Water Vapor Transfer over the Southwest Pacific: Mean Patterns and Variations during Wet and Dry Periods

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ABSTRACT

The mean water vapor transfer of the Southwest Pacific, as determined from radiosonde records near the 170°E meridional transect, is computed for the 1960–73 period. Emphasis is placed on defining average patterns, then examining variations that arise during the wettest and driest years and seasons in New Zealand over that period. Over the midlatitudes, the mean transfer is predominantly from the west, and most developed in summer. Over the subtropics, the mean summer transfer is predominantly from the north or northeast, but in winter a northwest flow prevails. Patterns of water vapor transfer during wet and dry periods over New Zealand differ more in direction than in magnitude, with the subtropical easterlies extending farther poleward during wet periods, especially in summer.

1. Introduction

The flux of water vapor in the atmosphere constitutes a major component of the global hydrological cycle, and is subject to considerable variation (Rosen et al., 1979). Although several workers discuss atmospheric water vapor transfer over the Southwest Pacific (Starr et al., 1969; Starr and Peixoto, 1971; Peixoto, 1972; Peixoto et al., 1976; Peixoto et al., 1978), their coverage of the region is, in general, only a part of larger studies and restricted to short time periods, often one year. This paper presents a more detailed analysis for the region since zonal, meridional, and vector water vapor transfers are calculated for six radiosonde stations near the 170°E meridional transect (see Fig. 1, Table 1), from Nadi (17°46'S) to Campbell Island (52°33'S) over the period 1960–73.

As noted by Rosen et al. (1979), most studies of large scale moisture flux emphasize average patterns rather than departures on a year to year or seasonal basis. In order to make the present study as complete as possible, the second part of the paper is concerned with an investigation of characteristics of short-term averages of water vapor transfer during the wettest and driest periods of 1960–73 over New Zealand. Hereafter, these periods will be abbreviated "wet" and "dry." Such an analysis is of practical importance to a country where weather-dependent agricultural exports dominate the economy, and provide 70% of its overseas earnings.

From the data of Tomlinson (1980), the 1960–73 rainfall average, as obtained from the mean of 20 representative stations spread throughout New Zealand, was within 1% of the corresponding long-term average calculated from 1900–78. However, rainfall over the latter part of the 1960–73 study period was the lowest for forty years over much of the country. The period of study is thus "representative" in that it is close to the long-term average while at the same time it includes a considerable rainfall range for individual years and seasons.

New Zealand has high relief, with the main axial ranges running southwest to northeast, and reaching an elevation of 3764 m (Fig. 1). The mean wind flow is from the west/southwest, but there are variations depending on the frequency of fronts, depressions, and wave cyclones in the westerlies, together with occasional tropical cyclones from the north. The orientation of the airflow ahead of or behind these disturbances determines the spatial distribution of rainfall over New Zealand. Salinger (1980) demonstrates that precipitation anomalies are strongly localized, because the rugged topography triggers orographic precipitation on most windward coasts.

Salinger (1980) showed that months with negative pressure anomalies to the south of the country (i.e., a westerly circulation predominates), are associated with rainfalls higher than normal in the west, and lower in the east and north. Conversely, whenever pressures are lower than average to the north of New Zealand, a more easterly flow develops, so that the north and east are wetter than normal, and the south
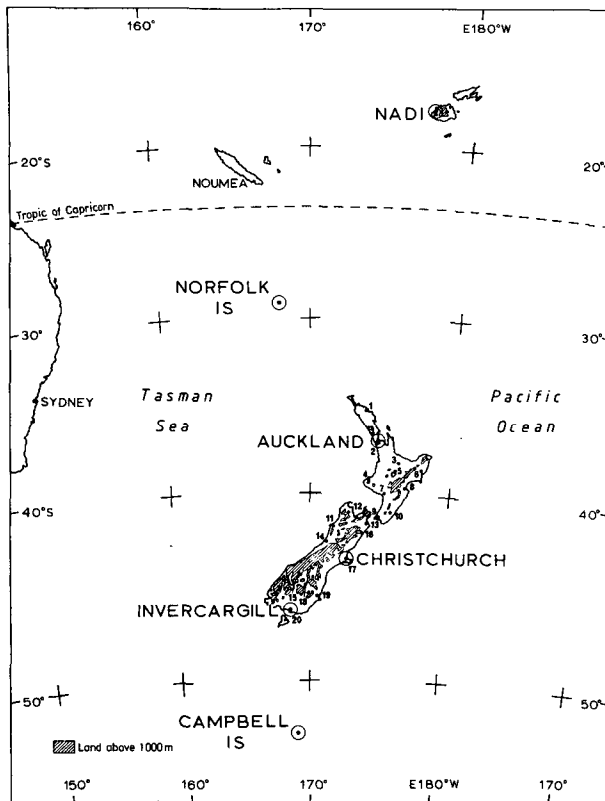
FIG. 1. Location of the radiosonde stations along the Southwest Pacific meridional transect and of rainfall stations given in Table 2.

