Kidson's Synoptic Weather Types and Surface Climate Variability over New Zealand

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Abstract

Daily synoptic classifications developed by Kidson in the late 1990s have been updated through mid-2010. This paper documents the update in terms of the relative frequency of occurrence of the synoptic types and associated regimes, demonstrating that on average, synoptic type frequencies have not changed significantly over the past decade, although some long-term trends in occurrence frequency have been reported elsewhere. The regimes are associated in dynamically reasonable ways to the phase of the ENSO cycle and to the polarity of the SAM, with more zonal flow during El Niño and more blocking types during La Niña, more trough types during the negative SAM and more zonal and blocking types during the positive SAM. The synoptic types and regimes are closely associated with coherent daily climate anomalies, as illustrated using the high-resolution Virtual Climate Station Network dataset. The mean magnitude of the daily climate anomalies associated with the Kidson types and regimes is much larger than suggested by Kidson's original results, because Kidson's results were based on regional averages and mixtures of the effects of different regimes within months.

1. Introduction

Synoptic-climatological classification is a well-known technique for defining surface climate and local atmospheric circulation variability over a region (e.g., Yarnal 1993). Such a classification analysis for New Zealand was carried out in the late 1990s, as

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described in Kidson (2000, hereafter K2K). Kidson defined twelve synoptic weather types, based on twice-daily fields of 1000 hPa height from the NCEP/NCAR (National Centers for Environmental Prediction/National Center for Atmospheric Research) reanalyses (Kistler et al. 2001). The twelve types were also grouped into three sets or "regimes" that described predominantly unsettled conditions (the "trough" regime), westerly flow over New Zealand (the "zonal" regime) and predominantly settled, anticyclonic conditions (the "blocking" regime). An analogous set of types was also found by Jiang (2010) using a similar analysis approach.

The thrust of K2K was to characterise daily local circulation variability and its expression in surface climate, and to relate large-scale to local-scale variability, effectively a form of downscaling analysis. While the derived circulation types and regimes successfully characterised synoptic variability over New Zealand, the results were somewhat equivocal in terms of "downscaling" to surface climate and in terms of relationships with large-scale signals such as the El Niño-Southern Oscillation (ENSO) cycle. Kidson felt that his classification scheme was more useful in a qualitative rather than quantitative sense.

Since Kidson's landmark paper, his synoptic classification scheme has been used by many researchers, to investigate local climate variability and its association both with impacts (e.g., Gosai et al. 2003) and with large-scale forcings (e.g., Kidson and Renwick 2002). Recently, the Kidson regime classification has been used as a qualitative downscaling technique for palaeoclimate research (Lorrey et al. 2007), largely in the sense envisaged in K2K.

This paper describes the current status of the K2K synoptic type time series, and outlines a quantitative estimate of the daily climate variability associated with the occurrence of each of the synoptic types and regimes defined by K2K. It makes use of the recently-developed Virtual Climate Station Network (VCSN, Tait and Woods 2007; Tait et al. 2006; Tait 2008) which defines daily surface climate variability over New Zealand on a ~5 km × 5 km grid, for a wide range of variables.

The paper is set out as follows. Data sets and methods are described in the following section. Statistics of the synoptic types and regimes, and their expression in

New Zealand surface climate are illustrated in section 3. Section 4 contains a summary and discussion, and touches on the wider implications and utility of these results for related investigations.

2. Data and Method

(a) Kidson's synoptic types

The definition of daily synoptic classifications for New Zealand uses a data set that has been continually updated since the original analysis of K2K. In that paper, the data covered the period January 1958 through June 1997. The data set continues to be updated regularly, and currently runs from January 1958 through mid-2010[1]. On a quarterly basis, 1000 hPa height fields are downloaded from the NCEP/NCAR reanalysis web site http://dss.ucar.edu/datasets/ds090.0/data/pgbf00-grb2d/, and height fields at 00 and 12UTC daily over New Zealand are classified into one of the 12 types (and hence one of the three regimes). The classification is as carried out in K2K, defined in terms of similarity to the mean 1000 hPa height field for each cluster (defined in K2K as the mean over all members of each cluster). A given height field is projected upon the five leading empirical orthogonal function (EOF) patterns of the 1000 hPa height (as defined in K2K) and the root-mean square difference is calculated between those five pattern amplitudes (principal components) and the matching principal component values for each of the cluster mean patterns. Whichever cluster mean is closest (smallest RMS difference) is the assigned synoptic type.

(b) New Zealand surface climate data

Daily surface climate over New Zealand is defined in terms of the VCSN time series, a high-resolution gridded data set developed from interpolation of available station observations (Tait and Woods 2007; Tait et al. 2006; Tait 2008). The VCSN data provide estimates of daily climate in approximately 5 km × 5 km grid boxes over the whole of New Zealand, daily since January 1972 (1960 for rainfall, and 1997 for wind

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[1] The synoptic type time series are available in near-real time from the author.

speed). There are several variables available: 24h rainfall, maximum/minimum/10 cm earth temperature, daily solar radiation, 24h-average wind speed, potential evapotranspiration, soil moisture, and 9am relative humidity/vapour pressure.

(c) Method

The analysis conducted here is straightforward and solely descriptive. A monthly mean climatology was calculated for each of the VCSN daily climate variables, by averaging all fields in the full time series for each month of the year separately. Daily anomalies from the climatology were calculated as percentage departures from normal for rainfall and solar radiation, and as arithmetic differences from normal for all other variables.

Using the K2K synoptic type defined for midday (00UTC) every day in the VCSN series, each day's VCSN anomaly fields were assigned to the appropriate synoptic type (and the regime associated with each synoptic type). The VCSN anomalies were then averaged for each synoptic type and regime, separately for the four standard seasons (March-May, June-August, September-November, December-February) and for the year as a whole. The resulting patterns of daily climate anomalies represent the average departures from normal to be expected on a typical day experiencing each of the synoptic types or regimes.

3. Results

(a) Status and characteristics of the Kidson types data

The time series of synoptic types defined in K2K continues to be updated routinely, and currently extends through mid-2010. Here, the analysis covers the 52 full years from January 1958 to December 2009, a total of 37,986 12-hourly observations (the time series in K2K covered 39.5 years, January 1958 to June 1997).

