1 **Building a long-time series for weather and extreme weather in the Straits Settlements:**
2 **a multi-disciplinary approach to the archives of societies**
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10 **Abstract:** In comparison to the Northern Hemisphere, especially Europe and North America,
11 there is a scarcity of information regarding the historic weather and climate of Southeast Asia
12 and the Southern Hemisphere in general. The reasons for this are both historic and political,
13 yet that does not mean that such data do not exist. Much of the early instrumental weather
14 records for Southeast Asia stem from the colonial period and, with some countries and regions
15 changing hands between the European powers, surviving information tends to be scattered
16 across the globe making its recovery a long and often arduous task. This paper focuses on data
17 recovery for two countries that were once joined under British governance: Singapore and
18 Malaysia. It will explore the early stage of a project that aims to recover surviving instrumental
19 weather records for both countries from the late 1780s to the 1950s, with early research
20 completed for the Straits Settlements (Singapore, Penang and Malacca) between 1786 and
21 1917. Taking an historical approach, the main focus here is to explore the types of records
22 available and the circumstances of their production. In so doing, it will consider the potential
23 for inaccuracy, highlight gaps in the record and use historical context to explain how and why
24 these problems and omissions may have occurred. It will also explore the availability of
25 narrative and data evidence to pinpoint extreme periods of weather such as drought or flood
26 and consider the usefulness of historical narrative in identifying and analysing extreme events.

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1 Introduction

There is now an extensive and convincing literature citing the value of extended instrumental observational datasets of past weather conditions for studying climatic trends and variability and, for identifying potential anthropogenic climatic changes (Ashcroft et al, 2014; Brázdil et al., 2010; Brönnimann et al., 2018b, 2019). In particular, instrumental observations, usually covering a period of two-hundred years or more, are considered vital for calibrating the differences between natural proxy reconstructions and model simulations (Brohan et al, 2012; Brönnimann et al., 2018b, 2019). The instrumental record for Southeast Asia however is very patchy, leading to less accurate climate reconstructions and even grey areas (Brönnimann et al., 2019.

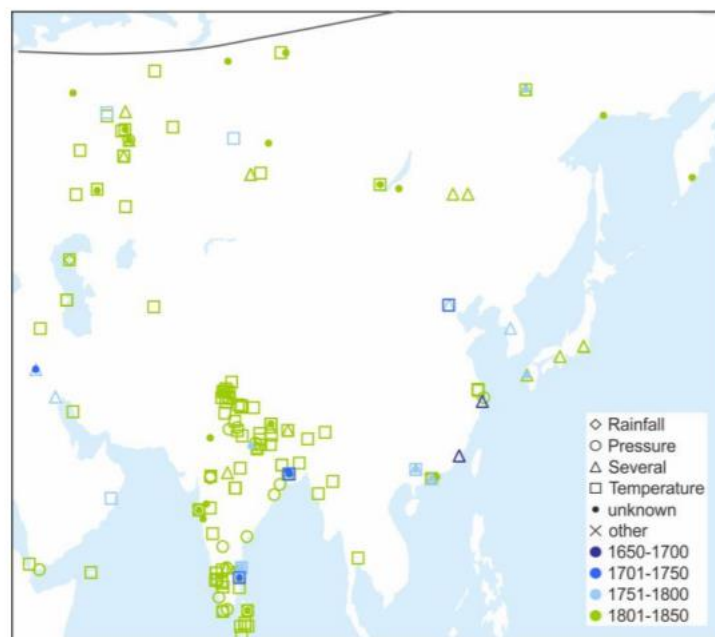



Fig. 1. Series inventoried for Asia pre-1850 (Figure 5 from Brönnimann et al., 2019)

The effectiveness of, for example, the Twentieth Century Reanalysis (20CR) which relies on data assimilation from surface observations of synoptic pressure to generate a four-dimensional global atmospheric dataset, improves with improved data quality and quantity across longer time periods (Compo et al, 2011; Brönnimann et al., 2018a). Relatedly, while there is a small literature on extreme events – such as flood and droughts - that have impacted on this region, there is very little for the Malay Archipelago specifically. While there is potential here for improving the long record of climate-induced disaster (Brázdil, 2018), from an historical climatology perspective there is also great potential for studies that investigate environmental and climatic catalysts for socio-cultural and political change (Lee et al, 2017; Hsiang & Burke, 2014) or, exploring long-term patterns of human-environmental interaction (Brook, 2010; Bankoff, 2003).

This article focuses on surviving, known records for the Straits Settlements, now part of modern Singapore and Malaysia. The Straits Settlements were a collection of British colonies established as one administrative unit under the English East India Company from 1826 to 1867 and thereafter under the British Colonial Office until 1946, though British settlements had existed on the peninsula since 1786. The chief areas under this arrangement comprised Penang Island, Singapore, Malacca and later, the Christmas Islands, along with other sub-regions including Province Wellesley (now mainland Penang), the Dindings (now Manjung,

84 southwest Perak) and Labuan (Sabah, East Malaysia). The bulk of the instrumental records for
85 the nineteenth century are centred on urban or peri-urban areas, due to the fact that British
86 influence was less widespread in the rural areas and interior at this time. With the exception of
87 a few isolated observations made on plantations or during unusual or extreme weather events,
88 rural recording only really began in earnest during the 20th century. It could be argued that
89 meteorological recording moved through several distinct phases, with a military and medical
90 drive across the first phase, roughly 1800-1845, an interim period of fairly loose private
91 enterprise across the 1850s and early 1860s, followed by a push to integrate weather more
92 firmly into administrative practices. Then, from 1869, weather watching was introduced
93 formally as part of the Medical Department's services until the early 20th century. Thereafter
94 the challenges of the newly created aviation industry, especially acute during the First World
95 War, placed increasing pressure on the government to create a centralised and dedicated
96 meteorological department which began operations in 1929.

2 Methods

99 This dataset is based on instrumental observations for the Straits Settlements c. 1786 to 1917.
100 It is intended to - eventually – form the core of a larger body of data that spans the whole of
101 British Malaya, covering areas known as the Federated Malay States (FMS) including
102 Selangor, Perak, Negri Sembilan and Pahang, for which data was increasingly collected under
103 direction of the British colonial authorities after the 1880s. Instrumental observations for this
104 area are largely to be found in historic archives and libraries covering the period of British
105 colonial rule. Thus, holdings are located in the national archives of both Singapore and
106 Malaysia, the National Library Board of Singapore (both in-house and online repositories),
107 especially in documents such as government gazettes and newspapers. However, observations
108 have also been identified in contemporary scientific, horticultural and agricultural journals as
109 well as in overseas archives and libraries, especially The National Archives (UK); the UK
110 Meteorological Office Library and Archive, the British Library and the Cambridge Library and
111 Archives (UK).