and west drier. Previously Trenberth (1977) had investigated the relationships among inflow into hydro lakes, precipitation, and broad scale atmospheric circulation patterns in the southwest of the country. He also found that precipitation was associated with westerlies and also northerlies to a lesser extent. Southerlies were not found to be favorable to precipitation. A major factor in the northerly flow precipitation was considered to be the increased moisture transported into the hydro lake region from the tropics.

There are also pronounced secular fluctuations in annual rainfall over New Zealand (Tomlinson, 1976, 1980, Vines and Tomlinson, 1980). By using a set of four filters, which relate to the approximately 21 year double sunspot cycle and its first and second harmonies, these authors showed that a definite nonrandom element exists in New Zealand's temporal rainfall over the period 1900–78. The years in the early 1910s, 1920s, 1930s and 1970s tended to be dry, while groups of wetter years occurred regularly in each decade. The present study goes some way toward a causal explanation of such fluctuations through linking wet and dry periods to specific patterns of vapor flux.

While studies have examined abnormal climatic periods elsewhere in the world (e.g., Hastenrath and Heller, 1977; Kidson, 1977; Kanamitsu and Krishnamurti, 1978; Nicholson, 1981), there has been little attempt to investigate whether these periods are accompanied by changes in the vapor flux field. Kidson (1977) was restricted by the incompleteness of his humidity data, but he noted that it was unfortunate this "prevented a comparison of the vapor budgets for wet and dry years." Wetter and drier periods could also be related to other parameters such as variations in the divergence of the vapor flux, the divergence and vorticity of the velocity field, the vertical motion, and in tropospheric static stability. However, divergence calculations require radiosonde stations to be distributed over an area, and are not suitable where stations are along a transect as is the case in this study, and information on vertical motion was not available.

2. Data and procedures

For a given level in the atmosphere the magnitude of the instantaneous zonal, meridional and vector transfer of water vapor is defined by

$$Q\lambda_L = g^{-1}qu, \tag{1}$$

$$Q\phi_L = g^{-1}qv, \tag{2}$$

$$\mathbf{Q}_L = g^{-1}q\mathbf{c}, \tag{3}$$

where

$Q\lambda_L$ zonal water vapor transfer for a given level (kg m^{-1} mb^{-1} s^{-1}),

$Q\phi_L$ meridional water vapor transfer for a given level (kg m^{-1} mb^{-1} s^{-1}),

$\mathbf{Q}_L$ vector transfer of water vapor for a given level (kg m^{-1} mb^{-1} s^{-1}),

g acceleration due to gravity (9.81 m s^{-2}),

q specific humidity (g kg^{-1}),

$\mathbf{c}$ vector wind (magnitude: m s^{-1}; direction: true °),

u zonal wind component (m s^{-1}),

v meridional wind component (m s^{-1}).