Table 1 shows the occurrence frequency of the synoptic types and regimes for the year as a whole and by season, for Kidson's original 39.5-year set and for the 52 years to 2009. By and large, average occurrence frequencies have changed very little with the addition of another 12.5 years' data. However, statistically significant trends have been found in the occurrence frequency of the TSW and NE types (McKerchar et al. 2010).

Table 1: Percent frequency of occurrence of Kidson synoptic types and regimes, annually and by season. Columns labelled "K2K" use the time series Jan 1958-Jun 1997 as in Kidson (2000) and those labelled "Current" use the time series Jan 1958-Dec 2009.

	Annual		MAM		JJA		SON		DJF	
	K2K	Current	K2K	Current	K2K	Current	K2K	Current	K2K	Current
T	12.3	12.0	8.8	8.3	13.3	12.9	16.0	15.8	11.2	11.1
SW	11.3	11.3	10.8	10.7	11.2	11.3	13.2	13.8	9.7	9.6
TNW	7.6	7.3	6.3	5.9	7.4	7.2	7.9	7.3	8.9	8.9
TSW	7.3	6.9	5.2	5.2	8.5	7.9	6.5	6.2	9.0	8.4
H	12.9	13.2	14.8	15.1	15.3	15.5	14.2	14.5	7.1	7.5
HNW	6.9	7.2	8.4	8.1	7.9	8.6	7.6	8.3	3.3	3.7
W	4.8	4.9	4.1	4.1	5.0	5.3	7.3	7.3	2.9	3.1
HSE	13.7	13.6	17.4	18.1	10.9	10.6	8.9	8.6	17.4	17.1
HE	7.1	7.3	7.0	7.4	7.5	7.8	7.5	7.6	6.4	6.5
NE	6.3	6.1	5.8	5.7	4.9	4.7	4.9	4.6	9.6	9.3
HW	5.4	5.5	6.6	6.5	4.2	4.4	3.4	3.5	7.3	7.7
R	4.7	4.6	4.9	4.9	3.8	3.8	2.7	2.5	7.4	7.3
Trough	38.4	37.6	31.1	30.0	40.5	39.3	43.5	43.1	38.8	38.0
Zonal	24.5	25.3	27.3	27.4	28.2	29.4	29.0	30.0	13.2	14.2
Block	37.1	37.1	41.6	42.6	31.3	31.3	27.4	26.8	48.0	47.8

As noted in K2K and in Kidson and Renwick (2002), there are statistical associations between the occurrence of specific types and regimes and the state of the large-scale circulation, and the El Niño-Southern Oscillation (ENSO) cycle. This is illustrated briefly below in relation to ENSO and to the state of the Southern Annular Mode (SAM, Kidston et al. 2009; Marshall 2003). Table 2 shows the average monthly frequency of occurrence of the three regimes, during the upper and lower quartiles (25-percentiles) of the 3-month mean Southern Oscillation Index (SOI, after Mullan 1995) and the monthly mean SAM index (after Marshall 2003).

Table 2: Average monthly frequency of occurrence of Kidson regimes, annually and by season, for lower ("Neg") and upper ("Pos") quartiles of the distribution of the SOI (top three rows) and the Marshall (2003) SAM index (bottom three rows).

		Annual		MAM		JJA		SON		DJF	
		Neg	Pos	Neg	Pos	Neg	Pos	Neg	Pos	Neg	Pos
SOI/ENSO	Trough	35.7	35.5	29.0	24.7	34.2	44.3	44.6	44.2	35.3	31.0
	Zonal	30.5	22.5	33.0	27.0	33.6	22.4	35.9	28.6	19.4	12.0
	Block	33.8	42.0	38.0	48.3	32.1	33.3	19.6	27.2	45.4	57.1
SAM	Trough	48.5	28.2	42.6	23.5	48.3	24.9	55.6	35.4	47.1	27.9
	Zonal	20.3	28.9	21.1	30.0	24.3	37.0	24.9	33.4	11.7	16.1
	Block	31.2	42.8	36.2	46.5	27.3	38.1	19.5	31.2	41.2	56.0

In the annual mean, occurrence of the Trough regime is insensitive to the phase of ENSO. Zonal regimes tend to occur more frequently during negative SOI (El Niño) periods at all times of year, while Blocking regimes tend to occur more frequently during positive SOI (La Niña) periods, especially in summer and autumn, corroborating the general picture of ENSO teleconnections over New Zealand (Jiang 2010; Kidson and Renwick 2002; Mullan 1995; Salinger and Mullan 1999).

The polarity of the SAM strongly modulates the occurrence of all three regimes. Trough regimes occur much more frequently during the negative SAM, when the Southern Hemisphere storm track lies equatorward of its mean position (Kidston et al. 2009). Zonal and Blocking regimes both occur more frequently during the positive SAM. For Zonal regimes, the influence is strongest in winter, while for Blocking, the influence is strongest in summer. Since the Kidson types and regimes are defined in terms of the full height field (not anomalies from climatology), it is the state of the background mean circulation plus the SAM-related anomaly that must be considered when relating the circulation to the Kidson regimes. Seasonal changes in the background mean circulation (i.e. mean latitude of the subtropical high pressure belt and the sub-polar surface westerly jet) are presumably a major factor in determining how the SAM affects the relative frequencies of the different regimes in different seasons.

(b) Expression of Kidson types in New Zealand surface climate

The patterns of daily climate anomalies associated with the synoptic types and regimes is illustrated here only for temperature and rainfall. Statistics are available for the other VCSN variables, and are discussed as appropriate.

Figure 1 shows annual mean departures from normal associated with the three K2K regimes, for maximum temperature, minimum temperature, and daily rainfall. Several features of the typical interaction of prevailing low-level wind flows with the country's topography (Salinger and Mullan 1999; Sturman and Tapper 2006) are evident in this figure.

For maximum (typically early afternoon) temperatures, the Trough regime brings below-average conditions, especially in the South Island, while the Zonal regime sees warmer than average conditions in most regions. The exception is in the west of both Islands, where onshore flows keep maximum temperatures below (or near) average. The Blocking regime is associated with reduced westerly flow over the country and hence above average maximum temperatures in western regions and below average in the east.