113 The dataset covered in this article represents several years-worth of research under the auspices
114 of the international Atmospheric Circulation Reconstructions over the Earth (ACRE) initiative
115 for Southeast Asia, a project designed to facilitate the recovery of instrumental terrestrial and
116 marine observations from historical documents, with the ultimate aim of digitising them in
117 electronic formats to share publicly with research communities across the world. This project
118 also has close links to the UK Newton Fund's Climate Science to Service Partnership for China
119 (ACRE China under CSSP China) (Scaife et al., 2020). Data found are catalogued, imaged
120 when not already in digital format, and digitised. Ultimately, ACRE-facilitated data is
121 deposited in global weather data repositories such as the International Surface Pressure
122 Databank (ISPD) and the new Copernicus C3S Data Rescue Service. Here, it can be used for
123 climate reanalyses tools and platforms, including the NOAA-CIRES-DOE Twentieth Century
124 Reanalysis (20CR). The dataset presented here in this paper represents only that data which
125 has been through all stages of recovery from archival original form to fully digitised and usable
126 sources. Much more has been uncovered and is yet to be digitised, especially for the post-1917
127 period and for the more rural states of Malaysia. Completed datasets are available on request
128 to ACRE.

130 While the predominant focus of the ACRE project has been instrumental data, the project has
131 also unearthed vast quantities of narrative account of weather, especially extreme weather,
132 during the course of research. While this is not currently in any comprehensive publicly

available form, it is being used to provide context to instrumental data across a number of funded historical projects with other organisations (see Allan et al., 2016).

3 Results

The table below highlights data that has been recovered and its current status.

No	Source	Observer or authorising officer	Location	Start date	End date	Duration (months/years)	Frequency	Variables				Availability
								T	P	R	O	
1	Observations made by Captain Francis Light, 1786.	Captain Francis Light, Superintendent, Penang	Fort Cornwallis, Penang	10.1786	11.1786	1 month	Once daily				1	2
2	Meteorological Observations taken at Malacca by William Farquhar, 1809.	William Farquhar, British Resident at Malacca.	Government House, Malacca	1809	1809	1 year	2 times daily, only abstracts survive	1	1	1	1	3
3	Charles Edward Davis	Military Staff Officer, EEIC	Government Hill, Fort Canning, Singapore	01.1820	12.1824	6 years	3 x daily, monthly averages	1	1			3
4	The Singapore Free Press and Mercantile Advertiser	Unknown	Unknown	10.1835	10.1837	2 years	Daily	1		1	1	3
4a	The Singapore Free Press and Mercantile Advertiser	Unknown	Unknown	12.1840	12.1840	1 month	Daily	1	1	1	1	3
5	Meteorological Register of Joseph S. Travelli	Joseph S. Travelli, Missionary	Ryan's Hill, Singapore	11.1839	02.1841	1 year, 2 months	Daily, but only abstracts survive.					2
6	Magnetical Observations made at Singapore	Lieutenant Charles Elliot, EEIC	Singapore Magnetic Observatory, Singapore	01.1841	11.1845	4 years, 11 months	Hourly	1	1		1	3
7	Observations made by J. D. Vaughan at Killeny Estate,	J. D. Vaughan, Police magistrate	Killeny Estate, River Valley Road	01.1863	09.1865	2 years, 9 months	Originals 3 times daily, but	1	1	1	1	3

No.	Title	Observer	Location	Start	End	Duration	Frequency					
	River Valley Road.						surviving records not consistent					
8	Arthur Knight's Observations made at Mount Pleasant, Thomson Road, Singapore	Arthur Knight, Audit Officer	Mount Pleasant, Singapore	01.1864	11.1869	5 years, 11 months	Mixed	1	1	1	1	3
9	Raffles and Horsburgh Lighthouses	J. W. Flory, 2nd Keeper and Thomas Todd, Senior Keeper respectively	Raffles Lighthouse, Coney Islet, Pulau Satumu, Singapore Horsburgh Lighthouse, Pedra Branca, Singapore	12.1864	12.1867	3 years	3 times daily	1	1	1	1	3
10	Convict Jail Hospital, 1869-1874	H. L. Randall, Colonial Surgeon (and A. F. Anderson, Acting Principal Civil Medical Officer Aug 1872-June 1873)	Convict Jail, Bras Basah	01.1869	12.1874	6 years	3 times daily	1	1	1	1	3
11	Kandang Kerbau Hospital, 1875	H. L. Randall, Principal Civil Medical Officer; T. Irvine Rowell, Principle Civil Medical Officer from 01.1877 to 12.1886; Max F. Simon, 01. 1887-1889; H. S.	Kandang Kerbau Hospital	01.1875	06.1917	41 years, 6 months	3 times daily	1	1	1	1	3

#	Name	Observer/Officer	Location	Start	End	Duration	Frequency					
		Colston, Acting Colonial Surgeon 1889; T. S. Kerr, Colonial Surgeon, 1893-?										
12	MacRitchie Reservoir Monthly Rainfall, 1879-1948	Municipal Engineer	MacRitchie Reservoir, Singapore	01.1879	12.1948	69 years	Monthly				1	3
13	Monckton Coombs' Thermometrical Registers	Lieutenant-Colonel John Moncton Coombes, Madras Army, EEIC.	Penang Island, Malaysia	06.1815	06.1816	1 year	3 times daily	1			1	3
14	Ward's Medical Topography	Dr T. M. Ward	Various, Penang Island, Malaysia	07-1815	06.1830	15 years	3 times daily	1			1	3
15	Rainfall observations at Penang Island 1884-1885	T. Irvine Rowell, Principle Civil Medical Officer for the Straits Settlements.	Fort Cornwallis, Central Prison, Government Hill, Leper Asylum	01.1884	12.1885	2 years	Daily	1				3
16	Observations made at District Hospital Penang Island, 1885-1886, 1896-1904, 1906-1917.	T. Irvine Rowell, Principle Civil Medical Officer for the Straits Settlements.	District Hospital, George Town, Penang, Malaysia	01.1885	06.1917	31 years, 6 months	3 times daily	1	1	1	1	3
17	Criminal Prison Hospital, Penang	T. C. Mugliston, Colonial Surgeon	Criminal Prison Observatory	01.1905	12.1908	3 years	3 times daily	1	1	1	1	3
18	Province Wellesley	The Colonial Surgeon (various).	Bukit Mertajam Hospital	01.1896	12.1915	19 years	3 times daily					
19	Christmas Island, 1901-1952	W. S. Anderson and Dr Faulkener 1901-1912; H. A. Forrer, District	Flying Fish Cove, Christmas Island	06.1901	11.1952	51 years	Twice daily	1	1	1	1	3

		Officer, 1913 - ?											

Table 1. Summary of meteorological observations recovered under ACRE for the Straits Settlements, 1786-1952.

NB On availability, 1 indicates that no metadata; 2 indicates metadata is available, 3 indicates metadata is available and has been digitized. All data is in original formats (Fahrenheit and insHg) unless otherwise stated.