The vertically integrated magnitude of the instantaneous transfer of water vapor (kg m^{-1} s^{-1}) is approximated by

$$Q\lambda = g^{-1}\int_{p_s}^{400} qudp, \tag{4}$$

$$Q_\phi = g^{-1}\int_{p_s}^{400} qvdp, \tag{5}$$

$$\mathbf{Q} = g^{-1}\int_{p_s}^{400} q\mathbf{c}dp, \tag{6}$$

and the total amount of precipitable water (kg m^{-2}) is obtained by similar integration

TABLE 1. Characteristics of radiosonde stations.

Station	Latitude	Longitude	Elevation (m)	Surrounding terrain
Nadi	17°46'S	177°21'E	18	This airport station is on the NW of the island of Viti Levu and in the lee of 1300 m high mountains 20 km to the east.
Norfolk Island	29°03'S	167°51'E	109	The island is 8 km long and 5 km wide. Highest point is 317 m and the station is on the SW of the island.
Auckland	37°01'S	174°48'E	7	This airport station is surrounded by low land or sea.
Christchurch	43°29'S	172°33'E	36	This airport station is located on an open plain, but in the lee of the Southern Alps (3000 m) 80 km to the west.
Invercargill	46°25'S	168°20'E	2	This airport station is at the southern margin of an extensive plain. Nearest high ground is 40 km to northwest.
Campbell Island	52°33'S	169°09'E	15	The island is 16 km in diameter with rugged hills 300–570 m high. The station is on an inlet 7 km from ocean.

$$w = g^{-1} \int_{p_s}^{400} q\,dp, \qquad (7)$$

where p_s is surface pressure.

The mean of the above parameters over a specified time period is defined by the function

$$(\bar{x}) = T^{-1} \int_0^T (x)\,dt, \qquad (8)$$

where the bar operator denotes a time average of the specified quantity (x) for the time interval T.

The basic data for the computation of the above parameters consist of surface and upper air measurements of mixing ratio and wind, as observed once or twice daily (at 0000 and sometimes at 1200 GMT) at the six radiosonde stations for the period 1960 to 1973. Details of the stations are given in Table 1. Less than 0.5% of the observations are missing. In the calculation of the abovementioned parameters, observations at eight or more pressure levels were used (surface, 900, 850, 800, 700, 600, 500, 400 mb, and in some cases 950 and 750 mb as well).

TABLE 2. Wet and dry periods from the period 1960–73 selected for analysis, and the spatial distribution of rainfall over New Zealand. Values are given as percentages of normal (1941–70); the stations are located by number in Fig. 1.

Station number	Station name	Dry year 1973	Wet year 1968	Dry summer 1972–73	Wet summer 1965–66	Dry winter 1969	Wet winter 1968
1	Kerikeri	79	115	60	151	73	120
2	Auckland	86	130	31	164	86	117
3	Rotorua	74	99	48	169	60	125
4	New Plymouth	98	102	49	112	107	77
5	Taupo	77	93	61	136	50	115
6	Gisborne	97	98	96	68	57	164
7	Wanganui	73	94	37	87	85	88
8	Napier	101	102	62	131	62	138
9	Wellington	82	107	36	113	66	106
10	Masterton	77	91	28	83	57	87
11	Westport	91	122	83	102	61	123
12	Nelson	66	102	26	114	36	130
13	Blenheim	64	106	12	133	19	119
14	Hokitika	91	111	60	127	69	117
15	Queenstown	87	107	51	90	87	115
16	Kaikoura	58	96	48	70	62	135
17	Christchurch	76	116	40	74	40	105
18	Alexandra	91	127	39	118	64	182
19	Dunedin	85	130	52	118	59	85
20	Invercargill	95	105	80	85	96	84
Average for New Zealand (% of normal)		84	107	54	116	67	114
Actual New Zealand rainfall for period (mm)		975	1246	142	307	218	369

The Diamond Hinman radiosonde, used at all the six stations, is subject to failure beyond a temperature/humidity threshold, indicated by the "motorboating" effect (Hutchings, 1961). The true mixing ratio is unknown in such situations, although it must lie between zero and the mixing ratio calculated using the cutout threshold temperature and humidity (Tomlinson, 1975). "Exclusive" values given in this paper refer to motorboating situations in which the mixing ratio was set to zero. "Inclusive" values are those where the mixing ratio has been calculated using the threshold values.

