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Trends, periodicities and ENSO relationship of New Zealand rainfall

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सार - न्यूजीलैंड के छः समरूपी क्षेत्रों में 1901 से 1996 तक के वर्षों में वर्षा ठीक ढंग से एक जैसी (अधिकतम एकरूपता+0.6) नहीं पाई गई है। इन सभी महीनों में वर्षा लगभग समान रूप से हुई थी। इन सभी छः क्षेत्रों की वर्षा का रूझान (समग्र परिवर्तन लगभग 90 वर्षों में) ~ 0,+11,+2,-6,+1,+8 (~ 4 की घट-बढ़ के साथ) प्रतिशत था। मौसमी वर्षा के दृष्टिकोंण से क्षेत्र 1 के.डी.जे.एफ. के दीर्घ रूझान में 19 प्रतिशत की कमी और एम.ए.एम. के रूझान में 16 प्रतिशत की बढ़त पाई गई है। स्पेक्ट्रल विश्लेषण से यह पता चलता है कि क्यू. बी.ओ. की अधिकतम (अर्ध - द्विवार्षिक दोलनों, 2-3 वर्षों) रेंज थी तथा उच्चतर आवृत्तियाँ लगभग 3,4-5, 6-9, 10-11 वर्षों में थी। एनसो के संबंधों में अधिक स्पष्टता नहीं थी। एल नीनों की अलग-अलग घटनाओं में से केवल 1972-73, 1982-83 और 1997-98 के वर्षों की अत्याधिक प्रबल घटनाओं के कारण न्यूजीलैंड में अधिकांश भागों में सूखा पड़ा जबकि 1940-41 के वर्षों की एल नीनो की घटना के कारण अत्याधिक वर्षा हुई। सभी अन्य एल नीनो की घटनाओं के समय न्यूजीलैंड में कुछ महीनों में अधिकतम अथवा न्यूनतम वर्षा हुई। जिसके कारण इसके बाद कुछ महीनों (दोलनी स्वभाव) में वर्षा अधिकतम अथवा न्यूनतम हुई। यह स्थिति किसी ऋतु विशेष के विशेष महत्व के बिना कुछ घटनाओं में समान थी। जबकि अन्य घटनाओं में यह समान नहीं थी। ला नीना (प्रति-एल नीनों) घटनाओं के दौरान भी दोलनों का पता चला है।

ABSTRACT. The rainfall series for six homogeneous regions of New Zealand for 1901-1996 were not well intercorrelated (maximum correlation +0.6). Rainfalls were almost equally spread in all months. Trends (total changes over about 90 years) were ~0, +11, +2, -6, +1, +8 (±~4)% for the six regions. For seasonal rainfall, large trends were -19% for DJF and +16% for MAM of region 1. Spectral analysis showed peaks in QBO (Quasi-biennial oscillations, 2-3 years) range and near 3, 4-5, 6-9, 10-11 years and higher periodicities. ENSO relationships were not clear-cut. In individual El Niño events, only the very strong events of 1972-73, 1982-83 and 1997-98 were associated with widespread droughts in New Zealand, while the 1940-41 El Niño event was associated with excess rainfall. During the durations of all other El Niño events, New Zealand rainfalls were excess or deficit for a few months, followed by deficit or excess for the next few months (oscillatory nature), similar in all regions in some events, dissimilar in others, with no preference for any season. During La Niña (anti-El Niño) events also, oscillations were observed.

Key words – El-Nino, ENSO, QBO, Rainfall, New Zealand.

1. Introduction

Rainfall regimes in the Australasian region are very diverse. Even different parts of Australia do not have similar regimes (Srikanthan and Stewart, 1991). About 1600 kilometers to the east of Australia is New Zealand, an island 1600 kilometers long (northeast to southwest), but not more than 450 kilometers wide at its widest part, and surrounded by a large expanse of ocean (Fig. 1), and with mostly a marine climate (Mullan, 1998). De Lisle (1961) found trends in annual precipitation similar in certain areas, particularly in the north island (Figs. 1&2). Area rainfall studies by Coulter (1968), Tomlinson (1976) and Salinger (1979) suggested that, for secular variations, 20 stations could be considered as representative. For these, Tomlinson (1980) found some coherence and, from the average for the whole of New Zealand, some periodicities could be located which, when extrapolated, indicated possible droughts during 1983-86, similar to those predicted for southern and eastern Australia around