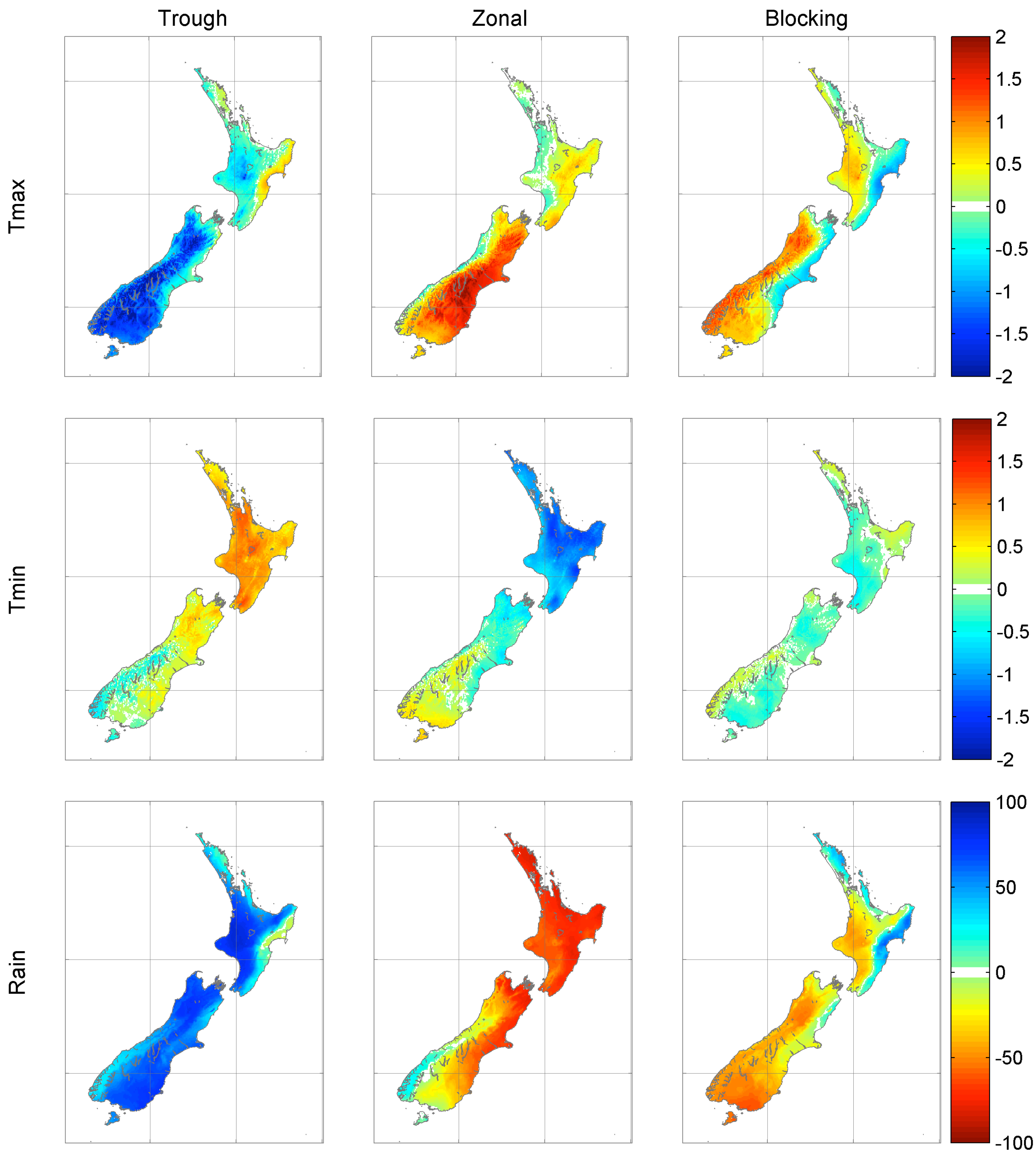

Figure 1: Annual average surface climate anomalies associated with the three regimes from K2K: Trough (left column), Zonal (middle column), and Blocking (right column). The top row shows maximum temperature anomalies (°C, darkest blue –2°C to darkest red/brown +2°C); the middle row minimum temperature anomalies (°C, same colour conventions as maximum temperature); and the bottom row rainfall anomalies (%, darkest red/brown –100% to darkest blue +100%).

For minimum (typically pre-dawn) temperatures, the pattern is quite different. The Trough regime is associated with relatively warm nights in most places, while the Zonal regime is associated with below average night time temperatures in many regions, especially in the North Island. Minimum temperatures are within a few tenths of a degree of normal on average during the Blocking regime, averaged through the year. Hence, the Trough regime is associated with a reduced diurnal temperature range (DTR), while the DTR is generally increased during the Zonal regime, and tends to be increased in the west and decreased in the east during the Blocking regime.

Rainfall anomalies vary strongly with regime. Most of the country is wetter than normal during the Trough regime, as might be expected, while much of New Zealand is drier than normal during the Zonal regime (apart from some areas in the southwest of the South Island). The Blocking regime also tends to be dry over New Zealand in association with the dominance of high pressure patterns, except in eastern parts of the North Island, where wind flows are often on-shore. Such patterns of rainfall anomalies are also typical of patterns of potential evapotranspiration (PET) and soil moisture, and of solar radiation (with inverse anomalies, i.e. less solar radiation where there is higher rainfall, and vice versa).

The annual mean patterns of response discussed above are in many cases expressed quite differently at different times of year. Figures 2-7 give examples, for winter (June-August, JJA) and summer (December-February, DJF).