The main errors in computed values of water vapor parameters arise from instrumentation faults, such as the lag in humidity elements of the radiosondes and inadequate wind resolution. There are also the inevitable interpolation errors arising from the fact that water contents are measured at preselectetd points. These problems have been discussed by Hutchings (1957), Starr et al. (1969) and Peixoto (1973).

The "wet" and "dry" periods chosen for analysis were the wettest and driest year, summer and winter, that occurred within the 1960–73 period at the New Zealand radiosonde stations, as supported by "maps of rainfall departure from normal" and "summary of weather" contained in "Meteorological Observations" published by the New Zealand Meteorological Service. The chosen periods were also wetter and drier than normal (1941–1970 mean rainfall) as determined by calculating averages for the periods concerned using the same 20 stations as Tomlinson (1980) in his New Zealand series (Table 2).

The 20-station mean has secular variations closely similar to that of the spatial average incorporating all New Zealand stations (Tomlinson 1976, Salinger 1979), consistent with the wide dispersion of the 20 stations on both sides of the main mountain ranges (Fig. 1). Tomlinson (1976) notes that annual rainfall totals at each of 340 stations throughout New Zealand are correlated to one of these 20 stations with a correlation coefficient that is no worse than 0.70. As a result, the average of the 20 stations can be used to represent "New Zealand rainfall" for each period. Some of the deviations from normal shown in Table 2 are small for New Zealand rainfall thus defined, because the data are averaged over space throughout the whole country.

a. Dry year (1973)

This year, rainfall in New Zealand was 84% of normal, or about two standard deviations below the long-term mean. All stations were drier than usual, except for Napier (station No. 8, Fig. 1) where rainfall was close to normal. The central part of the country was driest, with Kaikoura (No. 16) having only 58% of normal rainfall, or almost two and half standard deviations below the mean.

b. Wet year (1968)

Rainfalls were not excessively high, but 1968 rainfall was one standard deviation above the long-term mean. Over New Zealand rainfall was 107% of normal. Auckland (No. 2) and Dunedin (No. 19) both had 130% of normal rainfall (more than 1.5 standard deviations above the mean), but six stations in the central area of the North Island were drier than usual.

c. Dry summer (1972–73)

The summer was dry over the whole country, with New Zealand rainfall being 54% of normal. At Blenheim (No. 13), rainfall was only 12% of normal, and it was also very dry at Auckland (No. 2), Masterton (No. 10) and Nelson (No. 12).

d. Wet summer (1965–66)

New Zealand rainfall was 116% of normal. In the north, rainfall was more than 150% of normal, and Blenheim (No. 13) and Hokitika (No. 14) also received greater than 125%. However, six stations were drier than usual, notably Christchurch (No. 17) and Kaikoura (No. 16).

e. Dry winter (1969)

Record low rainfalls occurred north and south of Christchurch, with Blenheim (No. 19) having 19% of normal. It was drier than normal at all stations, except at New Plymouth (No. 4) in the west of the North Island. Overall, New Zealand rainfall was 67% of normal.

f. Wet winter (1968)

Compared with long-term values, this was not an excessively wet year, but it did experience 114% of normal rainfall. The inland station of Alexandra (No. 18) had 182% of normal rainfall, and it exceeded 130% at Gisborne (No. 6), Napier (No. 8), and Kaikoura (No. 16). Five stations, mainly in the middle North Island, were drier than normal.

