

## **Learning About the Weather in Early Colonial New Zealand**

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### **Abstract**

When the first European settlers occupied the eastern South Island lowlands and hill country they had to learn for themselves about the area's weather, climate and hydrology. We traced 47 diaries and letter books written between 1835 and 1869, and found that most contained qualitative accounts of daily weather. The few meteorological measurements reported in them were usually low barometric pressures. For much of the South Island, settlers' observations are the only weather records available to us until the late 1860s, when a national network of meteorological observatories was in operation. Before informal weather reports can be used with any confidence, however, they must be validated. Accordingly, we analysed Joseph Munnings' qualitative accounts of the daily weather in Christchurch and its environs between November 1859 (when he arrived in the settlement) and late November 1866 (when his diary ends) and found (a) clear seasonal variations in temperature, precipitation, wind strength and direction, (b) evidence of cooling to 1861 then steady warming for the remainder of the period, (c) worsening drought after 1862, (d) severe winter snow storms in 1861, '62 and '63, then frequent dust storms, and (e) persistent, strong northwest winds inland and northeast winds near the ground with northwest winds aloft in Christchurch. We then compared his diary entries for three historically significant months with entries in contemporaneous accounts from other parts of the eastern South Island and found that independent observers had often noted the same or comparable wind direction and strength, type of precipitation, and stormy weather. In addition, the geographic spread of dates for the onset and end of an extreme weather event gave a realistic account of its passage across the eastern South Island.

The findings reported here accord with the historical record, but provide greater detail about weather systems in the early colonial period. We conclude that despite their limitations, informal weather records, such as those in Munnings' diary, can be used to identify weather patterns and events for the period before meteorological measurements were widely recorded, and for areas far from meteorological observatories. We also show that information from runs of several years of continuous daily weather observations can indicate multi-year changes in the prevalence of particular weather systems, and suggest that the daily weather reports in Munnings' diary point to El Niño conditions in eastern South Island during the mid-1860s.

## 1. Introduction

In the first two decades of organised settlement, New Zealand newspapers occasionally printed descriptive accounts of local weather during the previous 24 hours, as well as weather and hydrological reports from correspondents in the gold fields, abstracts of weather information in ships' logs, and weather notes that had appeared in magazines and newspapers published elsewhere days or weeks before. Full runs of newspapers published in the larger centres have been preserved in local and national archives, but others are incomplete. Those records, along with compilations of unstandardised weather observations from meteorological stations in the larger centres, are not, however, the only sources for the weather and climate of early colonial New Zealand. In this paper we show that information from a geographical spread of settlers' diaries can reveal significant weather events and patterns at a time when far-reaching decisions were being made about land use, bridges and other infrastructure, the locations of large and small settlements, and protective works along the banks of rivers.

For several decades, settlers had to recognise and interpret the signs of impending weather systems then predict their impact upon land and livelihood (Hay, 1915; Holland and Mooney, 2006). In September 1874, the *Lyttelton Times* reported a lecture to members of the Kaiapoi Farmers' Club by Marmaduke Dixon in which he drew attention to 'the considerable variation of temperature in the different localities, and the large amount of rainfall ... in some places as compared with others'. His talk was illustrated by 'a suitable map and carefully compiled meteorological statistics', and he concluded 'that the New Zealand farmer's first and most important business was to study the climate of the different parts of the colony, and farm his land accordingly.'

We traced 47 diaries and other private papers that contained references to the weather between 1835 and 1869 – 38 from eastern and 9 from northern South Island (Appendix 1) – and are certain that more remain in regional archives or private hands. Most reported wind direction and strength, but several also included details about cloud cover, precipitation, when storms began and ended, and when nearby rivers rose and fell. A few referred to air temperature in human comfort terms. Some intending settlers followed the advice of land company agents (Hursthouse, 1861) or provincial authorities (Canterbury Provincial Government, 1862) and brought

barometers and thermometers with them from England, but few reported daily observations of barometric pressure and air temperature in their diaries.

The principal source of information for this research was the diary of a young Canterbury immigrant, Joseph Munnings, for the seven years beginning November 1859. It contains daily records for the following weather features in Christchurch and its environs: wind direction, strength and duration; the nature, intensity and duration of precipitation, including snow fall; and air temperature in terms of human comfort. Munnings also reported dust storms, which are rarely noted in the meteorological record.

Our research strategy had four parts. First, we checked if a reasonable account of weather and climate in early Christchurch could be produced from Munnings' diary entries. Secondly, we developed the following three assessment criteria to help us decide if diary entries can be used with any confidence for accounts of regional weather and climate at a time when standardised meteorological measurements were rarely made:

1. Independent observers should report major weather events in their diaries. When collated, the geographical spread of recorded times for each such event should provide a realistic account of the weather system's passage across the country.
2. There should be clear seasonal patterns in reported weather features – notably precipitation and temperature – and independent observers should report comparable or compatible wind systems for specific periods.
3. Major wind, precipitation or hydrological events should be evident in diary entries from geographically dispersed places and have comparable onset times, duration and magnitude.

Thirdly, for three historically significant months we compared weather notes in Munnings' diary against those in diaries from elsewhere in eastern South Island. Fourthly, we checked if runs of independent weather observations indicated seasonal

as well as longer term changes in weather and climate. The paper ends with a summary of what the first generation of European settlers found noteworthy and challenging in the weather systems of eastern South Island, what they apparently learned about the area's climate, and their interest in weather forecasting.