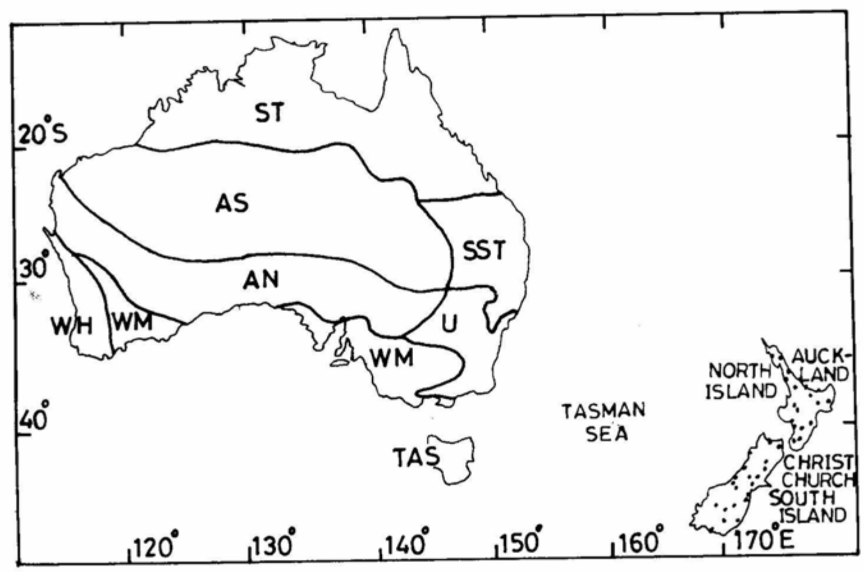


Fig. 1. Map of Australia and New Zealand. In Australia, the symbols ST *etc*. indicate the locations of eight major regions marked by Srikanthan and Stewart (1991). Four of these on the east side (TAS, WM, U, SST) have been considered for comparison with New Zealand. In New Zealand, the dots mark the 44 climatological sites used for analysis by Mullan (1995a,b)

1983-84 by Vines (1977, 1979). However, in all cases, considerable differences between different regions were also seen, probably due to high localization caused by orography.

Relationships of New Zealand weather with the southern oscillation were studied by Ward (1985) and Gordon (1985, 1986). Gordon (1986) found that SOI related anomalous wind flows caused different rainfall patterns in different parts of New Zealand, partly due to orography. Mullan (1989, 1995, 1996) showed that although it is often reasonable to assume a reversal between El Niño and La Niña, non-linearities are also evident, particularly so in the southern parts of New Zealand in the winter and spring seasons.

For ENSO (El Niño/southern oscillation) studies, Mullan (1995, 1996) had earlier used data for 44 stations spread all over New Zealand (Fig. 1). However, in a recent paper, Mullan (1998) used rotated EOF analysis and identified six regions of distinct REOF patterns, in each of which major rainfall characteristics were qualitatively similar. Data for 74 stations were used, with 9-15 stations in each of the six regions. About half of these had records starting prior to 1930. However, actual precipitation (mm) varied considerably from station to station and hence, data for each station were normalised with respect to the 1961-90 climatology (*i.e.*, rainfall was % normal, rather than a value in mm). In this communication, results are presented about the trends, periodicities and ENSO relationships of the six regional series for New Zealand *viz*.

1. East coast south island,
2. Western and southern south island,
3. Northern New Zealand,
4. East coast north island,
5. Southwest north island and
6. Northern south island, delineated by Mullan (1998) and marked as 1 to 6 in Fig. 2.

2. Rainfall characteristics

The average monthly rainfall distribution for the six New Zealand rainfall regions showed that all months had almost the same average rainfall (~100 mm), though southern summer rainfalls (December, January, February) may be slightly larger. For ENSO studies, Gordon (1986) and others recommended a May-April year, which breaks the calendar year at the well-known northern hemisphere

TABLE 1

Percentage trends (total percentage change over about 90 years) with their standard errors, in the rainfall level of the six regions, obtained by a regression analysis of monthly, seasonal, yearly and 11-year moving averages. Trend values exceeding twice the standard errors are shown bold