Abbreviations:
EEIC – English East India Company
T- Temperature
P-Pressure
R- Rainfall
O- Other

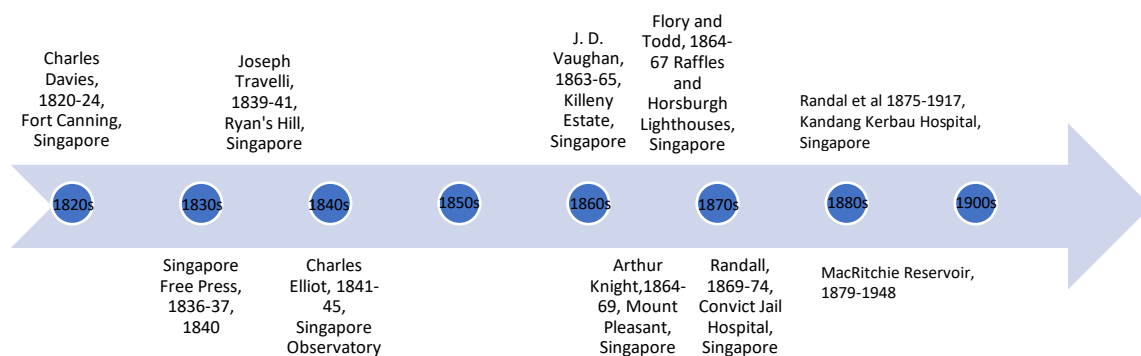



Fig. 2 Summary timeline of observations for Singapore, 1820-1948

4 Discussion

4.1 Historical Sources: 1786-1845

The first weather observations to be made in the Straits Settlements were by military officers engaged in explorative studies of the regions climate for strategic and economic purposes and, by doctors whose concern was to establish the 'healthiness' of the region for European colonisation (Ward, 1830). The first known such records were made within a few months of the English East India Company (EEIC) taking possession of Penang (then Prince of Wales Island) in August 1786 (Bonney, 1965). Francis Light, the man then in charge of this strategic venture, recorded observations of wind and weather from Fort William, the EEIC's newly established military base across the October of that year. While only a short account, these data remain the first continuous terrestrial observations made by the British in what would within a few decades become the Straits Settlements. The next weather records were made under British Resident at Malacca, William Farquhar in 1809; in Singapore during 1815-16 and in Penang also in 1815-16. There is some confusion over the originator of these records. Farquhar was British Resident at Malacca from 1802 and of the newly founded Singapore from 1819 until 1823 and is often credited with making the observations. However, although the readings made in Malacca during 1809 connect with his time in residence, the Singapore and Penang sets offer complications. The timeframe for the Penang observations overlaps with those for Singapore and, were more likely made under Lieutenant-Colonel Monckton Coombes, an officer of the Madras Native Infantry under the English East India Company and appointed Town Mayor of Penang until 1825 (Bastin, 2014). For Singapore, with observations continuing until the end of 1824, it is unlikely that Farquhar made these himself. He had been dismissed from his post in late 1822 by Stamford Raffles and, although he had continued living in Singapore, he was

180 stabbed in March 1823 by a local merchant with a personal grudge. Both circumstances – along
181 with his important role as Resident - suggest that, although he may have signed off the
182 observations personally, he was likely delegating the physical task of daily recording to a
183 subordinate. Indeed, in some accounts, the EEIC Bengal Native Infantry officer Charles
184 Edward Davies is credited with making the Singapore readings. It would not be too far a stretch
185 of the imagination to consider Davies the originator. The measurements themselves were made
186 using EEIC ship instruments, these being the only ones available in Singapore at that time, a
187 fact that also explains the absence of rain gauge data – an instrument normally reserved for
188 terrestrial, not marine, use.

189
190 Thereafter a few years of observations for Singapore alone were printed in the local press across
191 the late 1830s, but their originator is currently unknown. A clue from the same newspaper in
192 1840 (The Singapore Free Press and Mercantile Advertiser, 5 March 1840, p. 3), suggests that
193 these may have been made by a private individual, rather than as part of a military or formal
194 endeavour as the earlier ones had been and their lack of mention in any scientific journal of the
195 period perhaps supports this theory. Another dataset was produced by the American missionary
196 Joseph S. Travelli for two years from 1839 but the next major, comprehensive dataset to have
197 been produced was that made during the magnetic research of EEIC Lieutenant Charles Elliot.

198
199 Unlike the earlier observations, for which little survives bar the abstracts, Elliot's dataset is
200 both detailed and complete. Elliot was stationed in Singapore to establish and run a magnetic
201 observatory between 1841-5. It was part of a global experiment, sponsored by the British Royal
202 Society and the British Association for the Advancement of Science (BAAS), to create a linked
203 system of observatories and weather stations to investigate magnetism, astronomy and weather,
204 more commonly known as the 'Magnetic Crusade' (Cawood, 1979). Elliot's observatory was
205 described as small but well designed. Air flow was maximised by the placement of open
206 windows and direct sunlight was prevented from reaching the meteorological instruments. The
207 walls were 18 inches thick and painted white in order that they should reflect, rather than retain
208 heat (Elliot, 1849). For four years, Elliot and his small team – comprising of locally hired
209 assistants and observers – worked on a shoe-string budget making hourly magnetic,
210 temperature and pressure observations from this building. Elliot himself lived on site and it
211 was largely down to his tireless efforts to record and publish the observations, that we still have
212 access to this incredible resource today, now digitised. He also made two months of readings
213 while on a trip to Borneo in 1842. Sadly, the observatory was closed in 1845, due to the
214 withdrawal of finances for this aspect of the magnetic project in Singapore, the instruments
215 sent to India for re-use at Bombay and the building was left empty for several years.

216
217 Several early-nineteenth century studies were conducted using these early datasets, especially
218 by colonial officers and scholars interested in monitoring long-term changes in rainfall. James
219 Richardson Logan, for example, founder of the *Journal of the Indian Archipelago and Eastern*
220 *Asia* published an article on the climate of Penang Island in 1848 (Logan, 1848), as too did
221 Lieutenant-Colonel James Low (Low, 1836); coroner Dr Robert Little (Little, 1848) and
222 apothecary and medical assistant J. J. L. Wheatley (Wheatley, 1881). All attributed changes in
223 rainfall to the rampant deforestation that had been taking place over the first years of British
224 settlement, virgin jungle making way for plantation, urbanisation and infrastructure (Ward,
225 1830).

226
227 **4.2. Historical Sources: 1845-1869**
228 The periodisation of this section reflects the ending of the magnetic observatory observations
229 in 1845 and the formal introduction of meteorology to the Medical Department administration