Figure 2 shows results for the Trough regime. For maximum temperatures, the annual pattern is most strongly expressed in summer, with much below average daytime temperatures over most of the South Island. The winter pattern is relatively muted. Conversely, for minimum temperatures, the annual pattern is most strongly expressed in winter, with much above average night time temperatures over the North Island. The summer pattern is similar to winter, but much weaker. Such seasonal differences may in part reflect seasonal differences in land-sea temperature contrast, and in part the effects of day length. Cloudy nights associated with the Trough regime have more of an effect on minimum temperatures in winter than they do during shorter summer nights. For

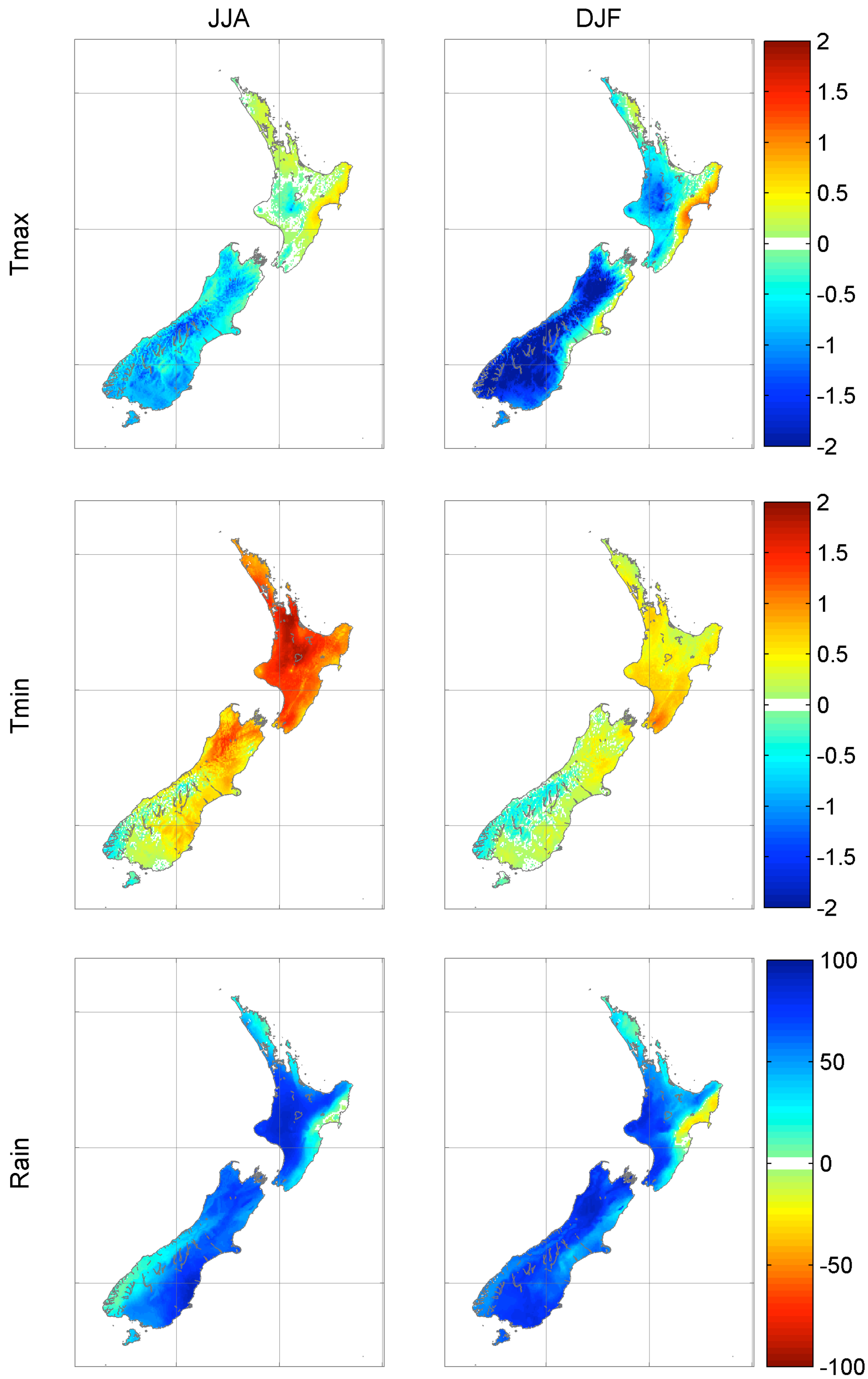

Figure 2: Average surface climate anomalies for winter (JJA, left column) and summer (DJF, right column) associated with the Trough regime from K2K. The top row shows maximum temperature anomalies; the middle row minimum temperature anomalies; and the bottom row rainfall anomalies. The colour scales are the same as for Figure 1.

rainfall, the overall pattern is relatively invariant with season, although north-south differences are most marked in summer.