	Monthly	DJF	MAM	JJA	SON	Yearly	11-year
Region 1	+ 0.0 ± 5.7	**-19.3 ± 3.1**	**+15.6 ± 2.9**	+ 5.0 ± 2.8	- 4.8 ± 2.8	- 0.2 ± 6.1	- 1.0 ± 1.6
Region 2	**+10.8 ± 4.3**	**+14.1 ± 3.4**	+ 3.2 ± 2.2	**+10.5 ± 2.8**	- 0.2 ± 2.8	**+11.4 ± 4.2**	**+ 7.0 ± 1.6**
Region 3	+ 2.6 ± 4.5	**+10.9 ± 4.3**	- 4.0 ± 2.6	**+ 8.6 ± 1.7**	- 0.9 ± 1.7	+ 2.4 ± 4.9	**+ 3.8 ± 1.3**
Region 4	- 6.9 ± 5.7	- 7.3 ± 4.1	**- 8.8 ± 4.4**	+ 0.3 ± 2.2	+ 3.5 ± 2.2	- 6.0 ± 6.3	**- 3.2 ± 1.4**
Region 5	+ 0.6 ± 4.2	- 1.8 ± 3.4	+ 2.5 ± 1.8	**+ 6.2 ± 1.7**	**-11.4± 2.0**	+ 0.5 ± 4.0	- 1.2 ± 0.9
Region 6	+ 8.0 ± 4.9	- 2.6 ± 4.2	**+14.5 ± 3.1**	**+ 5.5 ± 2.1**	+ 3.4 ± 2.5	+ 7.7 ± 4.8	**+ 5.0 ± 1.2**
All, 1-6	+ 2.5 ± 3.3	- 1.0 ± 2.8	**+ 3.8 ± 1.7**	**+ 6.0 ± 1.1**	- 1.7 ± 1.5	+ 2.7 ± 3.3	**+ 1.8 ± 0.7**

spring predictability barrier. Plots of the 12-monthly (May-April) rainfall for each of the six regions during the period 1901-96 showed that the year-to-year variations were very large (60% to 140%) and the standard deviations ranged from 11% to 18%. Excess rains in 1905, 1935, 1979 and droughts in 1914, 1972 were widespread all over New Zealand; but many other wet or dry years were restricted to smaller areas. Intercorrelations between the 6 regions were moderate. The maximum was +0.59 ± 0.07 between regions 3 and 5. Regions 3, 4, 5 and 6 had correlations of ~ +0.5 between themselves; but the correlation of region 4 with region 6 was only +0.34. As such, no external factor (*e.g.*, ENSO) is likely to have the same relationship with all the regions. The low correlations must be atleast partly due to orographic differences.

3. Long-term trends

Underlying the large year-to-year fluctuations, the plots of the various time-series indicated possible long-term trends. A regression analysis using monthly, seasonal and yearly values and 11-year moving averages, yielded trends (total change over about 90 years) in the 6 regions, as given in Table 1. In the 11-year values, regions 2 and 6, indicate significant uptrends with total changes of atleast ~7% and 5% during the last ~90 years. (The procedure of calculating moving averages reduces the number of degrees of freedom, but some of these trends are significant even at a 3σ level). In regions 3 and 4, there are significant total changes of ~+4% and -3%. In regions 1 and 5, trends aresmall and insignificant. For the whole of New Zealand, the trends are small and barely significant, with a total change of ~+2%.

In the trends for different seasons DJF, MAM, JJA, SON, there are 13 significant trends (marked bold), but in different seasons in different regions. There are 10 uptrends and 3 down trends. Thus, different parts of New Zealand have widely different long-term variations, different in different seasons. Some differences must be of orographic origin; but others could be due to differences in the rainfall response to trends in near and far environmental parameters like coastal temperatures and temperatures in the Indian Ocean. This needs further detailed investigation.

4. Spectral analysis

To detect periodicities, all the series were subjected to a power spectrum analysis, using MESA (Maximum Entropy Spectral Analysis), with a LPEF (Length of the prediction filter) of ~50% of the data length. Estimates of amplitudes were obtained for the various MESA periodicities T_k by a Multiple Regression Analysis (Kane and Trivedi, 1982). Fig. 3(a) shows the spectra (amplitudes *versus* periodicities) for the whole period 1901-1996, using yearly values (May-April). The abscissa scale is log T, where T is the periodicity in years. The following may be noted:

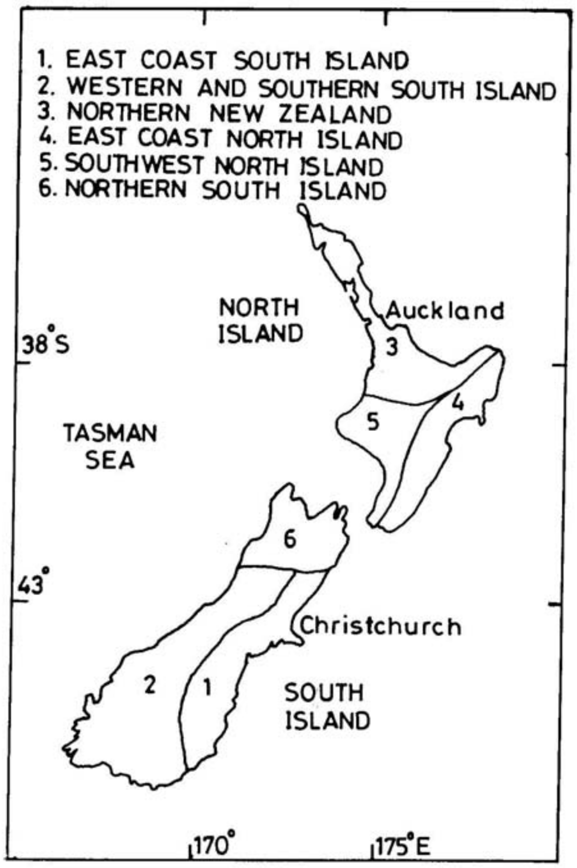


Fig. 2. Map of New Zealand showing the broad regions (1) East coast south island, (2) Western and southern south island, (3) Northern New Zealand, (4) East coast north island, (5) Southwest north island and (6) Northern south island, identified from an EOF analysis by Mullan (1997) as six homogeneous rainfall regions

(*i*) All the series have significant (protruding above the hatched portion 2σ limits) QBO (Quasi-biennial Oscillation, 2-3 years) peaks. However, there are generally more than one peak, indicating that the QBO is irregular or multiple.

(*ii*) There are several other significant peaks in each series, at 3.0, 3.9, 4.4, 5.6, 6.4, 8.3 and 9.9 years.

(*iii*) Signals at 10-12 years are seen in some series; but these are not very prominent. Currie and Vines (1996) reported a 10.5±0.7 years solar cycle signal and a 18.3±1.8 years luni-solar signal in several Australian rainfall series. The luni-solar M_n signal is seen in regions 1, 3, 4, 5 and whole New Zealand.

(*iv*) All regions (excepting region 2) have longer periodicities: 39.5, 34.8, 49.1, 45.3, 35.6, 42.5 years, in regions 1, 3, 4, 5, 6 and the whole of New Zealand. When the 11-year moving averages were subjected to MESA, these periodicities were seen prominently as shown in Fig. 3(b).

Pittock (1984), Nicholls (1984), Allan *et al*. (1995), Mullan (1995) indicated that characteristics and relationships may not remain constant with time. Allan *et al*. (1995) reported that the SSTs were cooler at midlatitudes and warmer in the subtropical southern Indian ocean during 1900-41 as compared to 1942-83. This long-term variability could be reflected in New Zealand rainfall also (Mullan, 1998). To check this for spectral characteristics, MESA was performed for two successive periods of 48 years each, 1901-48 and 1949-96. The following was noted:

(*i*) Peaks in the QBO region were seen more consistently in the first 48 years.

(*ii*) There were persistent peaks near 3, 4-5 (ENSO origin), 6, 8-9 and 10-12 years.

Gordon (1985, 1986) demonstrated that the rainfall characteristics in various seasons were different. To check this, MESA was performed for the rainfall series for seasons DJF, MAM, JJA, SON separately, using one value per year of each parameter, for 1901-1996. QBO and/or periodicities near 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 years and some very long periodicities were noticed, some in some seasons and regions, some in others; but no two region-seasons had similar spectra. A signal at 10-12 years was significant in many series. Some series had periods of ~16 years. Similarly, many series had significant peaks in the 20-23 year range.

5. ENSO relationship

The southern oscillation (Walker, 1924) is a seesaw of atmospheric mass between the Pacific and Indonesian regions. When the pressure is below normal in the southeast Pacific (*e.g.,* Tahiti T) and above normal over Indonesia and Australia (*e.g.*, Darwin D) and the pressure difference (T-D) is very low, the Pacific trade winds weaken and sea-surface temperatures (SST) increase along the Ecuador and Peruvian coast (warm water events). This SST warming is known as El Niño. On the other hand, when the pressure difference (T-D) is high, SSTs are below normal and the phenomenon is known as La Niña (cold water events). The El Niño/Southern oscillation phenomena are reported to be associated with droughts in several parts of the globe and excess rains in some others. Reverse conditions occur during La Niña (Ropelewski and Halpert, 1987, 1989; Allan *et al*., 1996). El Niño events are catalogued by Quinn *et al*. (1987).