230 in 1869. Between 1845 and the early 1860s, weather data is obscure. It is not clear whether
231 observations were made and have been lost, or whether there were no observations made at all.
232 The first surviving attempts at creating a consistent weather record originate from private
233 individuals - plantation owners – who were primarily interested in rainfall as an aid to
234 agricultural productivity.
235
236 Jonas Daniel Vaughan was the first and one of the most comprehensive observers of this period.
237 Vaughan's main jobs at this time (as police magistrate, councillor and lawyer) had little
238 obvious connection with meteorology but prior to this he had served in the Bengal Marines,
239 before being posted to Singapore as Master Attendant and Marine Magistrate (the senior officer
240 in port) in Singapore in 1856 (Gibson-Hill, 1960; Makepeace, 1921). After retiring from this
241 role, he had started a plantation in the River Valley Road area alongside his police duties, on
242 what was then known as the Killeny Estate (Buckley, 1984). He made a series of observations
243 starting in 1863, which were subsequently published in the Straits Settlements Government
244 Gazette over three years (e.g. Vaughan, 1865). His neighbour - Arthur Knight - also made
245 inroads into meteorological observation during the same period and into the 1880s at Mount
246 Pleasant in Toa Payoh (Irvine Rowell, 1885). This would have been an incredible long-time
247 series spanning 17 years but unfortunately only the 1864-1869 data can be found, with the
248 exception of the annual rainfall abstracts (Wheatley, 1881). Into the early 1870s, Alsagoff and
249 Company, who owned lemongrass plantations around the modern-day Geylang area, then
250 called Perseverance Estate, were also responsible for a rainfall series (Straits Settlements
251 Government Gazette 1875). The family run business was headed by Syed Omar bin Mohamed
252 Alsagoff who was a leading member of the local Muslim community and one of the biggest
253 plantation owners in Singapore (Tan, 2009).
254
255 The backgrounds of the observers and emphasis placed on rainfall measurement during this
256 period demonstrates the importance of long-term records to local agriculturalists and
257 landowners, but formal, governmental involvement appeared limited. The only authorised
258 observations were those made at Singapore's Horsburgh and Raffles lighthouses during 1864
259 to 1867 by Thomas Todd (senior keeper) and J. W. Flory (second keeper) respectively (e.g.
260 Todd, 1864). This series is short but very detailed. Observations encompassed pressure,
261 temperature, wind, aspect of the sky, and rainfall by pluviometer, all taken 3 times per daily at
262 sunrise, noon, and sunset. Horsburgh was the first lighthouse to be built through British funding
263 in Singapore, opening in 1850. It was named for Captain James Horsburgh, hydrographer to
264 the EEIC from 1810 to 1836, famed for his surveys and charts of seas in the region. Raffles
265 was the second lighthouse, opening four years later and still in operation today. Of any other
266 observations, though the keepers likely continued to make records, no more were published
267 that this author is aware of currently. One plausible reason for this, is a change of governance
268 structure in 1867 when the Straits Settlements became a crown colony under direct control of
269 the Colonial Office in London. This was reflected in shifts in the format, scope and content of
270 the government gazettes and, hence, what was published in them.
271
272 **4.3. Historical Sources: 1869-1917**
273 In 1869, meteorology for the Straits Settlements was finally brought under control of the
274 Medical Department. The reasons for this were both historic and practical. First, the nineteenth
275 century had witnessed a surge of interest in what is known as medical meteorology, a field of
276 medical research that based its investigations on connections between health and weather. This
277 concept of disease causation had been inspired by centuries of Hippocratic thought, which
278 placed the environment and climate as significant elements in the construction of human health.
279 Particular peaks, such as very hot and dry weather, followed by exceptionally heavy rains were

280 considered unhealthy, as too were droughts and floods. As the century progressed, a
281 quantitative method of comparing disease incidence with meteorological data became common
282 practice across the colonies of the British Empire (e.g. Walker, 1876, 1925). The collation and
283 correlation of large quantities of statistical data for weather and disease incidence created
284 recognisable medical and scientific frameworks for understanding the relationship between
285 climate and health. The medical department also offered a coherent infrastructure for the
286 systematic collation of observations within a controlled environment directly under the
287 purview of the colonial government.
288
289 The first official set of observations under the medical department were made in Singapore at
290 the Convict Jail (Bras Basah) Hospital between 1869 and 1874. This hospital had originally
291 been intended to hold transported prisoners (mainly of Indian origin) from other British
292 colonies. The emphasis was on reformative labour and the prisoners were engaged in many
293 projects that enabled Singapore to develop as port town, providing manual and skilled labour
294 for construction, carpentry and so on (Yang, 2003). The weather data is very detailed, using
295 standardised sheets of similar format to those being used across the Straits Settlements and the
296 British colonies at this time. Readings were made 3 times per day of pressure, temperature
297 (using a wet and dry bulb); there were self-registering thermometers for readings made in the
298 sun, on grass and in shade; a hygrometer for dew point temperature, elastic force of vapor,
299 degree of humidity and saturation; and of course, rainfall, wind and remarks on state of
300 weather.
301
302 Despite the detailed records, little is known about the small-scale observatory within the prison
303 or, who made the observations. The prison itself was designed and established by George
304 Coleman, Superintendent of Public Works and of Convicts as an open plan area with numerous
305 workshops and studios, one of which was presumably an observatory space (McNair & Bayliss,
306 1889). Coleman handed operations to his successor Major John Frederick McNair, also a
307 prominent architect and an engineer. McNair was fluent in Hindustani and - according to some
308 contemporaries – had a good relationship with the predominantly Indian prisoners (The Straits
309 Times, 1884). He may have supervised a subordinate or even a trusted prisoner to make the
310 observations, but they were ultimately signed off by the Colonial Surgeon H. L. Randall. In
311 1867, the practice of transporting prisoners ended and, some six years later, around the time
312 that this observational set ended, most of the transportees had been removed and the original
313 department was disbanded entirely. The story of the hospital thus explains the beginning and
314 the end of this particular data set.
315
316 Kandang Kerbau Hospital took over the meteorological role, becoming the foremost source of
317 governmental public information on the weather for the remainder of the century, despite the
318 presence of conterminous datasets. Kandang Kerbau hospital became the largest medical
319 facility in Singapore, also housing a Lock Hospital by 1873 (Lee, 1990). The dataset is one of
320 the longest daily time series covering the widest set of perimeters for the Straits Settlements
321 during this period. Their extraordinary survival is result of the fact that the observations were
322 issued publicly in both government gazettes and the local press. The data includes sub-daily
323 pressure; temperature (dry and wet bulb) made at 9am, 3pm, and 9pm; self-registering
324 thermometers, placed in the sun, on grass, and in the shade; hygrometer readings; precipitation;
325 mean direction of wind; and general remarks on the weather. Again, we do not know who made
326 the observations but there are references that point to Assistant Surgeons and apothecaries
327 working at the hospital undertaking the role (*Government Gazette*, 1892). By the 1910s the
328 format had changed slightly, with more emphasis on cloud types. The records also note

329 important metadata context, by showing the height at which thermometers and the rain gauge
330 rim were set above the ground.
331

332
333 Fig. 3. Meteorological Observations taken at Kandang Kerbau Observatory, December 1911 published
334 in the Straits Settlements Government Gazette, 11 October 1912, pp. 1609-10.
335

336 The Kandang Kerbau observations are not published in the government gazettes beyond 1917
337 although they continued to be made. A possible explanation for their public disappearance is
338 that meteorology was moved out of the Medical Department and into the Museums Department
339 under Herbert Robinson at around this time. This rather unlikely home could have sounded the
340 end of the continued practice of public weather reports, had it not been for Robinson's own
341 personal interest in the science. Robinson was been critical of prior efforts to create
342 standardised and reliable readings, a problem that – in his opinion - appeared to afflict the rural
343 stations especially. Thus, from 1921, he began to recruit specialist staff and to improve
344 observer's training. His major achievement came in 1924, when he arranged the hire of a
345 dedicated Meteorological Officer for Malaya. After this, all meteorological returns for the
346 peninsula were collated by specialist clerks in the employ of the Museum's Department (SEL:
347 SEC 1108/1925). This was the preamble to the establishment of a formal, dedicated Malayan
348 Meteorological Department in 1929 (Maxwell & Robinson, 1927).
349

350 Elsewhere in the Straits Settlements, hospitals were also key to charting the weather. In Penang,
351 the District Hospital and the Leper Hospital, the latter situated on Pulau Jerajak, were the site
352 of continuous datasets throughout the late nineteenth century. The District Hospital records
353 begin in 1885 and - like Kandang Kerbau - follow through to 1917. Their disappearance is
354 likely linked to the changing governance structure for meteorology at that time. The
355 observations follow the same format too, as the Medical Department issued standardised sheets
356 for the making of sub-daily readings based on the typical British colonial standard.
357