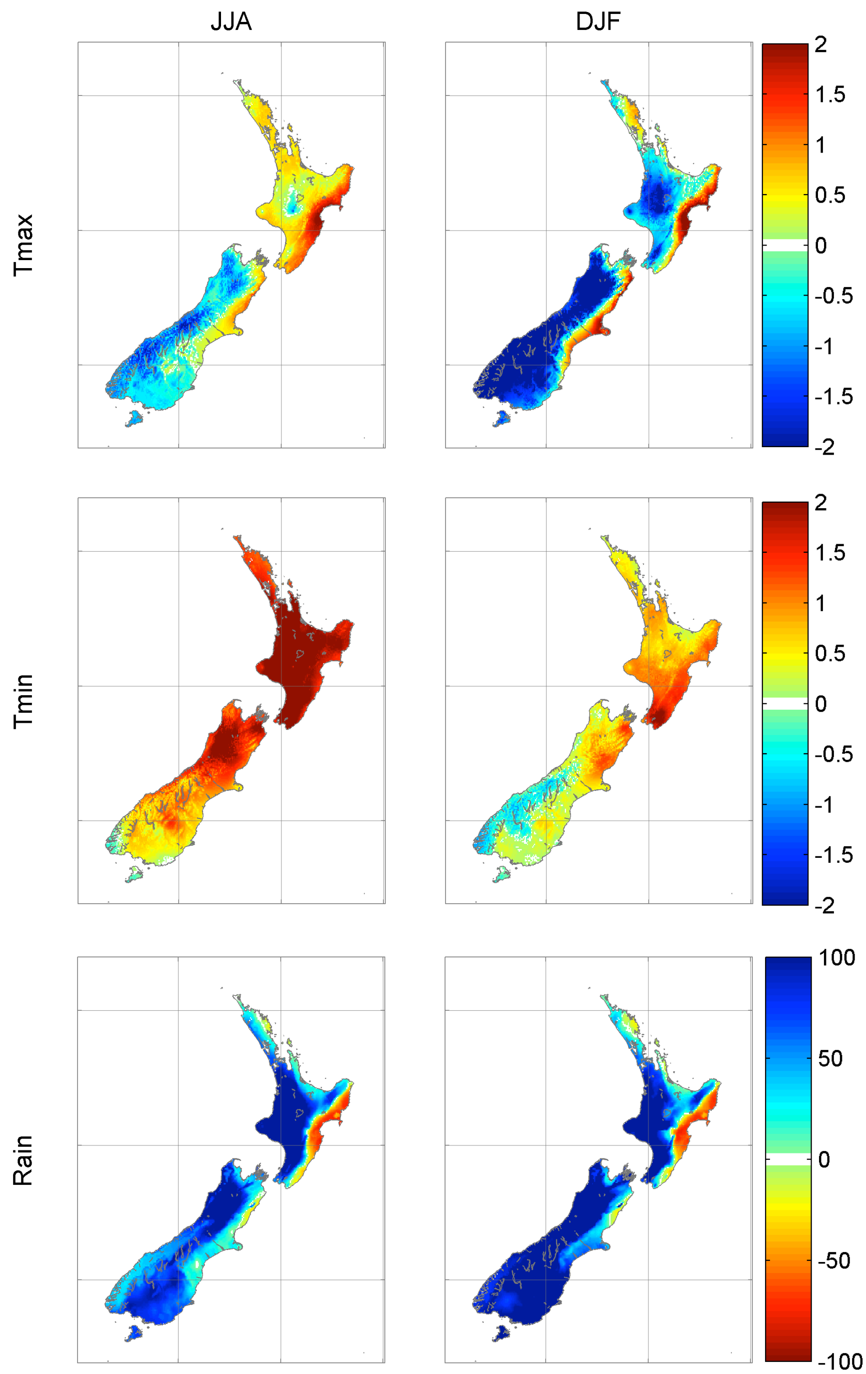

Figure 3: As in Figure 2 but for the T synoptic type from K2K.

Focusing further, Figure 3 shows results for the “T” (trough) synoptic type (which accounts for 12.3% of all days in the full sample, and around one third of all days in the Trough regime). Again, the pattern of maximum temperature anomalies is most strongly expressed in summer, while the pattern of minimum temperature anomalies is clearly strongest in winter. In summer, on average over the South Island, maximum temperatures are 1.8°C below normal, compared to being 0.5°C below normal in winter. Conversely, minimum temperatures are on average 2.1°C above normal over the North Island in winter, compared to 0.9°C above normal in summer. The rainfall pattern is again fairly invariant with season, although the anomalies over the South Island are larger in summer than in winter. The latter effect may be due to the higher specific humidity seen on average in summer.

Seasonal variations for the Zonal regime are shown in Figure 4. Here, the patterns of surface climate anomalies are relatively consistent with time of year. Zonal regime days are associated in the North Island with dry conditions and cool (presumably clear) nights. Daytime maximum temperatures exhibit more of an east-west gradient, reflecting topographic influences, with downslope warming in the east and a tendency for cloudy conditions west of the main mountain ranges in predominantly zonal flows.

Concentrating on the “W” synoptic type (Figure 5), the most zonal of the Zonal regime types (but also the least frequent at 4.8% of all days overall and around one in five of all Zonal regime days), reveals a more topographically-modulated pattern of surface climate anomalies. The east-west gradient in maximum temperatures is very pronounced in all seasons, with the eastern South Island typically around 3°C above average, while the west and south of the South Island are near average or below average. The west and south of the South Island tends to experience nearly double normal rainfall at all times of year during the W synoptic type, while the north and east of the North Island tends to be 30-50% drier than normal. Such a pattern is typical of El Niño conditions over New Zealand.