TABLE 2

Rainfall status during El Niño years of the types(a) Unambiguous ENSOW, (b) Ambiguous ENSOW, (c) Other types of El Niños. Columns represent rainfalls of: (AI) All India summer monsoon, (SS-TA, SS-W, SS-U, SS-ST) Australian Tasmania and southeast, New Zealand (1) East coast south island, (2) Western and southern south island, (3) Northern New Zealand, (4) East coast north island, (5) Southwest north island, (6) Northern south island and (7) whole New Zealand

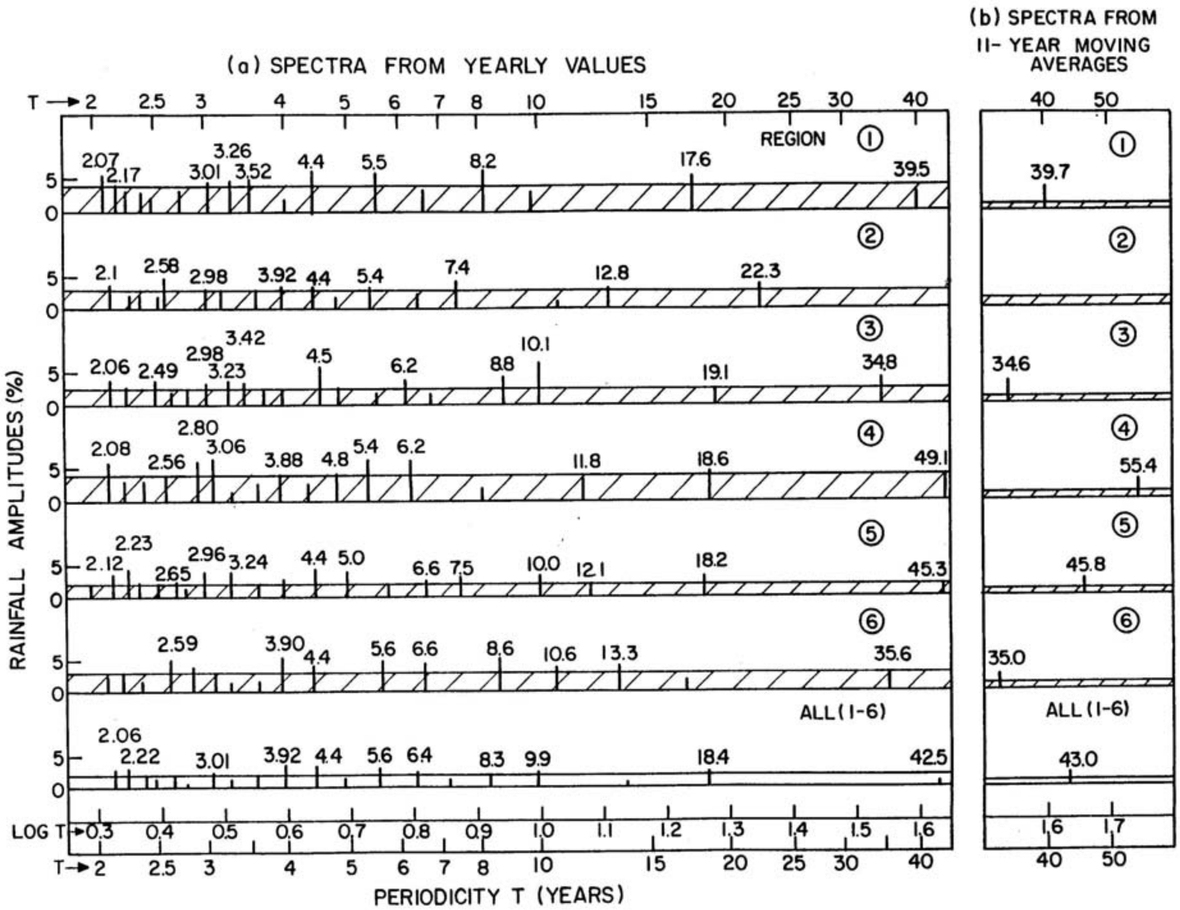
		India	Australia				New Zealand						
(a)	Unambiguous	AI	SS	SS	SS	SS	1	2	3	4	5	6	7
	ENSOW		TA	W	U	ST							
	13 events												
	Dev. Positive	1	2	3	2	2	3	7	1	4	7	6	4
	Dev. Negative	12	11	10	11	11	10	6	12	9	6	7	9
	Positive/Total	.1	.2	.2	.2	.2	.2	.5	.1	.3	.5	.5	.3
(b)	Ambiguous	AI	SS	SS	SS	SS	1	2	3	4	5	6	7
	ENSOW		TA	W	U	ST							
	13 events												
	Dev. Positive	8	5	6	6	7	4	7	5	4	5	5	6
	Dev. Negative	5	8	7	7	6	9	6	8	9	8	8	7
	Positive/Total	.6	.4	.5	.5	.5	.3	.5	.4	.3	.4	.4	.5
(c)	Other El Niños	AI	SS	SS	SS	SS	1	2	3	4	5	6	7
			TA	W	U	ST							
	All EN-33 events												
	Dev. Positive	12	12	14	11	13	12	17	9	12	16	14	13
	Dev. Negative	21	21	19	22	20	21	16	24	21	17	19	20
	Positive/Total	.4	.4	.4	.3	.4	.4	.5	.3	.4	.5	.4	.4