## **2. Joseph Munnings and the Weather in Christchurch: 1859 to 1866**

Joseph Munnings emigrated from southern England to Canterbury in November 1859, worked as a farm labourer in Governor's Bay until May 1861, operated a carting business in Christchurch until December 1863, then became co-owner of a general store in the city. His diary ends in November 1866. While working as a carter he made occasional trips out of Christchurch: most were within 20 km of the city, but two or three short trips annually were to rural properties on the Plains and in the foothills of Mid Canterbury. His daily entries typically contain 15 to 20 words about the weather between dawn and dusk, but also about significant weather events at night: major wind shifts, onset of heavy rain, thunder storms, and heavy frost. He recorded when storms began, and noted flooding in large and small rivers. For example, on Christmas Day 1865 he observed a rapid rise in the Avon River and a surge of unusually turbid water. Munnings inferred that the Waimakariri River, swollen by northwest storms in the back country (which he recognised from the characteristic arch of clear sky over front ranges of the Southern Alps), had broken its banks and was flowing down the Avon and into the Heathcote Estuary.

We compared his records of wind direction for 1864 (Figure 1 (a)), when he spent the entire year in central Christchurch establishing his business, with published statistics from the recently established meteorological station in the nearby Botanical Gardens (Figure 1(b)). Munnings reported calm periods, referred to the four cardinal directions only when the wind was shifting, and usually reported only four directions: NE, SE, SW and NW. The two wind roses are strikingly similar despite the fact that Munnings reported changes in wind direction over the day whereas the observer in the Botanical Gardens measured wind direction at 9:00 am. Both wind roses show a preponderance of NE and SW winds, but with the meteorological station reporting

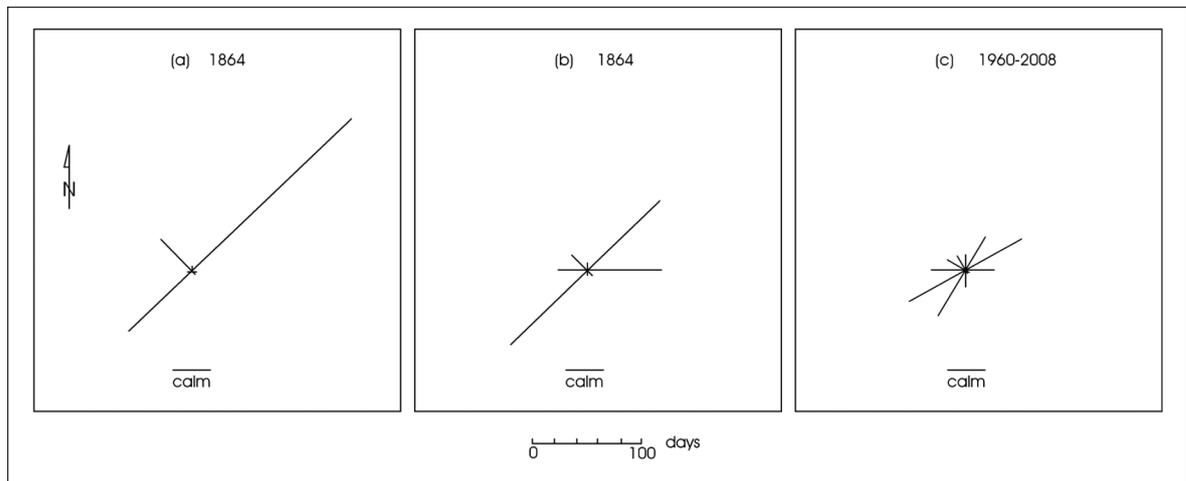


Figure 1. Wind roses for Christchurch: (a) 1864, derived from records in Joseph Munnings' diary; (b) 1864, as recorded at the Christchurch Meteorological Station (source: New Zealand Government Gazette, Province of Canterbury 12(15), 21 March 1865, p 102); and (c) cumulative values for 1960 to 2008 at Christchurch Airport (source: T Appelhans, pers. comm.)

winds from eight directions. The wind rose for 40 years of continuous recordings at Christchurch Airport (Figure 1 (c)) is in increments of 30 degrees. Given the complex wind field of the Christchurch area (Sturman, 2008) it is not appropriate to compare Munnings' observations with long-term average conditions in the expectation of identifying departures from normal conditions, but his qualitative records compare well with the normals for wind direction and can therefore be used with a measure of confidence.

Munnings seems not to have owned even rudimentary meteorological sensors, and virtually all his daily weather reports are qualitative. They are also inherently 'noisy'. For that reason, we applied a conservative statistical filter to information compiled from his diary, and calculated seasonal rather than monthly, weekly or daily values. Summer was uniformly treated as December to February, autumn March to May, winter June to August, and spring September to November. Those four clusters were explicitly recognised by Munnings as well as by his acquaintance, the surveyor and land owner, Charles Torlesse, who kept daily records of wind direction and precipitation while a resident in the Christchurch area (Roche 1984).

For the seven years of Munnings' weather reports, we coded each 24-hour period according to the specified or implied fraction of the day with wind from a stated direction, then obtained seasonal totals. We used those totals to calculate values of

two indices. The first index is given by the number of days with winds between NNE and SSE, divided by the number of days with winds from any direction. It shows the seasonal predominance of winds from either the western or the eastern half of the compass. The second index is given by the number of days with winds between WNW and ENE, divided by the number of days with winds from any direction. It shows the seasonal predominance of winds from either the northern or the southern half of the compass. A value  $> 0.5$  indicates the predominance of easterly winds (first index) or northerly winds (second index). Identical frequencies of days with either easterly or westerly winds (first index) or northerly and southerly winds (second index) are given by a value of 0.5. And a value  $< 0.5$  indicates the predominance of either westerly winds (first index) or southerly winds (second index).