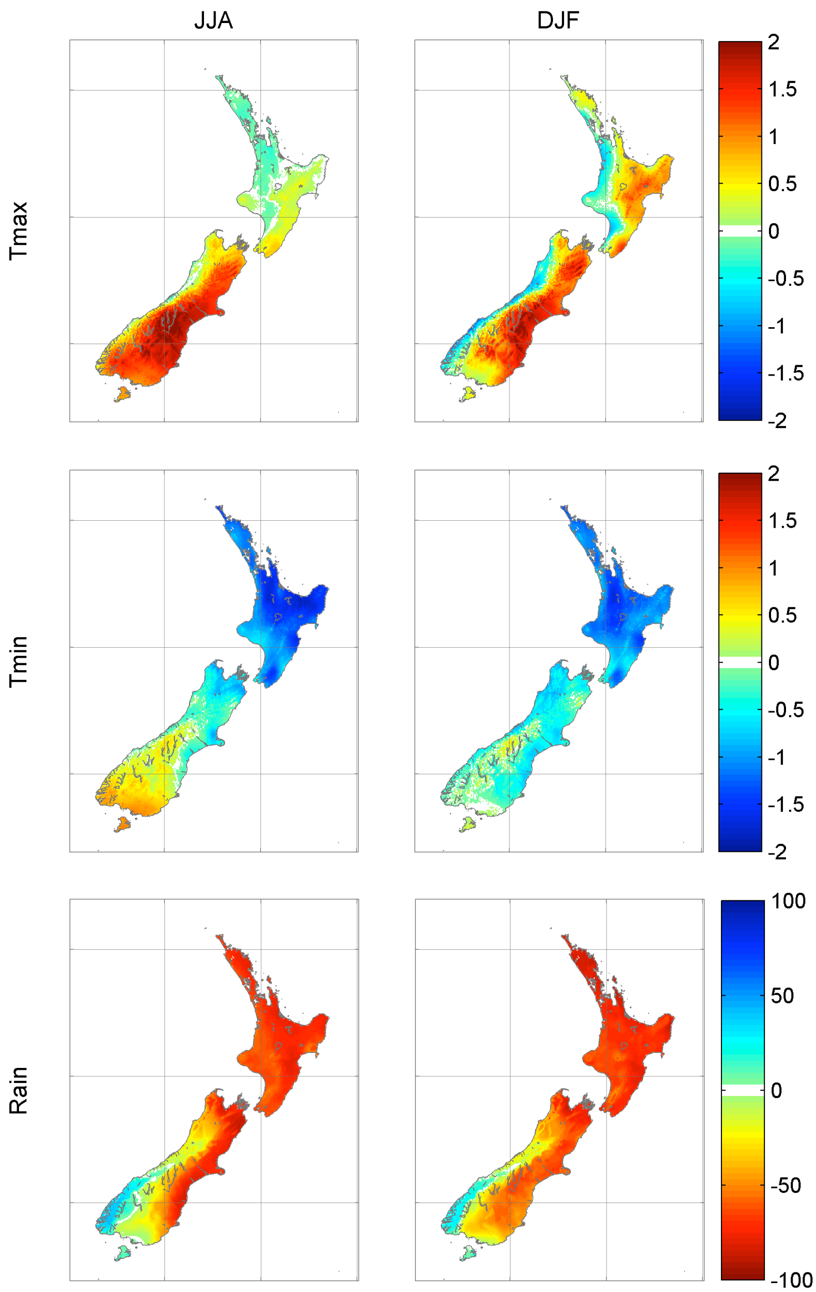

Figure 4: As in Figure 2 but for the Zonal regime from K2K

Turning to the Blocking regime, Figure 6 shows that the temperature response exhibits marked seasonality in many parts of the country. The temperature response is more towards positive anomalies in summer rather than in winter, especially for maximum temperatures, as may be expected from the associated weather conditions (lighter than normal winds, relatively clear skies) and the longer day length in summer.

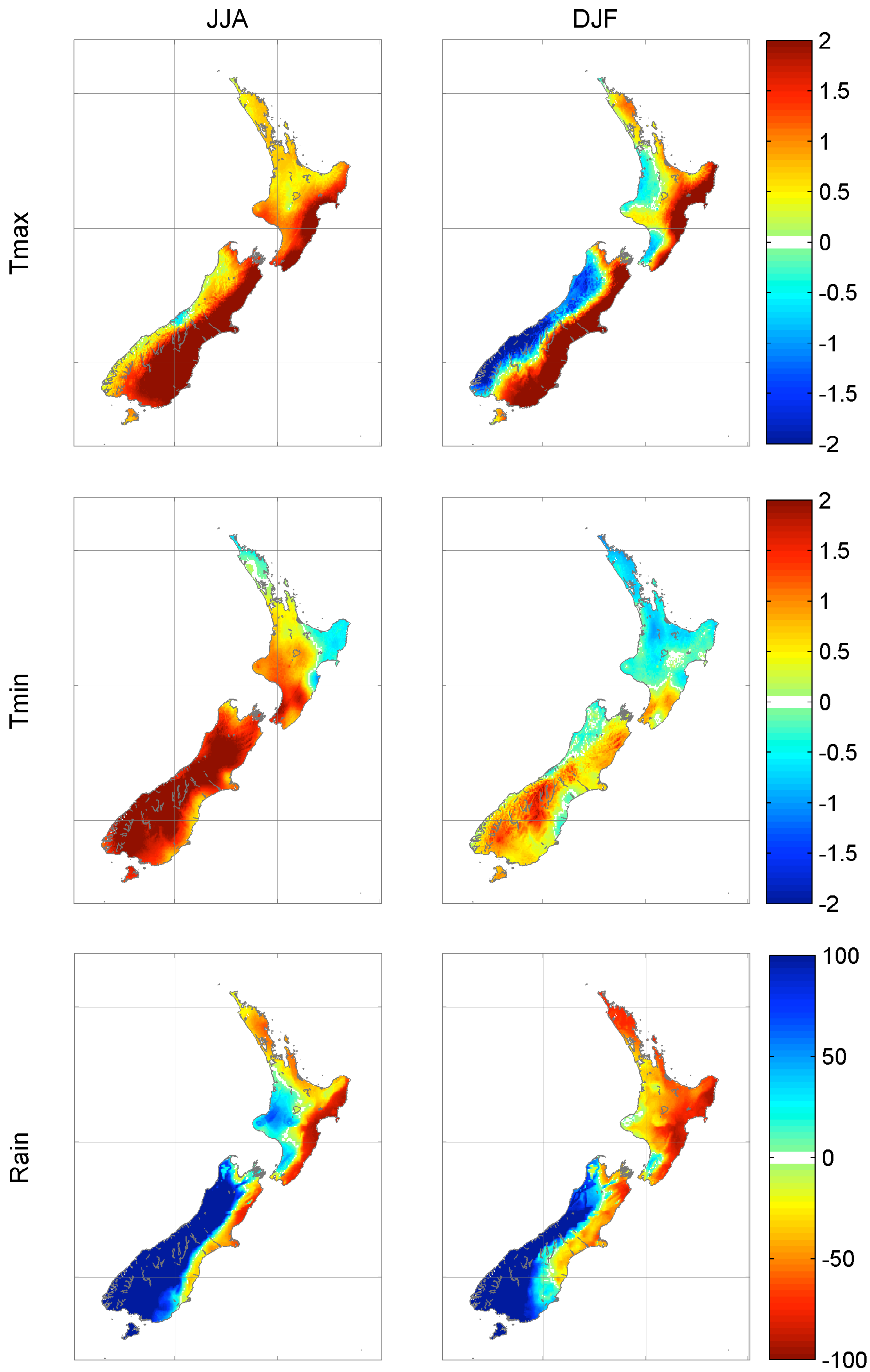

Figure 5: As in Figure 2 but for the W synoptic type from K2K

The Blocking regime is relatively dry over New Zealand throughout the year, but again more strongly in summer than in winter.