However, not all El Niños seem to be equally effective. Keeping this in mind, Kane (1997a,b) attempted a finer classification of years as follows:

The term ENSO is used nowadays for the entire ocean-atmosphere phenomenon, with El Niño as its warm phase and La Niña as its cold phase. However, in our classification, its components EN, SO were used in their literal sense. Thus, every year was examined to check whether it had an El Niño (EN) (Quinn *et al*. 1987), and/or Southern Oscillation Index SOI minimum (SO) and/or warm (W) or cold (C) equatorial eastern Pacific sea surface temperatures (SST). Several years had ENSOW *i.e*. El Niño (EN) existed and SOI had minima (SO) and Pacific SST were warm (W). The 12-monthly running averages of (T-D) and Pacific SST showed that during El Niño years, the (T-D) went through a broad minimum and Pacific SST went through a broad maximum, centered either in the middle of the calendar year (May-August) or in the beginning or end of the calendar year. Hence, the ENSOW years were further subdivided into two groups *viz*.,

(a) Unambiguous ENSOW where El Niño existed and the SOI minima and SST maxima were in the middle of the calendar year (May-August) and could be attributed unambiguously to that year.

(b) Ambiguous ENSOW where El Niño existed, but the SOI minima and SST maxima were in the early or later part of the calendar year, not in the middle, and would be attributed to that and the next year. Besides these, there were other years.



Figs. 3(a&b). (a) Spectra from yearly values (1901-96) of rainfall of regions 1, 2, 3, 4, 5, 6 and whole New Zealand (1-6). Note that the abscissa scale is log T and the numbers show the periodicities T. Circled numbers indicate the regions and (b) Spectra obtained by using 11-year moving averages

(c) Having El Niños of different types. Some other years did not have an El Niño and were of the types SOW, SOC, SO, W, C where the last category C contains all anti-El Niños, *i.e*., La Niñas. Years not falling into any of these categories were termed as non-events. This classification was made for all years from 1871 onwards and is illustrated in Kane (1997a,b). In the present communication, only events from 1901 onwards are considered.

5.1. *Unambiguous and ambiguous ENSOW*

Rainfall for every year was represented by symbols, + and – indicating positive and negative deviations within 0 to σ and, Δ (positive) and O (negative) indicating deviations exceeding σ. Table 2 shows the results for (a) Unambiguous ENSOW events, (b) Ambiguous ENSOW events and (c) Other El Niños. In each, the New Zealand series are 1 to 6 for the regions 1, 2, 3, 4, 5, 6 while 7 represents the whole of New Zealand. Besides these, five other series are considered *viz*., AI (All India summer monsoon rainfall, Parthasarathy *et al*., 1992) and four SS (Srikanthan and Stewart, 1991) series for Australian Tasmania and southeast (Fig. 1). The results for individual events are not shown, only their occurrence frequencies are indicated. In Table 2(a), there are 13 years of Unambiguous ENSOW type. The numbers at the bottom indicate the occurrence of positive deviations (*e.g.*, 1 for AI), occurrence of negative deviations (*e.g.*, 12 for AI), and the fraction of positives (*e.g.*, 1/13 = 0.1, for AI). Fractions 0.4, 0.5, 0.6 can be considered as indicative of poor relationship, 0.0, 0.1, 0.2 indicative of preference for droughts, 0.8, 0.9, 1.0 as indicative of preference for excess rains and 0.3 or 0.7 as mild relationships. For the next four columns examining Australian southeast rainfall, 10 or more events have negative deviations and the fractions of positive deviations is only ~0.2. Thus, Unambiguous ENSOW type years are overwhelmingly associated with deficit rainfalls in India as well as in southeast Australia. For New Zealand, only region 1 and 3 have low ratios, (0.2 and 0.1) implying association with droughts. Region 4 and 7 (whole of New Zealand) have a ratio 0.3, implying only a mild preference for deficit rains, while regions 2, 5, 6 have a ratio of 0.5, implying almost equal numbers (no preference) of positive and negative deviations, *i.e*., poor relationship.