We grouped the words that Munnings used to describe precipitation – (1) 'mist', 'drizzle', 'light rain' or 'showers', and (2) 'heavy rain', 'sleet' or 'snow' – then coded each day according to the stated or implied fraction with precipitation in each of the two classes. Those values were then summed to give seasonal totals. We also counted the number of days during a season when Munnings recorded falling snow and dust storms.

Munnings reported air temperature in terms of human comfort, and we used his words to code his diary entries: (1) 'very cold', (2) 'cold', (3) 'cool' or 'mild', (4) 'warm', (5) 'hot' or 'very hot', and (6) 'distressingly hot'. The first of those six categories is likely to correspond with sub-zero temperatures for much of the day, the second with severe morning frosts and air temperature below 10 degrees Celsius by mid-afternoon, the third with a low of about 7 degrees soon after dawn and an afternoon maximum of 20 degrees, the fourth with a morning low of 12 degrees and a high of 25 degrees later in the day, the fifth with a morning low of 15 degrees and a high of 30 degrees during the afternoon, and the sixth with air temperature in excess of 20 degrees for much of the day and the maximum exceeding 35 degrees. Munnings often noted changes in sensible temperature over a 24 hour period, notably between late morning and early afternoon. The numbers in brackets, above, were treated as interval data and used to score whole or fractions of days. Those values were then used to calculate seasonal and annual averages for the period from December 1859 to November 1866.

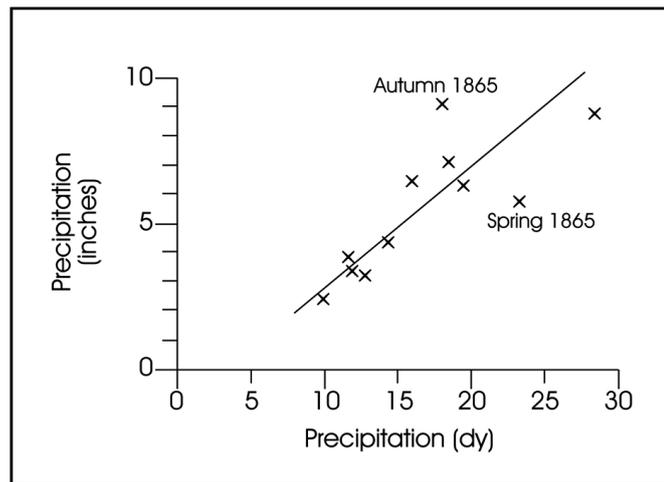


Figure 2. Seasonal precipitation inferred from Joseph Munnings' diary compared with measured precipitation at the Christchurch Botanical Gardens ( source: New Zealand Government Gazette, Province of Canterbury XIII (17), 24 February 1866). Derivation of the precipitation surrogate is explained in the text. Trend line fitted by eye.

For the period between autumn 1864 and spring 1866 we could compare Munnings' qualitative accounts of seasonal precipitation with actual measurements reported in the *New Zealand Government Gazette* (Figure 2). With the exceptions of autumn and spring 1865, a close relationship was found between the two sets of observations. In his diary, Munnings noted several convectional storms during autumn 1865, which may explain the apparent under-estimation of actual precipitation total, and his frequent reports of mist and light drizzle in spring 1865 may account for the apparent over-estimation of actual precipitation total.

The graphs of seasonal and annual average temperature (Figure 3 (a)) show a cooling trend to 1861, then steady warming with progressively milder winters (shaded columns). There are no comparably clear patterns for the other three seasons. Salinger (2001) graphed air temperatures estimated from measurements of stalagmites and found evidence for a decline of about 0.5 degrees Celsius in the 1860s, which accords well with Munnings' observations. Further support might be expected from high-resolution pollen analyses or measurements of wood rings, as Michaelsen (1989) found in North America.

The greatest reported precipitation was in winter 1860 (Figure 3(b)). Seasonal and annual values declined steadily from them until late spring 1866, when Munnings' diary ends.