Focusing on the most common of the Blocking synoptic types, HSE (which accounts for around one in three of all Blocking days), seasonal differences in response are even more marked than they are for the Blocking regime as a whole. Figure 7 shows that the South Island experiences generally above average maximum temperatures in summer (South Island average anomaly +1.7°C) and below average in winter (South Island average anomaly –0.8°C) during the HSE type. Similarly, much of the country tends to experience below average minimum temperatures during HSE in winter, while minimum temperatures are near average overall in summer during HSE. This picture fits with the concept of a "cold high" in the winter months, while anticyclonic conditions are less associated with cold air during summer.

Rainfall tends to be below normal everywhere under HSE conditions, with the exception of the eastern North Island and eastern Northland in winter. This is consistent with the notion of settled conditions associated with large anticyclones, plus the effects of on-shore flow in eastern regions of the North Island.

The daily climate anomalies illustrated above are relatively large in magnitude, with local temperature departures of ±2°C or more quite common, and rainfall anomalies of ±30% or more. Such results appear to be at variance with the regional summary shown in K2K (his Figure 8), which shows anomalies of a few tenths of a degree and rainfall anomalies of around 10% associated with the three regimes.

However, two factors explain the apparent mismatch in the magnitude of the surface climate anomalies. In this study, averages have been taken of daily climate anomalies, grouped according to the daily occurrence of each of the synoptic regimes. Moreover, values are calculated separately at each of the VCSN grid points. The values shown in Figure 8 of K2K are regional averages (regions shown in K2K Figure 1) and are based on monthly average climate anomalies. To calculate the average monthly surface climate departures for each regime, it appears[2] that Kidson categorised each

[2] The approach is not actually stated in Kidson's paper.

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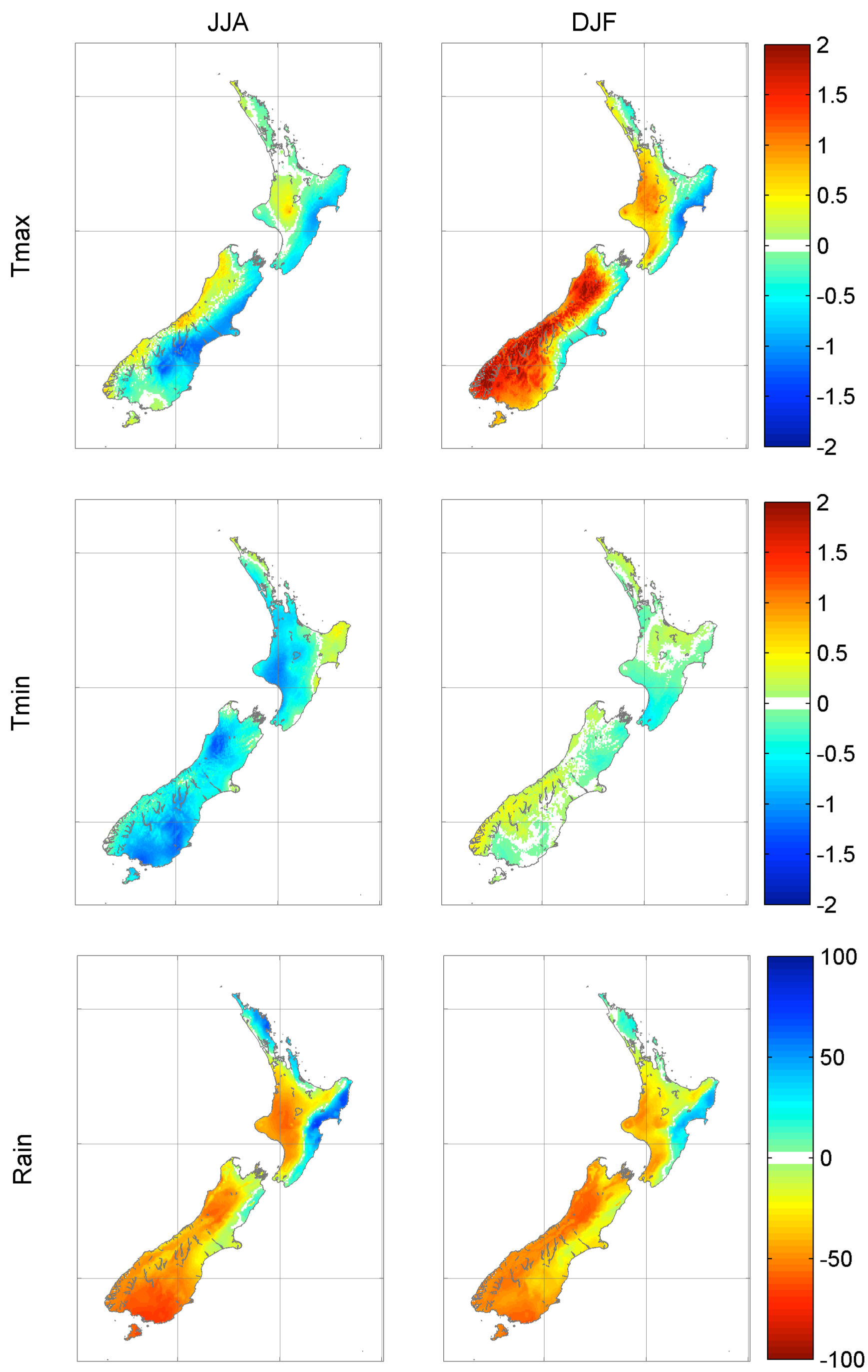

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Figure 6: As in Figure 2 but for the Blocking regime from K2K.