Table 2(b) refers to Ambiguous ENSOW events. From the 13 events, 8 were associated with positive deviations and 5 with negative deviations for AI. Thus, such events had a poor relationship with Indian summer monsoon rainfall. If at all, there was a bias for excess rainfall (fraction of positives 0.6), opposite to that for Unambiguous ENSOW of Table 2(a). For Australian rainfall also, the positive fractions are 0.4 or 0.5, indicating poor relationship. For New Zealand rainfall, regions 1, 4 have mild preferences for droughts while other regions have a poor relationship.

Table 2(c) refers to other types of El Niño years. There were 33 years when El Niños of some kind or other were seen during 1901-90. All rainfalls show poor relationship (fraction of positives 0.4 and 0.5) except SS-U of Australia and region 3 of New Zealand which show a fraction 0.3 (mild relationship). Thus, just the presence of an El Niño may not necessarily assure a rainfall extreme. The Unambiguous ENSOW type shows the best relationship, certainly for All India summer monsoon rainfall and southeast Australian rainfall and regions 1 and 3 (and to a lesser extent, regions 4 and the whole) of New Zealand.

5.2. *Events SO, SOW etc*

Tables like Table 2 were made for other types of years also but are not shown here. For the 14 events involving SOW, SO, W, SOC, the relationship was poor or mild (fractions of positives 0.3 to 0.7).

5.3. *Non-events*

Among the 90 years (1901-90), there were 18 years when there was no El Niño, nor SO, nor W, nor C. The rainfall characteristics for these non-events would indicate what to expect even when there were no ENSO effects. The table is not shown here. For AI, among the 18 events, 9 showed positive and 9 showed negative deviations. This was as per expectation, except that 4 deviations were extreme positive and 3 were extreme negative. Thus, such extremes can occur without the presence of EN or SO or W or C. This should be kept in mind. For other rainfalls also, the number of positive and negative deviations was almost equal; but the occurrence of a considerable number of positive and negative extremes is disconcerting.

5.4. *Cold C (La Niña) events*

There were 25° C events which represent cold (below normal) water in the equatorial eastern Pacific and are mostly La Niña events. For AI, 23 deviations were positive and 2 negative (fraction of positives 0.9), indicating an overwhelming preference for excess rains. Thus, for India, La Niñas gave results opposite to those of El Niños (especially of the Unambiguous ENSOW type), as expected. For Australia, the effect was not so overwhelming. There were 14 to 19 positive deviations and 6 to 11 negative deviations. For New Zealand, the relationship was poor except for region 1 where a fraction of positives 0.3 was seen. However, for Unambiguous ENSOW also, the fraction of positives for region 1 was low (0.2). Thus, for both Unambiguous ENSOW and C events (opposite extremes of ENSO), region 1 has preference for droughts. This is similar to the nonlinearity behaviour of winter temperatures of central and southern south island, which are colder in both extremes of the southern oscillation (Mullan, 1995).

5.5. *ENSO- rainfall relationship in individual events*

Allan *et al*. (1996) showed composites illustrating the near-global physical impacts of ENSO phases (warm phase El Niño, cold phase La Niña) and gave time sequences showing simultaneous global MSLP and SST anomalies during the last few decades. We made a similar attempt, but restricted to a comparison of Pacific SST, Southern Oscillation Index (SOI) and New Zealand rainfall anomalies during major El Niño events. It was noticed that rainfalls in the various regions were deficit only during the three giant El Niño events of 1972-73, 1982-83 and 1997-98. In the 1940-41 El Niño, rainfalls were excess. In all other events, rainfalls were oscillatory, *i.e*., excess during a part of the event, followed or preceded by deficits in other parts of the event. During La Niñas also, similar oscillatory patterns were seen. Often, such patterns were seen even when SST anomalies were small. Thus, rainfall extremes were very common, but their presence during El Niños or La Niñas may well be by chance. This does not prove that ENSO effects are absent; but certainly, other effects are complicating the situation.