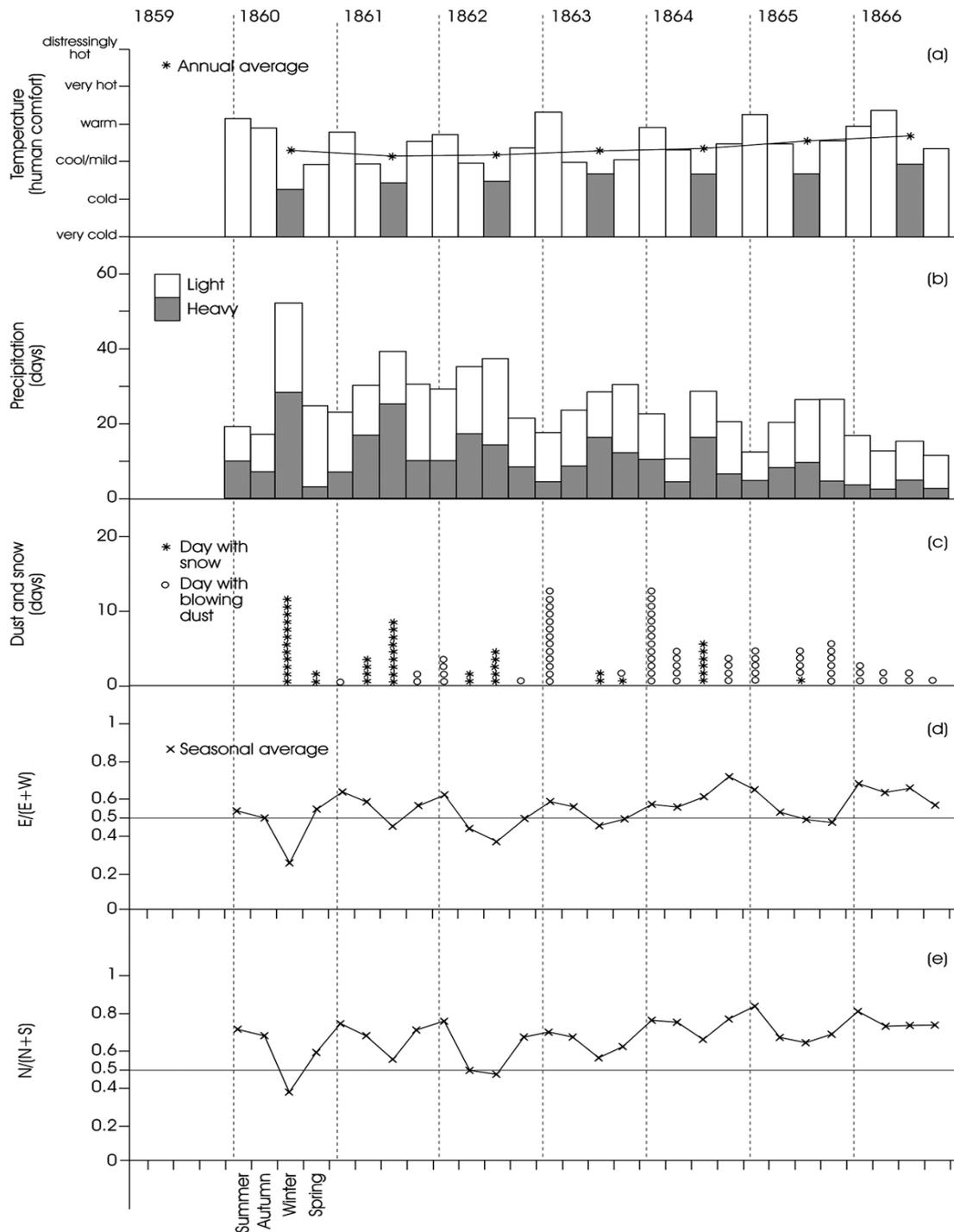


Figure 3. Seasonal weather in Christchurch and its environs from summer 1859-60 to spring 1866 based on information in Joseph Munnings' diary. Derivation of the temperature (a) and precipitation surrogates (b), and calculation of the two indices of prevailing wind direction (d) and (e) are explained in the text. Days with snow or blowing dust (c) are from diary entries, and expressed as days over the season.

Most years, Munnings reported dust storms (Figure 3(c)). During the early 1860s they were infrequent and mostly confined to late spring and summer, but from 1864 onwards they occurred throughout the year. Much of the dust that Munnings reported would have come from roadworks then underway in Christchurch, with the balance

from either the formerly extensive tussock grasslands west of the city that were being cultivated for farming, or the exposed bed of the Waimakariri River. As the Canterbury correspondent of the *Otago Witness* reported on 17 December 1862, 'The weather continues terribly warm and dry ... [and] Christchurch in such weather is a most disagreeable place of residence, especially after the exertions of our municipal council in forming our streets, for the dust is flying in thick clouds all day long, smothering all of us who venture out of doors'. Significantly, eleven years earlier Charlotte Godley had commented on the dustiness of Christchurch during the northwest winds of spring and summer (Godley, 1951). That was before tracts of vegetated land had been cleared for roads, housing and agriculture, so the dust that made conditions miserable for settlers must have come from bare ground west of Christchurch.

The first graph of seasonally predominant wind direction (Figure 3(d)) shows a steady shift towards relatively more frequent easterly winds over the seven years to spring 1866. Fifteen years earlier, Charles Torlesse wrote 'The sea breeze, and prevailing wind here [in Christchurch], is from the north-east and generally sets in at about 10 am, freshening up towards sunset when it is succeeded by calm or a light land breeze' (*Lyttelton Times* 5 July 1851). Munnings' diary entries show that a northeast wind in Christchurch was often associated with a strong northwest wind aloft as well as in the western mountains, and he reported many observations like these: 'NW stiff [until] 11 am [and] varying between NE and NW pm' (8 March 1863), 'Stiff NE, NW overhead all day and up country' (25 July 1863), 'Fine, very stiff [wind], shifting between NE and NW, hot' (18 March 1865), 'NNE, N'wester in the Back Country' (25 June 1865), and 'NE inclining to NW' (21 September 1866). The graph to show relative predominance of northerly winds (Figure 3(e)) closely tracks the previous graph, including the spike in winter 1860 when Christchurch experienced exceptionally heavy snow falls. Both curves show that stormy weather in winter was closely associated with winds from the west, and that seasonal precipitation totals declined as winds from the northern and eastern halves of the compass predominated.