358 All the hospital weather observations from across the settlements were signed off by successive
359 Principal Chief Medical Officers (PCMOs) but would have been created by a staff officer,
360 likely the Assistant Surgeon. The PCMO's attitude toward this overseer's role is also worthy
361 of mention. While all were obliged to maintain the records, those with an active interest in
362 weather science played a critical role in expanding meteorological services across the
363 peninsula. T. Irvine Rowell, who served as PCMO from 1877 is a case-in-point. His interest in
364 meteorology spanned far beyond the practice of medical meteorology but to understanding how
365 patterns of settlement might have impacted local weather, especially the purported connection
366 between deforestation and rainfall. Publishing studies using historic observations (Irvine
367 Rowell, 1885), he pushed hard to extend the number of registering stations across the country,
368 especially in rural areas, in order to understand anthropogenic changes in weather.
369

370 It is also worth highlighting one other important continuous dataset that has no connection to
371 the medical records. This was made at what is today known as MacRitchie Reservoir,
372 Singapore, from 1879. The reservoir opened after many years of planning and development at
373 the end of 1877 (Williamson, 2020; Broich, 2007). Meteorological observations commenced
374 in 1879 at two rain gauge sites, both of which still exist in almost their original locations today
375 (Gao, et al. 2019). Thus, their record serves as the longest continuous rainfall series for
376 Singapore, much of which has been recovered and digitised.
377
378 Finally, there is also evidence that observations were made at the Central Prison and at
379 Government Hill, Penang during the 1880s and at several other stations in and around
380 Singapore, including at the Pauper Hospital (Tan Tock Seng); the Peninsula and Oriental Steam
381 Navigation depot, the Botanic Gardens, and the Quarantine Station at St John's Island during
382 the late nineteenth century; the new Mount Faber Observatory and Fullerton Building from the
383 1920s and the Kallang airfield from the 1930s. There is enough evidence, either of reference
384 to observations being made, the existence of abstracts, or of scattered sets of readings
385 themselves, to show that unmined resources exist but, to date, these have not been recovered.
386
387 **4.4 Extreme Events: Droughts and Floods**
388 The detailed weather records that have been recovered, alongside either contextual and
389 narrative evidence from gazettes, newspapers, colonial reports and correspondence, eye-
390 witness accounts and contemporaneous historical writing, reveal a long record of drought and
391 flood across the Malayan peninsula. Indeed, the juxtaposition of data and narrative is more
392 revealing of events that were never purely meteorological but result as much from man's
393 encroachment on natural landscapes and the style and effectiveness of hydraulic engineering
394 and water resource management under the colonial authorities. Some of the worst disasters
395 stemmed not from excessive monsoon rains or, conversely, their failure, but from altering
396 natural water courses, urban, industrial or agricultural development on low-lying riverine or
397 coastal areas without proper attention to safeguards or, water supply failing to keep up with
398 rapidly expanding populations.
399
400 Major flooding events frequently entailed a similar combination of factors: the northeast
401 monsoon (especially at its peak in December); heavy rainfall in combination with a high tide
402 and man-made factors including limited sea defences; a high population density at riverine
403 low-lying land; soil erosion; deforestation and mining activities, among others. While floods
404 affected the Straits Settlements annually, some years proved exceptional, resulting in serious
405 damages, lost livelihoods and, on some occasions, population displacement and death. The first
406 severe event recorded during British colonial rule occurred across Penang and Province
407 Wellesley in December 1847. Contemporaries describing flood waters of more than three feet
408 (91.5 cm) when the river burst its banks, inundating plantations and washing away crops with
409 sluice like strength (The Singapore Free Press and Mercantile Advertiser, 1847). In Singapore,
410 it was 4 December 1855 before any severe events were noted, but on that occasion, the roads
411 became impassable under 2 foot (61 cm) of water, with witnesses describing turbulent weather
412 from the China Seas and ships grounded in port (The Straits Times, 1855).
413
414 Later events are better documented. The 1890s, for instance, were an especially difficult era,
415 with major floods in 1891, 1892, 1893 1897 and 1899. The 1892 event was especially unusual.
416 Occurring outside of the normal northeast monsoon in May, it quickly became immortalised in
417 community memory as the Great Flood. Pinpointing the event from contemporary newspaper
418 reports and looking at the meteorology from the records of Kandang Kerbau Hospital, we can
419 see an area of low pressure building on 28 May with rainfall of 1.04 inches. The following day,

a total 8.48 inches of rain was recorded within 24 hours. Contextual detail from the newspapers also reveals that the majority of this rain fell within four hours between 7am and 11am. Contemporary descriptions talk of a phenomenally heavy storm – or a squall from the China Seas - that broke all records since the hospital observations had begun in 1869. This is corroborated by record of a high south, south-westerly wind made during the 9am meteorological reading. The impact of all this on the town can be understood through contemporary official reports and descriptions in the press of damages and clean up operations, with infrastructural, transport and public health issues all recorded as significant issues (Singapore Free Press and Mercantile Advertiser, 1892).

In the early twentieth century, floods were recorded most years but events in 1909, 1910 and 1925 stand out in Singapore and in 1926 in Malaysia. The series of floods that occurred across the peninsula in late 1925 and into early 1926 were likely linked to strong ENSO conditions that had prevailed across that period, where heavy rains (often in combination with high tides in the Singapore case) created flash flooding, especially following extended dry periods. Reports from the press, photographs and engineering reports help contextualise the meteorological record, aiding in understanding the variable scales and extent of flood impacts across urban and rural parts of Singapore and Malaysia which had different levels of mitigation, land use and disaster responsiveness. Combining data and narrative reveals the potential value of historical context in fully appreciating the complex and dynamic natural and man-made circumstances that created a disaster (Pfister, 2009; Schenk, 2007).

For droughts, the value of the historical record is similar. Adding to known meteorological observation sets with additional stations or expanding daily or monthly sets with sub-daily data can help improve the quality of historical reanalyses of these events and, complementing this with extra context can augment our understanding of their human impacts. So, for example, while we have a near-global understanding of the physical signature of the 1877-8 El Niño event (Singh et al, 2018), we can improve and potentially re-assess such studies in light of enhanced observation quality and quantity (Huang et al, 2020).