Gordon (1985, 1986) explored the correlation between the southern oscillation and the New Zealand weather. Regarding rainfall, Gordon (1985, 1986) reported that the spatial average was less strongly correlated with SOI. Because of orographic effects, the SOI relationship may vary from region to region. The rainfall correlations varied considerably on a regional basis. As quoted in Gordon (1986) "In MAM, negative SOI gives anomalous southwesterlies which bring above-normal rainfall to the south island (regions 1, 2, 6) and southwestern parts of the north island (region 5), and below normal rainfall in the northeast (region 4). In JJA, the anomalous flow for a negative SOI is southerly, and this drier air result in lower than average rainfall for most of the country. In SON, the significant correlations are in the northern half of the north island (region 3), partly as a result of sheltering, giving lower rainfall in the east (regions 3, 4) for negative SOI and anomalous southwest flow, but also because a negative SOI is associated with generally high pressures and more settled weather in the north. In DJF, the anomalous flow is more westerly with lower pressures in the far south, and a negative SOI is associated with wetter conditions in the south and west (regions 1, 2) and drier in the east (regions 4, 6)". In our plots of individual events, the following was noted:

(a) Overall, whereas the Gordon expectations came true in some years, these failed in many other years. A striking example was 1997 when SOI was negative from May onwards and regions 1, 3, 5, 6 showed deficit rainfalls while region 2 showed mixed rainfalls and region 4 showed excess rainfall up to October and deficit thereafter.

(b) When the rainfalls are oscillatory for any region, the early part of the El Niño may be associated with any extreme (deficit or excess), irrespective of the season involved, or irrespective of the SOI condition. The oscillatory nature indicates some sort of a pressure wave and its subsequent relaxation and reappearance, not necessarily simultaneously in all regions. Considerable local effects must be involved which vitiate and obscure the ENSO effects.

6. Conclusions

Using the rainfall data for 1901-96 for six homogeneous regions of New Zealand defined by Mullan (1995, 1996) as, (1) East coast south island, (2) Western and southern south island, (3) Northern New Zealand, (4) East coast north island, (5) Southwest north island and (6) Northern south island, the general characteristics, trends, periodicities and ENSO relationships were examined. The following was noted:

(a) The six regions have diverse rainfall regimes and intercorrelations do not exceed +0.6. No region experiences extreme seasonality. But winter (June-August) is the wetter season generally in the north island (3, 4, 5). The seasonality is more complex in the south island.

(b) The interannual variability is large and different for different regions. The standard deviations are ~17, 12, 14, 18, 11, 14% for the six regions and 9% for the whole of New Zealand. For seasons MAM, JJA, SON, DJF, the standard deviations are ~20 - 40%.

(c) The overall long-term trends (total change over ~90 years) obtained from an analysis of yearly values are: ~0%, + 11%, + 2%, -6%, +1%, +8% (± ~4%) for the six regions, significant only for regions 2 and 6. For the whole of New Zealand, the trend is ~3%, not significant. For individual seasons, the trends in some regions are large (extremes, -19% for DJF of region 1 and +16% for MAM of region 1).

(d) The spectral characteristics indicate considerable quasi-biennial oscillations (2-3 years) in almost all regions. Other periods are seen near 3, 4, 5, 6, 7, 8, 9, 10,11 years. Their amplitudes and relative proportions are different in the various regions and in different seasons.

(e) Not all El Niños are equally effective in causing droughts or floods in any part of the globe, excepting in the core region (low latitude Pacific) of ENSO. Trenberth (1993) speaks of El Niño "flavours". Recently, Kane (1997a,b) observed that, among the El Niños, events of the type Unambiguous ENSOW, where El Niño (EN) existed and the Southern Oscillation Index represented by Tahiti minus Darwin atmospheric pressure difference had a minimum (SO) and the equatorial eastern Pacific sea-surface temperature SST had a maximum (W) in the middle of the calendar year, showed strong association with droughts in India, southeast Australia and some other locations on the globe. Thus, this classification might be picking some distinct "flavours". The present analysis showed that for New Zealand, such events seemed to have a special significance only for a few seasons in a few regions. But often, similar extremes were seen in years when there were no El Niños or La Niñas.

(f) A detailed comparison of central Pacific (Niño region 3.5) SST anomaly evolution in 21 El Niño events in this century with the corresponding rainfall anomalies in the six regions of New Zealand revealed that droughts were seen in all regions only in the three strongest El Niño events, namely, 1972-73, 1982-83 and the recent 1997-98. In the El Niño of 1940-41, the association was with excess rainfall (not droughts). In all other events, the rainfalls were excess for a few months, followed or proceeded by deficits in other months. These oscillatory patterns were similar in all regions in some events, but dissimilar in some other events. The spacing between successive excesses and deficits was about 6 months. No preferences for any particular season were observed, for any region.

(g) La Niña events also showed oscillatory patterns, with similar spacings and no preference for any season.

(h) In addition, such patterns were seen even in years when ENSO (El Niño or La Niña) events were absent. Thus, complications due to other factors unrelated to ENSO phenomenon were indicated. Prominent among these factors are the SST anomalies in the western Tasman sea and south Australia and in the Indian Ocean (Smith, 1994; Mullan, 1998).

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