It is unlikely that all northeast winds reported by Munnings were true sea breezes (Salinger, 2001), but the information displayed in Figure 3 suggests that the eastern

South Island was experiencing El Niño weather between 1862 and 1866. Garcia-Herrera *et al.* (2008) analysed a long archival record of river discharge and hydrology, infrastructure, fisheries, agriculture and land damage near Trujillo on the Pacific coast of Peru, and found evidence for periods of high El Niño activity centred on the years 1625, 1725, 1810 and 1890, with periods of reduced El Niño frequency around 1675, 1750 and 1850. Their data are consonant with the New Zealand historical record and information in Munnings' diary. There was benign weather with few extreme weather events during the 1850s, but conditions during the 1860s and '70s were unsettled and characterised by heavy rainfalls on the West Coast, northwest gales east of the Alps, floods and landslides, occasionally severe winter storms, and widespread summer drought.

### **3. Diaries as Sources for Studies of Regional Weather Patterns**

Analysis of entries in Munnings' diary has indicated what can be recovered from a long run of qualitative weather reports. In this section we show that diaries from locations across eastern South Island could be useful sources for accounts of regional weather and climate before the establishment of a network of meteorological observatories (Appendix 2). To that end, we coded daily weather conditions from geographically dispersed sites in eastern South Island for three months that environmental historians have described as challenging to settlers: July 1860 was exceptionally stormy across the eastern South Island, November 1861 was generally cool and damp, and in February 1863 gale force northwest winds raked the area and fanned major forest fires. For each of the three months, Munnings' diary was one of the sources of daily weather information.

With reference to the first assessment criterion (Section 1), Figure 4 shows that rain, snow or northwest gales were reported across eastern South Island for one or more of the three named months. Between 2 and 6 July 1860, Christchurch and the Parnassus area of North Canterbury were experiencing southwesterly weather while the Maniototo was apparently clear and frosty, suggesting that southwest weather systems had not penetrated far inland in East Otago. The second half of that month was different, with four southwest storms bringing heavy snow and rain to the three

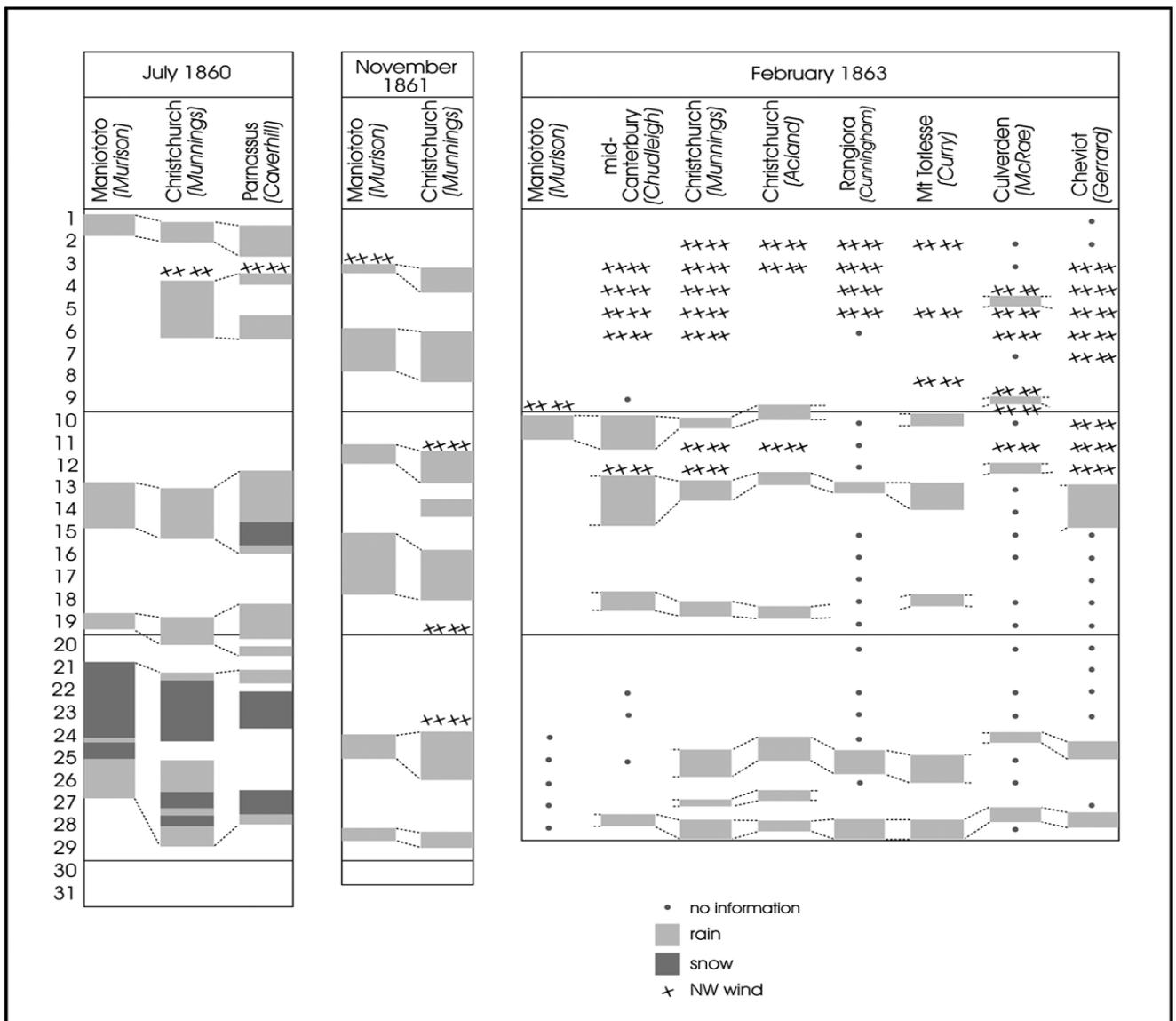


Figure 4. Eastern South Island weather in July 1860, November 1861 and February 1863, as reported in farm diaries.