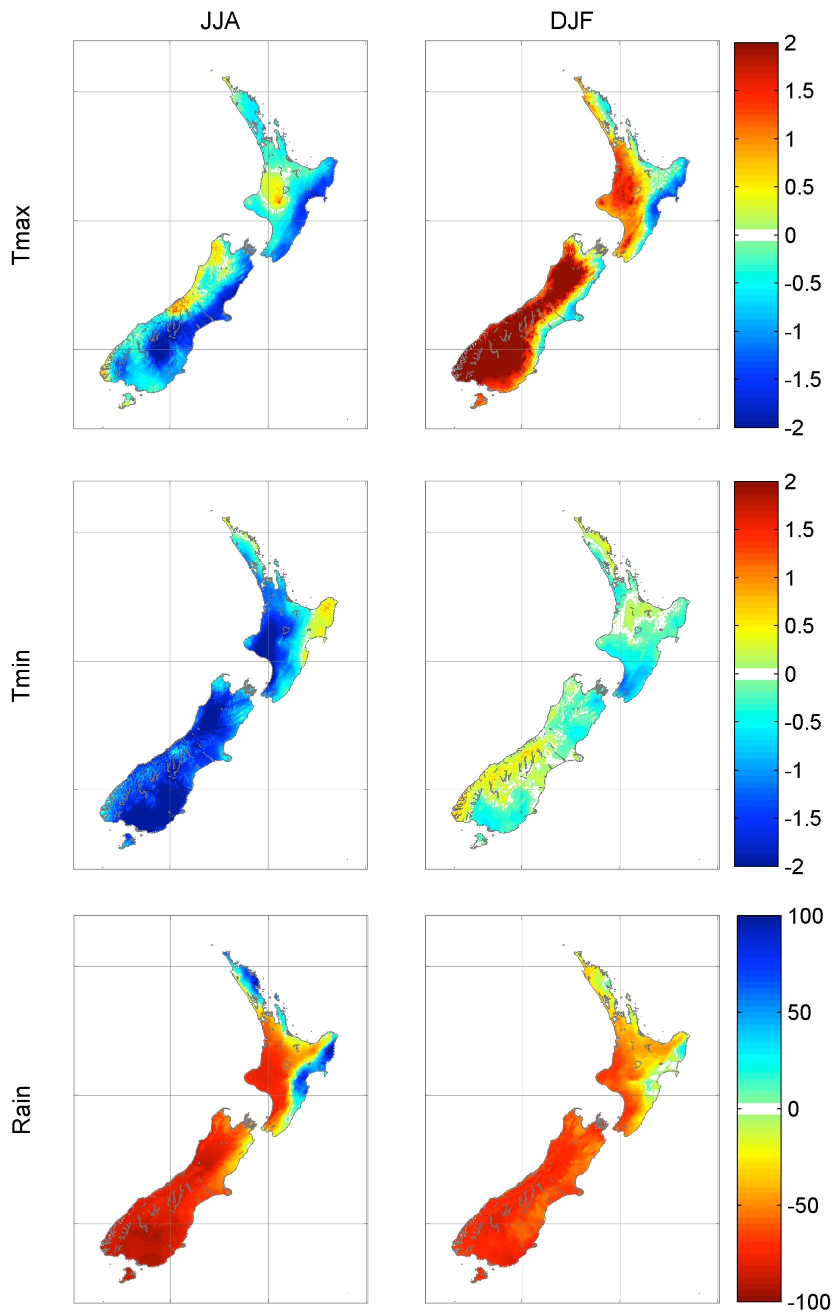

Figure 7: As in Figure 2 but for the HSE synoptic type from K2K.

month according to which regime was the most common (e.g. if a month was 60% Trough, the associated monthly climate anomalies were counted towards the "Trough" mean anomaly).

The K2K approach was replicated using VCSN data, for comparison. Daily grid point climate anomalies were averaged into the six climate regions, and into monthly mean values. The monthly values were averaged by Kidson regime, using the "most frequent regime" classification described above. Results are shown in Table 3. The mean climate anomalies obtained match those of K2K quite closely, especially for rainfall. Temperature statistics for the Trough regime are very similar to those given in K2K. For the Zonal regime, the figures given here are all higher than those in K2K but the spatial pattern is similar. For the Blocking regime, the pattern is also similar but the figures listed here are all lower than K2K. Hence, it appears that averaging by region smears out local gradients in surface climate associated with each regime (or synoptic type). More importantly, use of monthly mean data and categorising by the most frequent regime considerably weakens the apparent anomalies associated with each regime. The K2K climate anomalies represent weighted averages of all three regimes, while the anomalies shown here are "pure" averages of each regime, as they are based on daily fields associated with only one regime.

5. Discussion and Summary

This paper documents an update of Kidson's original time series of synoptic type classifications. It has demonstrated that the relative frequencies of occurrence of the types and regimes have not changed significantly over the past decade, compared to those obtained in the late 1990s. The K2K regimes are associated in plausible ways to the phase of the ENSO cycle and to the polarity of the SAM, with more zonal flow during El Niño and more blocking types during La Niña, more trough types during the negative SAM and more zonal and blocking types during the positive SAM

Table 3: Average regional climate anomalies, based on monthly averages, for each of the three K2K regimes. Region numbers are as given in Figure 1 of K2K (north, southwest and east of the North then South Islands). Rainfall figures are percent of normal, not percent departure from normal.

		Mean temperature (°C)			Rainfall (%)		
		Trough	Zonal	Blocking	Trough	Zonal	Blocking
Region	1 (North NI)	–0.13	0.01	0.13	106	81	103
	2 (SW NI)	–0.18	0.09	0.14	115	88	91
	3 (East NI)	–0.12	0.13	0.06	105	77	107
	4 (North SI)	–0.29	0.29	0.15	111	91	93
	5 (W & S SI)	–0.37	0.43	0.16	107	110	88
	6 (East SI)	–0.28	0.50	0.03	112	83	96

The synoptic types and regimes defined in K2K are closely associated with coherent daily climate anomalies at all times of year. The patterns of surface climate anomalies associated with each regime and synoptic type make meteorological sense in terms of known interactions between large scale (regional) circulation and New Zealand's rugged topography (e.g., Salinger and Mullan 1999). The mean magnitude of the daily climate anomalies associated with the Kidson types and regimes is much larger than suggested by Kidson's original results, because the K2K figures were based on regional averages, and mixtures of the different regimes within each month.

Such a descriptive study of the effects of the K2K synoptic types and regimes upon surface climate over New Zealand may help to refine qualitative interpretation of local scale climate variability, and may facilitate more in-depth studies of New Zealand climate variability, in palaeoclimate, climate change, or other contexts. Differences in mean climate associated with each of the synoptic types would no doubt have an expression in terms of the frequency of extreme events, and various climate "impacts" (flooding, land slips, fire risk, etc). Exploration of such avenues is the object of on-going research and will be reported in subsequent papers.

Acknowledgements

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