Zhang, J., & Crowley, T. J. (1989). Historical Climate Records in China and Reconstruction of Past Climates. *American Meteorological Society*, **2**, 833–849.

Zhisheng, A., Guoxiong, W., Jianping, L., Youbin, S., Yimin, L., Weijian, Z., Yanjun, C., Anmin, D., Li, L., Jiangyu, M., Hai, C., Zhengguo, S., Liangcheng, T., Hong, Y., Hong, A., Hong, C., & Juan, F. (2015). Global Monsoon Dynamics and Climate Change. *Annual Review of Earth and Planetary Sciences*, **43**(1), 29–77.

Zhou, T., Brönnimann, S., Griesser, T., Fischer, A. M., & Zou, L. (2010). A reconstructed dynamic Indian monsoon index extended back to 1880. *Climate Dynamics*. doi:10.1007/s00382-009-0552-5

Zubair, L., & Ropelewski, C. F. (2006). The strengthening relationship between ENSO and northeast monsoon rainfall over Sri Lanka and southern India. *Journal of Climate*, **19**(8), 1567–1575.

Supplementary Information

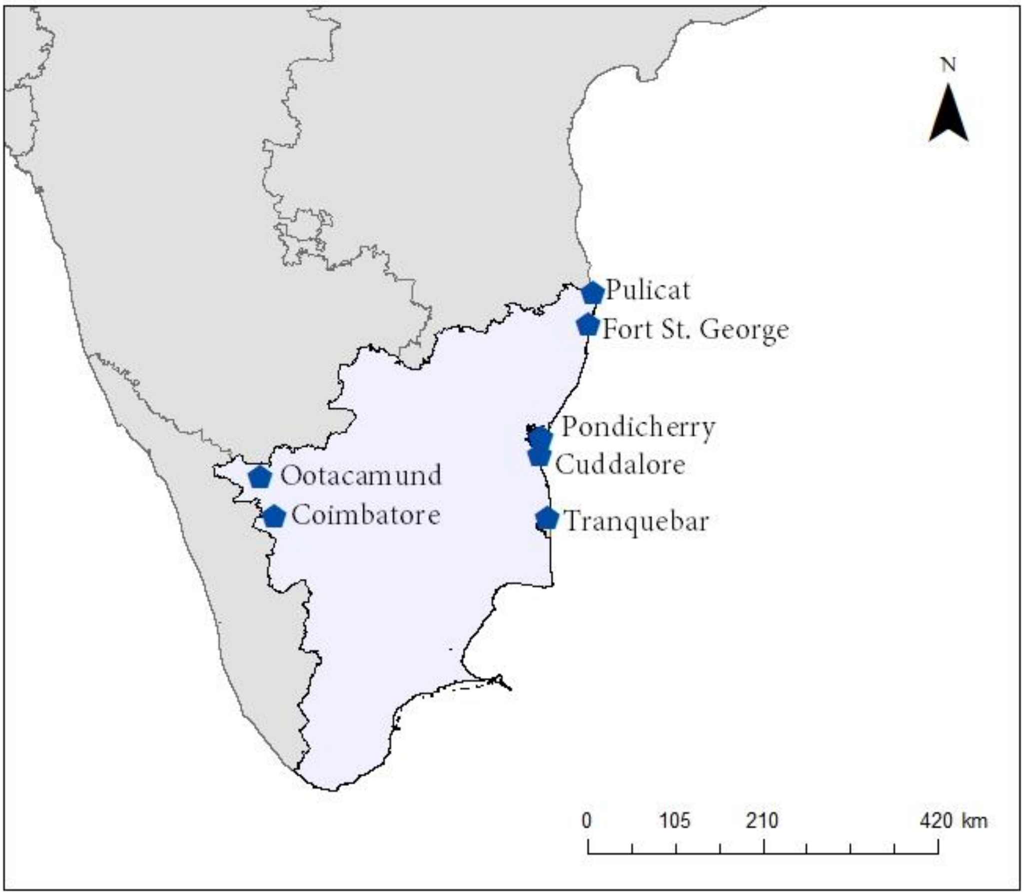

Figure S.1 – Map of additional places referred to in the text

Table S.2 - Mean and standard deviations for each of the eight transcribed early instrumental data sets

YEARS COVERED	MEAN	STANDARD DEVIATION
1791 - 1803	546	466
1804 - 1821	537	476
1822 - 1830	370	415
1830 - 1843	423	344
1844 - 1850	453	534
1851 – 1860	476	430
1861 - 1890	757	355
1897 – 1920	639	447

Table S.2 – An example of the raw data at each confidence interval

Confidence interval of 1: Example from 1756
October:
No Data
November:
"Owing to the severe rain from this morning and my attack of diarrhoea, I did not go out" - *The Diary of Ananda Ranga Pillai, vol. X (Dowdwell (eds.) 1925).*
December:
"My ill health kept me at home today. It was raining also." - *The Diary of Ananda Ranga Pillai, vol. X (Dowdwell (eds.) 1925).*
Seasonal summary:
No data