areas. The pattern for November 1861 is clearer: an alternation of fine weather with northwest winds inland and northeast winds along the coast, and with squally southwest changes affecting coastal and inland parts of eastern South Island. The Figure also shows widespread, short-duration rain-storms during the second half of February 1863, with variations in the time of onset reflecting geographical location. Areas close to the western foothills experienced strong northwest wind and rain, followed by a southwest change and further rain. The Figure shows the normal lag of approximately one day for the onset of stormy weather between East Otago and Mid Canterbury, and an often earlier onset of northwest weather in North Canterbury.

The longest continuous runs of weather records accessible to us were those of

Thomas Burns in Dunedin and Charles Torlesse in Christchurch-Rangiora, and they were used as benchmarks for an assessment of weather observations made over shorter periods elsewhere in the eastern South Island (second criterion). Strong westerly winds predominated from North Canterbury to South Otago in June 1851, September 1852, August 1860 and May 1869, with easterly winds predominating in November 1851, January 1855, August 1858, November 1861 and November 1864. There were minor cyclical variations around almost equal frequencies of easterly and westerly winds between 1849 and 1861, relatively more westerly winds (Index < 0.5) from then until summer 1868-69, and relatively more easterly winds (Index > 0.5) thereafter. Analysis of informal weather records for 'The Point' Station in the foothills of Mid Canterbury (Holland and Fitzharris, 1990) showed gale force northwest winds were common in spring and summer, and heavy snow falls were reported in the winters of 1867, 1868 and 1869. Easterly weather, with persistent low cloud, frequent drizzle and light rain began in summer 1869-70, and predominantly westerly weather resumed in 1871. The second assessment criterion also concerns seasonal patterns in precipitation, temperature and wind direction, something that Torlesse had noted while surveying Mid Canterbury for the Canterbury Association (Holland and Mooney, 2006). Munnings' observations (Figure 3) showed clear seasonal signatures, as did information recorded in other diaries with a year or more of daily wind records.

Finally, we checked if independent observers had noted the same major weather and hydrological events, and if the reported onset dates, duration and magnitude were comparable (third assessment criterion). Amongst the historically well-known examples of major weather and hydrological events for the period to 1869 are widespread heavy snowfalls and flooding in winter 1861, the storm which swept southwards in February 1862 and caused floods as far south as East Otago, several days of northwesterly gales in February 1863, widespread drought conditions during the 1860s, and the combination of autumn floods and heavy winter snowfalls which extended from Marlborough to Southland during 1868, and they were reported in diaries from those periods.

#### **4. Weather and Settler Society**

The 1860s were the decade from hell for European settlers in eastern South Island. There was heavy snow in the mountains and foothills of Canterbury in July 1860 and

down to the Plains the following July. The winter storm of 1861 was closely followed by strong easterly winds and flooding. In winter 1862 there were heavy falls of snow in the foothills, but the lowlands were dry. Drought conditions were reported from Southland to the southern half of the North Island during 1863, with widespread forest fires in February. Gale force northwest winds in July and August were accompanied by unsettled weather, heavy rain, landslips and flooding in the Otago gold fields and across northern Southland, as well as floods in the Rakaia and the other large east coast rivers. Severe northwest gales were experienced throughout the South Island during 1864, with heavy rain in the Otago gold fields and flooding in most east coast rivers. Stormy weather was widespread in 1865 and 1866: dry and dusty on the east coast of the South Island but exceptionally wet inland, with floods in the Taieri River basin. The Waimakariri River flooded in the spring of both years, and seepage led to flooding in the Avon River. Although the first half of 1867 was a time of variable, often stormy, weather a major snowfall in late July – early August blanketed much of eastern South Island for a week or more. In February 1868, during several days of wind from the southeast, severe flooding was experienced down the east coast as far as South Otago. Large and small rivers draining into the Pacific were flooded, sheep and cattle were lost and sown pastures destroyed, and major damage was done to roads and bridges, telegraph lines, and farm buildings. In mid-June that year a further round of unsettled weather brought flooding from Mid Canterbury to Southland, and it was followed by snow and further rain. In Canterbury alone, the wild winter weather of 1868 caused sheep losses in excess of 250,000 animals, and several run holders were forced from the land (Acland, 1951). The weather in 1869 was less extreme than that of the previous four years, although there were heavy winter falls of snow in the inner Canterbury Plains, foothills and mountains. In 1870, and for a further two years, easterly weather systems predominated, and low cloud, drizzle or occasionally heavy rains were common occurrences.

Given the often challenging weather of their new home, early settlers in eastern South Island were understandably drawn to weather forecasting. Russell (1855, 426) had described 'Weather prognostics [as] an exceedingly difficult and uncertain branch of knowledge' then outlined ways for interested people to interpret barometer readings, atmospheric transparency, cloud cover, and wind direction. He also aligned

himself with von Humboldt in dismissing 'appreciable' lunar influences on the weather. The seachange came in 1854, when Rear Admiral Robert Fitzroy, a former Governor of New Zealand, was appointed Director of the Meteorological Department of the Board of Trade in London (Anderson, 2005). In New Zealand, the need for reliable weather information was widely recognised, and completion of telegraphic links between large and small centres would later make national weather forecasts feasible.