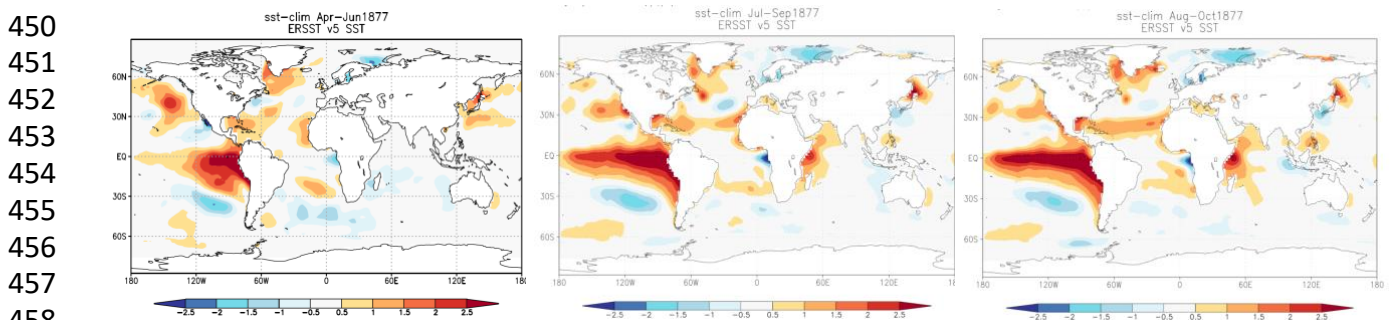
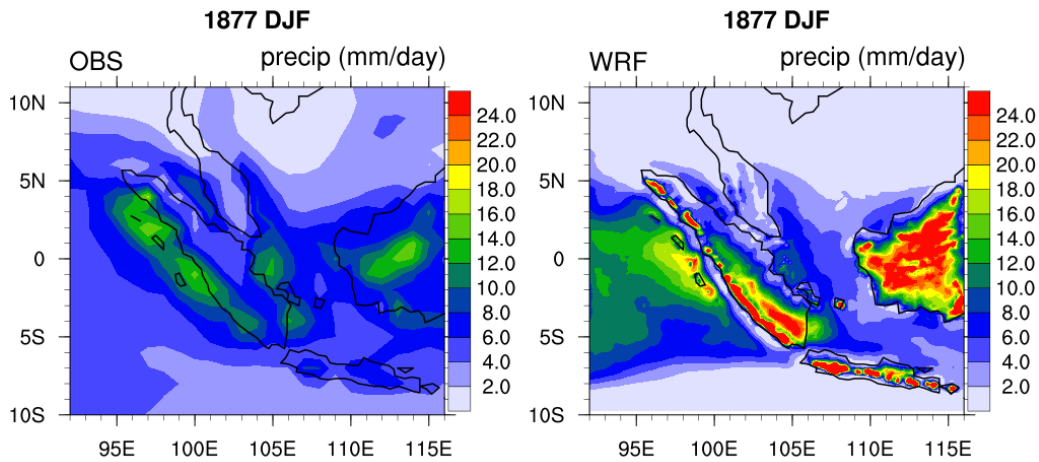



Fig. 4. Reconstructions of Sea Surface Temperature (SST) during April to October 1877 generated from the climate data from ERSSTv5 (SST anomalies with respect to the period 1854-2020) available on the WMO Climate Explorer, European Climate Assessment & Dataset (KMNI) (https://climexp.knmi.nl/start.cgi) using in-built correlation software, courtesy of Prof. Rob Allan, UK Meteorological Office (UKMO) and lead for the global ACRE initiative.

The extended observational set collated during this project for 1877-8 has been used so far to generate Weather Research and Forecasting (WRF) simulations of modelled and observed event using NCEP analysis at a greater extent than has been previously attempted, with recently recovered data from seven stations. Below are two examples of simulations created from the observed and WRF modelled precipitation data.

471
472 Fig. 5. Weather Research and Forecasting (WRF) and OBS simulations of DJF 1877 using
473 observational data from seven stations in Singapore using NCEP reanalyses. Source: Tropical
474 Marine Science Institute (TMSI), National University of Singapore (NUS), 2020.
475
476 The WRF model above was simulated at a spatial resolution of 18 km using data from the
477 stations noted below.
478

Observing Station	Coordinates
General Hospital, *Sepoy Lines*	1°16'51.1"N 103°50'10.3"E 1.280846, 103.836188
Kandang Kerbau Hospital	1°18'24.0"N 103°50'57.6"E 1.306661, 103.849336
Pauper Hospital (Tan Tock Seng)	1°19'03.5"N 103°51'27.2"E 1.317645, 103.857547
MacRitchie Reservoir, *Thompson Road*	1°20'36.4"N 103°50'11.9"E 1.343453, 103.836627
Mount Pleasant, *Thompson Road*	1°19'55.7"N 103°50'01.1"E 1.332141, 103.833630
Convict Jail Hospital, *Bras Basah Road*	1°17'45.0"N 103°51'01.0"E 1.295833, 103.850278
P & O Co's Depot, *New Harbour*	1°16'06.1"N 103°49'22.1"E 1.268357, 103.822805

479 Table. 2. Observing stations and co-ordinates used for the WRF analysis.
480
481 To enable comparison against observation locations, the closest grid point from the WRF
482 model was used (Raghavan et al., 2019; Raghavan et al., 2016; Skamarock, 2008) and, as the
483 simulations spanned historical climate, the WRF model simulations have been forced by NCEP
484 reanalyses using 20th century reanalysis V2 and 2c: (https://climatedataguide.ucar.edu/climate-
485 data/noaa-20th-century-reanalysis-version-2-and-2c).[1] The simulations reveal a relatively
486 close correction between the observed and WRF generated rainfall:

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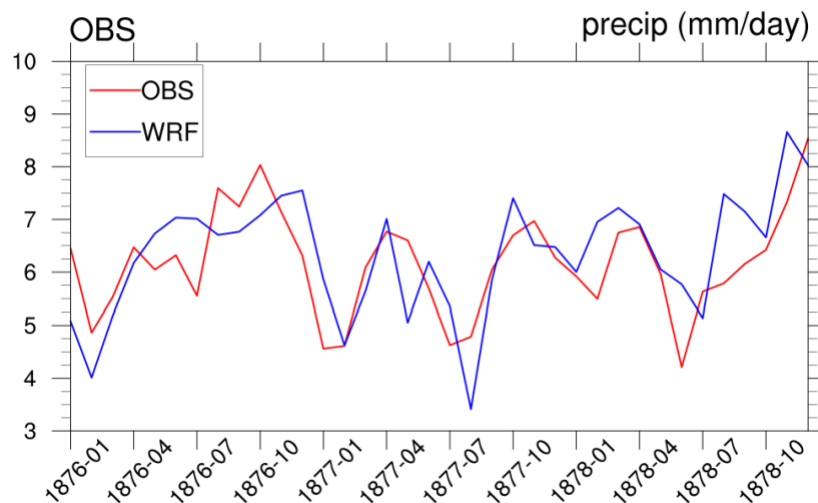
[1] 20CRv3 has data for this period but its currently a very course resolution and not useful for Singapore at this
stage. A detailed model of this event has not yet been attempted using 20CRv3.

487
488 Fig. 6. Correlation of Weather Research and Forecasting (WRF) and OBS simulations of DJF
489 1877-8 from seven historic stations in Singapore. Source: Tropical Marine Science Institute
490 (TMSI), National University of Singapore (NUS), 2020.
491

492 On the connected subject of how a close lens into such an event can also be used to further
493 contextualise social impacts, comparing the 1877 event with a comparable event in 1911 is
494 revealing of how atmospheric conditions might not always dictate obvious outcomes in the
495 society experiencing them. As a meteorological event, the scale of the El Niño inspired 1877
496 drought was especially severe in the Straits Settlements with some of the lowest rainfall ever
497 recorded at that time, though to a lesser scale than the impacts then witnessed in China and
498 India (Davies, 2001). The 1911 event was comparable meteorologically speaking to 1877 but
499 actually resulted in larger scale and deeper impacts on the people of the Straits Settlements.
500 While thorough analysis of the climatic conditions is essential to understanding what happened,
501 so too are factors including population, environment and infrastructure, especially as these
502 relate to population density in areas with limited access to water, the scale and quality of extant
503 mitigation measures (such as reservoir capacity), land-use and disaster preparedness. Filling in
504 observational gaps for this region will enable higher resolution dynamical reanalyses,
505 contextualised with the wider socio-economic, medical, and environmental context within
506 which such events have occurred over time. This has the potential to enable improved
507 frameworks to better inform policy decisions, as well as to improve forecasts of climate
508 variability and impacts.
509