Confidence interval of 2: Example from 1781
October:
No Data
November:
"The army was permitted to go into cantonments in the middle of November, after having been exposed to the most violent and continued rains for fifteen days, and when the face of the country was so much covered with water that they could no longer be regularly supplied" - *The life of Sir Thomas Munro (Gleig 1849)*
"On the 19th in the midst of heavy rain, we quitted the woods. The rain continued all this time increasing and was accompanied by such an extreme cold that many hundreds, both men and bullocks passed away. The rain continued without abatement for two days." - *The life of Sir Thomas Munro (Gleig 1849)*
December:
No Data
Seasonal summary:
No Data

Confidence interval of 3: Example from 1804
October:
No Data
November:
No Data
December:
"In December 1804, information of a general failure of crops in South Arcot was received. Subsequently, however, rain fell and owing to the exertions of private parties in importing grain, no government interference with a view to relieve the apprehension of a famine was necessary." - *Medical, geographical and agricultural report of a committee appointed by the Madras Government to inquire into the causes of the epidemic fever which prevailed in the provinces of Coimbatore, Madura, Dindigul and Tinnivelly, during the years 1809, 1810 and 1811. (Ainsle et al. 1816)*
Seasonal summary:
"The years 1804, 1805 and 1807 were remarkable over the Coimbatore, Dindigul, Madura and Tinnivelly districts, for their dryness; but they were very healthy" - *Manual of the South Arcot District (Garstin 1878)*

Confidence interval of 4: Example from 1878
October:
“Reports on the state of the season and prospects of the crops for the week ending 29th October 1878, state that in Madras general prospects continue good; in Kurnool the weather has been more favourable, and prospects are brighter in Tinnevelly, where rain has fallen; in Coimbatore some damage continues. The number 55891 - number on relief works shows a further decrease of 9064.” - *The Times of India (1878).*
November:
“Reports on the state of the season and the prospects of the crops for the week ending the 12th November, 1878, state that in Madras prospects have not altered materially; the north-east monsoon has not yet broken generally. In Tinnevelly rain is still much required and indigenous locusts and caterpillars are destroying crops in places.” - *The Times of India (1878).*
“Reports on the state of the season and prospects of the crops for the week ending 19th of November 1878 state that in Madras prospects are reported to be less favourable in consequence of the retardation of the monsoon. Rain is much wanted in Tinnevelly, Chingleput, Nellore and Trichinopoly.” - *The Times of India (1878).*
“In gloomy weather we made out the low coast of India; the north-east monsoon blowing hard across Adam's Bridge and down the Gulf of Manaar, the sea very rough” - *Diary in Ceylon and India 1878-9 (Montagu 1879).*
December:
“Cool and cloudy with occasional light showers and a strong north-east monsoon. … The surf was tremendous. A cyclone was going on in the Bay of Bengal, which afterwards we learnt had struck the coast some 30 miles North of Madras.” - *Diary in Ceylon and India 1878-9 (Montagu 1879).*
“The morning was cloudy and hot.” - *Diary in Ceylon and India 1878-9 (Montagu 1879).*
“A very hot, calm day. The surf was still very high but the boats were loading and unloading by the pier.” - *Diary in Ceylon and India 1878-9 (Montagu 1879).*
“The reports in the state of the season and prospects of the crops for the week ending 10th December, state that there is no material change in Madras; in parts of Chingleput and Tanjore the crops are withering from want of rain, and in some other districts rain is much needed” - *The Times of India (1878).*
Seasonal summary:
“The rains of the north-east monsoon, on which the southern districts mainly depend, were almost a complete failure.” - The history of Cholera in India from1862-1881. (Bellew 1885)

Table S.2 – The changing skill scores for reconstructions performed using 3 -10 days with data as the threshold minimum. Those shown in yellow are the highest skill scores for each state, season and reconstruction method.

	Kerala						**Tamil Nadu**					
	PCR			CPS			PCR			CPS		
	Win	SWM	NEM	Win	SWM	NEM	Win	SWM	NEM	Win	SWM	NEM
3	-0.29	-0.84	-1.66	-0.52	-0.22	-0.36	-0.57	-0.11	-0.31	-0.53	-0.4	0.17
4	-0.86	-1.32	-1.63	-0.52	-0.41	-0.29	-0.66	-0.54	-0.19	-0.21	-0.54	0.01
5	-0.84	-1.61	-1.44	-0.59	-0.45	-0.75	-0.53	-0.29	-0.53	-0.93	-0.51	-0.18
6	-0.98	-1.54	-1.5	-0.62	-0.7	-0.7	-0.58	-0.54	-0.36	-0.98	-0.72	-0.22
7	-0.82	-1.82	-1.08	-0.7	-0.8	-0.73	-0.49	-0.71	-0.29	-1.11	-0.78	-0.34
8	-0.59	-1.88	-1.25	-0.39	-0.71	-0.54	-0.48	-0.48	-0.26	-0.91	-0.92	-0.59
9	-0.71	-2.45	-1.7	-0.38	-0.75	-0.53	-0.54	-0.38	-0.52	-0.79	-0.75	-0.72
10	-0.83	-2.99	-2.21	-0.47	-1.03	-0.61	-0.69	-0.37	-0.65	-0.74	-0.71	-0.6