On 14 December 1860, *The Southern Cross* published an extended excerpt, 'How to foretell weather', from the *Manual of the Barometer* by Fitzroy and first published by the British Board of Trade. The Editor referred to that organisation in the 3 June 1862 issue of the *Otago Witness*, advocated a similar facility for New Zealand, and urged government to invite Fitzroy to send a competent person here to provide advice about meteorological instruments. Three years later, *The Press* in its 6 January 1865 issue reprinted a long letter published three months earlier by *The Times* of London in which Fitzroy set out the principles of stormy weather forecasts. Three years later, in his inaugural address to the New Zealand Institute, Sir George Bowen could state that 'the study of meteorology will prove of much practical benefit in these tempestuous latitudes, for the discoveries of Sir W Reed and his followers have enabled science to encircle with definite laws the apparently capricious phenomena of the atmosphere' (*Otago Daily Times*, 11 August 1868). Beginning January 1868, monthly statistical summaries of weather observations were published in *The New Zealand Gazette*, and by the 1870s – several years after Dr James Hector had been appointed Director of Meteorological Stations in New Zealand – a national network of weather observatories had been established. Daily, weekly and monthly weather statistics were published in local newspapers and often summarised in newspapers elsewhere in New Zealand. The observational, recording and reporting foundations for a rational understanding of New Zealand's weather and climate were in place by the 1880s. They, and further improvements in electronic communications, meant that people in cities, towns and the less remote country areas had timely access to reliable information about daily weather and forecast conditions. The task of observing, understanding and predicting local weather and climate was shifting from individuals on the land to professional scientists.

## **5. Conclusions**

Analyses of descriptive weather reports in diaries and letter books indicate how much and how quickly European settlers learned about the New Zealand environment. They also extend and deepen our knowledge of weather and climate in early colonial times, and may reveal patterns that were scarcely recognised and certainly not understood at the time. Until the mid-1860s, communications between population centres in New Zealand were costly and slow, there were few meteorological observatories, runs of standardised meteorological measurements were short, and residents could not compare what they had experienced against normals for the area. That so many rural people described each day's weather in their diaries shows the depth of interest in understanding environmental forces and conditions in the new country. As their experience grew, settlers learned to identify and interpret weather signs and take appropriate precautions.

Of the documents listed in Appendix 1, the Greenwood, Burns, Torlesse, Munnings, and 'The Point' diaries contain most weather information. The others, however, contain sufficient detail for a researcher to extend the record to other parts of New Zealand. The next step will be to establish an accessible data base in which all available weather observations, regardless of provenance and precision – in diaries, newspaper reports and ships' logs, and from formal as well as informal weather stations – are recorded. That information will enable environmental historians to investigate environmental conditions between 1800 and 1870, when important decisions were being made about infrastructure, land use and the rural economy, but for which we have few published weather records. It will also allow climatologists to confirm long and short term fluctuations in weather and climate, and relate them to patterns elsewhere in the Pacific basin. More importantly, it would make possible the production of a climatological atlas for the historically important first six or seven decades of European settlement in New Zealand.

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**Appendix 1**

*Diaries and other manuscript sources that contain reports of daily weather in eastern and northern South Island, in chronological order of starting date: author and type of source; location: inclusive dates (archive or publication).*

George Hempleman diary; Peraki, Banks Peninsula: 4 December 1835 to 4 March 1839, 11 April 1840 to 30 October 1840, 9 March 1841 to 27 April 1841, 27 April 1842 to 31 August 1842, 7 January 1844 to 13 March 1844 (Canterbury Museum).

JW Barnicoat diary; eastern South Island: March 1842 to March 1844 (Nelson Historical Museum).

Joseph Greenwood diary; Purau and Motunau, North Canterbury: 8 December 1843 to 31 May 1847 (Alexander Turnbull Library).

JG Ward diary; Nelson and the Wairau Valley: March 1843 to June 1854 (Canterbury Museum).

Margarey diary; Nelson: 13 April 1844 to 11 August 1844 (Nelson Historical Museum).

FG Moore diary; Nelson and Moutere: 8 September 1844 to 19 January 1845 (Nelson Historical Museum).

Timothy Ferens diary; Waikouaiti, East Otago: 23 March 1848 to 22 July 1849 (Otago Settlers Museum).

Thomas Burns diary; Dunedin: 11 May 1848 to 5 September 1851 (Otago Settlers Museum).

Charles Torlesse diary; Mid Canterbury: 12 December 1848 to 6 April 1851 (Maling, 1958).

anon. Diary; North East Valley, Dunedin: 26 June 1849 to 31 January 1853 (Hocken Library).

Charlotte Godley diary; Christchurch: 3 June 1850 to 1 January 1852 (Godley, 1951).

FS Pillans diary; Inch Clutha, South Otago: 26 August 1850 to 12 May 1852 (Hocken Library).

Edward Ward diary; Mid Canterbury and Lyttelton Harbour: 16 December 1850 to 22 June 1852 (Ward, 1951).

Charles Torlesse diary; 'Fernside' farm, Rangiora: 8 April 1851 to December 1860 (Canterbury Museum).