510 **5 Conclusion**
511 The dataset presented here represents only a small portion of the available information for this
512 region and is designed to highlight only that data which has already been through all stages of
513 recovery from archival form to fully digitised and usable sources. There is more data available,
514 but it has not yet been recovered. This paper largely also only focuses on urban Straits
515 Settlements as, weather registering stations did not begin to be established across the whole
516 peninsula until at least the 1880s, and data from these stations is more scattered and, in many
517 cases, has not survived. Much more remains to be done in the pursuit of recovering such
518 records, through initial research to imaging, to ultimately processing into digital formats the
519 remaining records for these two countries, especially in extending the database beyond 1917
520 and across the peninsula into the FMS. Eventually, this project also seeks to recover
521 observations from ships' logs, from vessels stationary in port for long periods at Penang,

Singapore and Malacca, many of which are located at the UK Hydrographic Office and The National Archives (UK). These data recovery activities fit under the umbrella of the Southeast Asian arm of the global ACRE project, recovery of data for which area will significantly improve the potential for reanalysis of extreme meteorological events in this wider disaster-prone region, as well as improving the quality of long-term climate projections. However, data recovery for the peninsula – especially the early focus on towns and cities – can, and is, also being used in other multi-disciplinary projects exploring ENSO, urban heat, and the impact of flood and drought on urban settlements including Singapore over time.[2] While historical sources are not the whole solution to understanding past weather or the complex dynamics and interplay of climate forcings especially their role in extreme events, they offer one additional layer of information to support reanalyses investigating particular questions or long-view studies of climatic changes.

Competing Interests
The author declares that she has no conflict of interest.

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References

Ashcroft, L., Gergis, J., and Karoly, D. J.: A Historical climate dataset for southeastern Australia, 1788-1859, Geoscience Data Journal, 158-178, doi: 10.1002/gdj3.19, 2014.

Bankoff, G.: Cultures of disaster: Society and Natural Hazards in the Philippines, London, England: Routledge, 2003.

Bastin, J.: Raffles and Hastings: Private Exchanges behind the founding of Singapore, Singapore: National Library Board, 2014.

Bonney, R.: Francis Light and Penang, JMBRAS 38,1: 135-158, 1965.

Brázdil, R., Kiss, A., Luterbacher, J., Nash, D., & Řezníčková, L.: Documentary data and the study of past droughts: A global state of the art, Climate of the Past, 14, 1915–1960, 2018.

Brázdil, R., Dobrovolny, P., Luterbacher, J., Moberg, A., Pfister, C., Wheeler, D., Zorita, E.: European climate of the past 500 years: new challenges for historical climatology, Climatic Change 101, 7–40. doi:10.1007/s10584-009-9783-z, 2010.

Brohan, P., Allan, R., Freeman, E., Wheeler, D., Wilkinson, C., Williamson, F: Constraining the temperature history of the past millennium using early instrumental observations, Climate of the Past 8, 1551–1563, doi:10.5194/cp-8-1551-2012, 2012.

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[2] For example, two current projects include: Reconstructing El Niño in Singapore and Malaysia: a multi-disciplinary approach, Singapore Management University, MOET1-19-C242-SMU-003; Heat in Urban Asia: Past, Present and Future, National University of Singapore MOE2018-T2-2-120

570
571 Broich, J.: Engineering the Empire: British Water Supply Systems and Colonial Societies, 1850-1900,
572 Journal of British Studies 46, 2, 346-365, 2007.
573
574 Brönnimann, S., Allan, R., Atkinson, R., Buizza, O., Bulygina, P., Dahlgren, D., Dee, R., Dunn, P.,
575 Gomes, V., John, S., Jourdain, L., Haimberger, H., Hersbach, J., Kennedy, P., Poli, J., Pulliainen, N.,
576 Rayner, R., Saunders, J., Schulz, A., Sterin, A., Stickler, H., Titchner, M., Valente, C., Ventura, C.,
577 and Wilkinson, C: Observations for Reanalyses. Bull. Amer. Meteor. Soc. 99, 9, 1851-1866,
578 doi:10.1175/BAMS-D-17-0229.1, 2018a.
579
580 Brönnimann, S., Brugnara, Y., Allan, R.J., Brunet, M., Compo, G.P., Crouthamel, R.I., Jones, P.D.,
581 Jourdain, S., Luterbacher, J., Siegmund, P., Valente, M.A. and Wilkinson, C.W.: A roadmap to climate
582 data rescue services, Geoscience Data Journal, 5, 28–39, doi.org/10.1002/gdj3.56, 2018b.
583
584 Brönnimann, S., Allan, R., Ashcroft, L., Baer, S., Barriendos, M., Brázdil, R., Brugnara, Y., Brunet,
585 M., Brunetti, M., Chimani, B., Cornes, R., Domínguez-Castro, F., Filipiak, J., Founda, D., Garcia-
586 Herrera, G., Gergis, J., Grab, S., Hannak, L., Huhtamaa, H., Jacobsen, K.S., Jones, P., Jourdain, S.,
587 Kiss, A., Lin, Kuan-Hui Elaine, Lorrey, A., Lundstad, E., Luterbacher, J., Mauelshagen, F., Maugeri.,
588 M., Maughan, N., Moberg, A., Neukom., R., Nicholson, S., Noone, S., Nordli, O, Ólafsdóttir, K.B.,
589 Pearce, P., Pfister, L., Pribyl, K., Przybylak, R., Pudmenzky, C., Rasol, D., Reichenbach, D.,
590 Řezníčková, L., Rodrigo, F.S., Rohr, C., Skrynyk, O., Slonosky, V., Thorne, P., Valente, M.A.,
591 Vaquero, J.M., Westcott, N.E., Williamson, F. and Wyszyński, P: Unlocking pre-1850 instrumental
592 meteorological records: A global inventory, Bull. Amer. Met. Soc., 100, 12, 1-62, 2019.
593 Brook, T.: The troubled empire: China in the Yuan and Ming dynasties, Cambridge, MA: Belknap
594 Press, 2010.
595
596 Buckley, C. B.: An anecdotal History of Singapore 1819-1867, Oxford, 1984.
597
598 Cawood, J.: The Magnetic Crusade: Science and politics in early Victorian Britain, Isis 70: 493–518,
599 1979.
600
601 Compo, G. P., Whitaker, J. S., Sardeshmukh, P. D., Matsui, N., Allan, R. J., Yin, X, Gleason, B. E.,
602 Vose, R. S., Rutledge, G., Bessemoulin, P, Brönnimann, S., Brunet, M., Crouthhamel, R. I., Grant, A.
603 N., Groisman, P. Y., Jones, P. D., Kruk, M. C., Kruger, A. C., Marshall, G. J., Maugeri, M, Mok, H.
604 YK., Nordli, Ø., Ross, T. F., Trigo, R. M., Wang, X. l., Woodruff, S. D., Worley, S. J. : The Twentieth
605 Century Reanalysis Project, Q. J. R. Met. S., doi.org/10.1002/qj.776, 2011.
606
607 Davies, M.: Late Victorian Holocausts: El Niño Famines and the Making of the Third World, London:
608 Verso, 2001.
609
610 Elliot, C.: The Singapore Observatory (In a note for Dr Little's paper on the Medical Topography of
611 Singapore &c), Journal of the Indian Archipelago and Eastern Asia, 3, xxxvii-xlvi, 1849.
612
613 Gao, E., Timbal, B., Williamson, F.: Creating Singapore's Longest Monthly Rainfall Record from 1839
614 to the Present, MSS Research Letters 2, 3-11, 2019.
615
616 Gibson-Hill, C. A: The Master Attendants at Singapore, 1819-67, JMBRAS 33, 1, 1-64, 1960.
617
618 Hsiang, S. M., & Burke, M.: Climate, conflict, and social stability: What does the evidence say?
619 Climatic Change 123,1, 39–55, 2014.
620
621 Huang, B., L'Heureux, M., Hu, Z. Z., Yin, X., & Zhang, H. M.: How significant was the 1877/78 El
622 Niño?, Journal of Climate, 33, 11, 4853-4869, https://doi.org/10.1175/JCLI-D-19-0650.1, 2020.
623