Hannah Caverhill diary; 'Motunau' (later named 'Hawkswood') Station, Parnassus, North Canterbury: 21 April 1851 to 18 March 1855, 26 September 1858 to 12 February 1861, 1 January 1865 to 31 December 1878 (Canterbury Museum).

William Rich diary; Canterbury and Otago: 2 January 1853 to 24 December 1858 (Otago Settlers Museum).

Henry Sewell diary; Mid Canterbury and Christchurch: 3 February 1853 to February 1856 (McIntyre, 1980).

A Mowat diary; 'Middlehurst' Station, Awatere Valley: 11 May 1853 to December 1867 (Marlborough Museum).

Thomas Burns monthly weather summaries; Dunedin: February 1854 to March 1868 (Otago Settlers Museum).

James Menzies diary; Maitai, Southland: 1 April 1854 to 24 December 1856 (Hocken Library).

JN Bland diary; Hope, Nelson: 1 January 1855 to 31 December 1855 (Nelson Historical Museum).

FW Teschmaker diary, South Canterbury and North Otago: 10 March 1857 to 26 November 1862 (South Canterbury Museum).

[John Pope] Sawyer diary; Okains Bay, Banks Peninsula: 15 November 1857 to July 1859 (Alexander Turnbull Library).

WK MacDonald diary; 'Orari' Station, Mid Canterbury: 18 January 1858 to 31 December 1863 (Canterbury Museum).

Matthew Morris diary; Christchurch, Kaiapoi and Leithfield: June 1858 to 20 April 1868 (Canterbury Museum).

Mark Stoddart diary; Diamond Harbour, Banks Peninsula: 24 August 1858 to 4 March 1859 (Canterbury Museum).

JB Acland diary; Christchurch and 'Mount Peel' Station, South Canterbury: 21 September 1858 to 29 February 1860, 1 January 1863 to 13 May 1871 (University of Canterbury).

James Murison diary; 'Puketoi' Station, Maniototo, Otago: 4 December 1858 to 7 September 1869 (Hocken Library).

Joseph Munnings diary; Christchurch and Mid Canterbury: 14 November 1859 to 22 November 1866 (Canterbury Museum).

John Beatson diary; Lower Wairau Valley, Marlborough: 1 January 1860 to 24 June 1865 (Nelson Historical Museum).

Agnes Willis diary; Christchurch: 16 January 1861 to October 1862 (Alexander Turnbull Library).

AH Cunningham and Mary Cunningham diary; 'Fernside' farm, Rangiora: 26 July 1861 to 24 May 1865 (Canterbury Museum).

Edward Curry diary; 'Mount Torlesse' Station, North Canterbury: 1 August 1861 to 31 December 1864 (Canterbury Museum).

A Fell diary; Nelson: 1 January 1862 to 13 March 1862 (Nelson Historical Museum).

James Buller diary; Dunedin, Christchurch and Nelson: 1 January 1862 to 31 December 1862 (Alexander Turnbull Library).

ER Chudleigh diary; Mid and South Canterbury, West Coast and Otago: 11 January 1862 to 31 December 1865 (Richards, 1950).

William McRae diary; 'Glens of Tekoa' Station, Culverden, North Canterbury: 14 June 1862 to 29 November 1865 (Canterbury Museum).

[William] Gerrard diary; 'Cheviot Hills' Station, Cheviot, North Canterbury: 3 February 1863 to 15 July 1864, 2 January 1865 to 31 December 1867, 1 January 1867 to 18 December 1873 (Canterbury Museum).

Charles Robjohns diary; Clutha Valley, South Otago: 16 May 1864 to 13 December 1864 (Alexander Turnbull Library).

John Hartley diary; Bell Island, Dunedin: 1 November 1864 to 24 September 1877 (Hocken Library).

Edwin Trolove diary; 'Woodbank' Station, Marlborough: 1 January 1865 to 31 December 1865 (Hocken Library).

William Smith diary; 'Tytler' Station, Marlborough: 10 August 1865 to 10 July 1866 (Canterbury Museum).

W Beatson diary; Nelson and Stoke: 26 March 1866 to 25 July 1866 (Nelson Historical Museum).

anon. diary; 'The Point' Station, Mid Canterbury: 1 August 1866 to 6 May 1871 (Canterbury Museum).

Walter Riddell diary; Sandymount, Otago Peninsula: 29 November 1867 to 22 September 1871 (Hocken Library).

David Munro diary; Nelson: 1 January 1868 to 31 December 1868 (Nelson Historical Museum).

John Maddison diary; Lake Ellesmere area: 31 January 1868 to 27 December 1868 (Canterbury Museum).

## **Appendix 2**

### *Published meteorological observations for Christchurch and its environs:*

1849- 60: days per month with wind from NE, NW, SW, SE or calm, and very fine, fine, showery or rainy weather (Christchurch, Rangiora and the Canterbury Plains).

1851: barometric pressure, shade temperature, wind direction, wind strength, cloud cover and precipitation (recorded 9:00 am and 3:00 pm daily at the Christchurch Land Office).

1854-58: monthly means for daily maximum, minimum and average barometric pressure, shade temperature, and rainfall (central Christchurch).

1858-61: monthly means for maximum, minimum and average barometric pressure, shade temperature, and rainfall (Central Christchurch).

1864 onwards: barometric pressure, solar intensity, terrestrial radiation, vapour pressure, relative humidity, average cloud cover, rainfall, wind direction and strength (Christchurch Botanical Gardens).

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