624 Irvine Rowell, T.: Meteorological Report for the year 1885, Journal of the Straits Branch of the Royal
625 Asiatic Society 16, 385-411, 1885.

627 Lee, H. F., Zhang, D. D., Pei, Q., Jia, X., & Yue, P. H. R.: Quantitative analysis of the impact of
628 droughts and floods on internal wars in China over the last 500 years, Science China Earth Sciences,
629 60, 12, 2078–2088, 2017.

631 Lee, Y. K.: A Short History of the Kandang Kerbau Hospital and the Maternity Services of Singapore,
632 Singapore Med J, 31, 599-613, 1990.

634 Little, R.: An Essay on Coral Reefs as the cause of Blakan Mati Fever etc, Part I: On the medical
635 Topography of Singapore, particularly its Marshes and Malaria', Journal of the Indian Archipelago and
636 Eastern Asia III, VIII, 449-71, 1848.

638 Logan, J. R.: The Probable Effects on the Climate of Pinang of the Continued Destruction of its Hill
639 Jungles, II, JIAEA, 534-36, 1848.

641 Low, J.: A Dissertation on the Soil & Agriculture of the British Settlement of Penang, Or Prince of
642 Wales Island, in the Straits of Malacca: Including Province Wellesley on the Malayan Peninsula. With
643 Brief References to the Settlements of Singapore & Malacca, Singapore Free Press Office, 817-8, 1836.

645 Makepeace, W., Brooke, G., Braddell, R. St. J., One-hundred years of Singapore: being some account
646 of the capital of the Straits Settlements from its foundation by Sir Stamford Raffles on the 6th February
647 1819 to the 6th February 1919, I, London: John Murray, 1921.

649 Maxwell, G. and Robinson, H. C.: Proposal to establish a Meteorological Department for Malaya:
650 Memorandum on a Pamphlet entitled 'A Meteorological Department for Malaya', written by Victor A.
651 Lowinger, Surveyor General, Federated Malay States and Straits Settlements), 24 October 1927. The
652 National Archives, UK, CO273/541/4.

654 McNair, J. F. A. and Bayliss, W. D.: Prisoners their own warders: A Record of the Convict Prison at
655 Singapore in the Straits Settlements, Westminster: Archibald Constable & Co, 1889.
656 https://www.gutenberg.org/files/26974/26974-h/26974-h.htm

658 Pfister, C.: Learning from nature-induced disasters: theoretical considerations and case studies from
659 Western Europe, in: Natural disasters, cultural responses: case studies toward a global environmental
660 history, edited by: Mauch, C. and Pfister, Lanham: Lexington Books, 17-40, 2009.

662 Raghavan, V.S., Nguyen, N.S., Hur, J., NG, D.H.L and Liong, S.Y.: Evaluations and Inter-comparisons
663 of Regional Climate Model simulations of Southeast Asian climate: past and future' - Review of current
664 RCM configurations over SE Asia and Singapore', Report submitted to the Centre for Climate Research
665 Singapore (CCRS), Singapore, 2019.

667 Raghavan, V.S., Vu, M. T. and Liong, S.Y.: 'Regional Climate Simulations over Vietnam using the
668 WRF model', Theoretical and Applied Climatology, 126, 161-182. doi:10.1007/s00704-015-1557-0,
669 2016.

671 SEL: SEC 1108/1925, National Archives of Malaysia.

673 Scaife, A., Good, E., Sun, Y., Yan, Z., Dunstone, N., Ren, H. L., Li, C., Lu, R., Wu, P., Ma, Z, Ke, Z.,
674 Furtado, K., Wu, T., Zhou, T., Dunbar, T., Hewitt, C., Golding, N., Zhang, P., Allan, R., Dale, K., Lott,
675 F., Stott, P., Milton, S., Song, L., and Belcher, S.: The Climate Science to Service Partnership – China,
676 JMR, **Submitted,** 2020.

Schenk, G. J.: Historical disaster research. State of research, concepts, methods and case studies. Historical Social Research 32:9–31, 2007.

Singh, D. R., Seager, B. I., Cook, M., Cane, M., Ting, E., and Davies, M.: Climate and the Global Famine of 1876-78. J. Climate, 31, 9445-9467, doi.org/10.1175/JCLI-D-18-0159.1, 2018.

Skamarock, W.C., et al.: A Description of the Advanced Research WRF Version 3. NCAR Technical Notes, NCAR/TN-4751STR, 2008.

Straits Settlements Government Gazette, 13 August, 557, 1875.

Straits Settlements Government Gazette, 21 October, 1892.

Tan, B: Syed Omar bin Mohamed Alsagoff, 2009
https://eresources.nlb.gov.sg/infopedia/articles/SIP_1624_2009-12-31.html, last access 10 October 2020.

The Singapore Free Press and Mercantile Advertiser, 7 December, 1, 1847.

The Straits Times, 4 December, 4, 1855.

The Straits Times, 4 October, 11, 1884.

The Singapore Free Press and Mercantile Advertiser, 25 June, 2, 1892.
Todd, T.: Meteorological Register of the Raffles Lighthouse, for the month of December 1864, Straits Government Gazette, Singapore, 86, 1864.

Vaughan, J. D.: Register at River Valley Road for the Quarter ending December 1864, The Straits Government Gazette 20 January 1865, Singapore, 1865.

Walker, G: The Meteorology of India' Journal of the Royal Society of Arts, 73, 3793, 838-55, 1925.

Walker, G.: Meteorology in India in Relation to Cholera, The British Medical Journal 2, 810, 55-56, 1876.

Ward, T. M.: Contributions to the Medical Topography of Prince of Wales Island, Or Pulo Pinang', in: Official Papers on the Medical Statistics and Topography of Malacca and Prince of Wales Island and on the Prevailing Diseases of the Tenasserim Coast, edited by Ward T. M., and Grant, J. P., Pinang: Government Press, 1830.

Williamson, F.: Responding to Extremes: Urban Water Scarcity in the Nineteenth-Century Straits Settlements, Water History, doi.org/10.1007/s12685-020-00260-6, 2020.

Wheatley, J. J. L.: Notes on the Rainfall of Singapore, Journal of the Straits Branch of the Royal Asiatic Society, Singapore, 31-50, 1881.

Yang, A. A.: Indian Convict Workers in Southeast Asia in the late eighteenth and early nineteenth centuries, Journal of World History 14, 2, 179-208, 2003.