3. Mean water vapor transfer over the Southwest Pacific

a. Zonal transfer

Patterns of mean water vapor transfer over the Southwest Pacific for the period 1960–73 generally reflect the region's major wind systems. Fig. 2, obtained by drawing isolines of mean $Q\lambda_L$, shows that zonal transfers over the midlatitudes are predominantly westerly in direction. The zonal transfers over the subtropics, on the other hand, are characterized by low-level easterly transfer, and by a weak but extensive high-level westerly flow. The subtropical transfer patterns closely resemble the configuration of the east–west Walker Circulation as described by
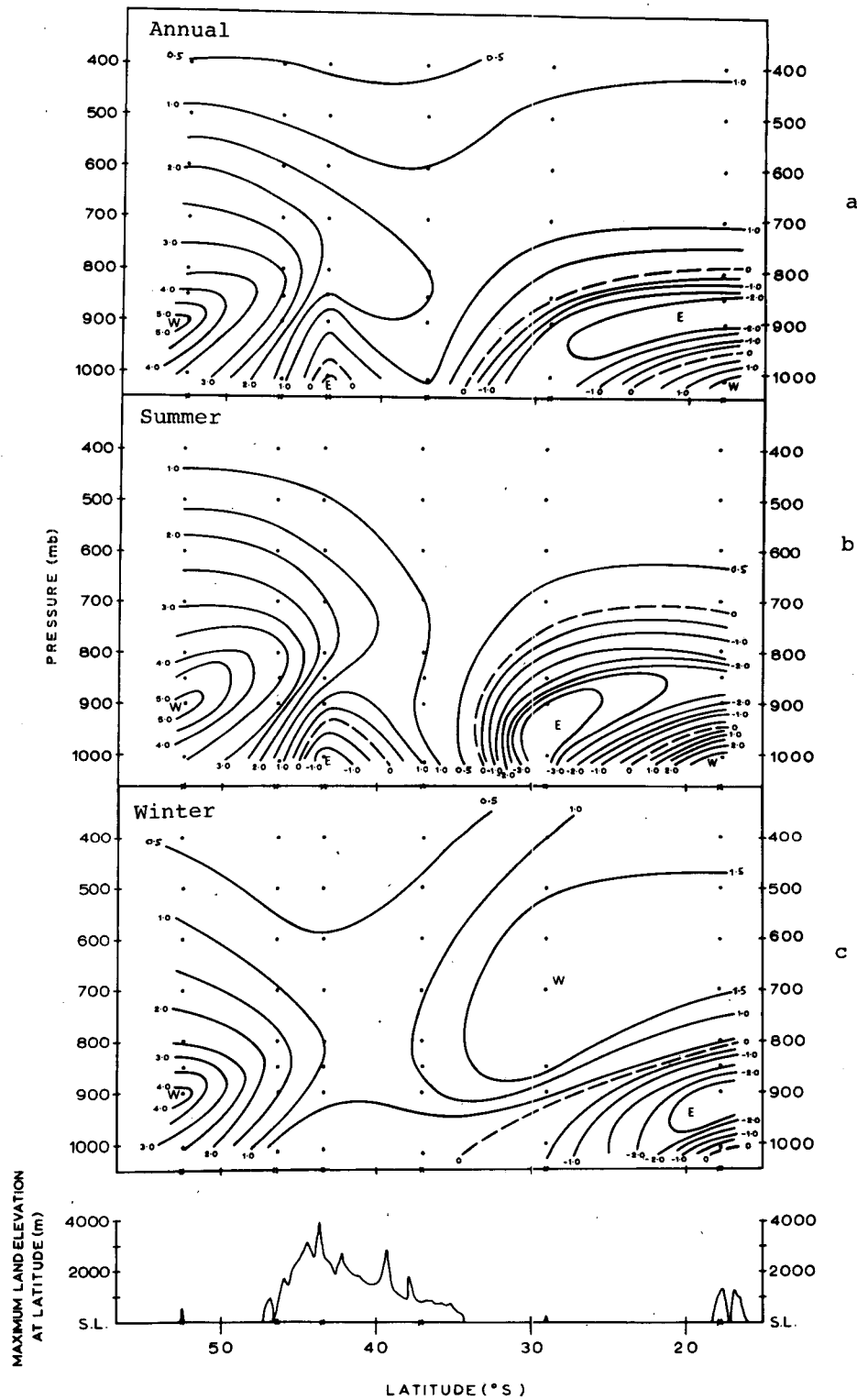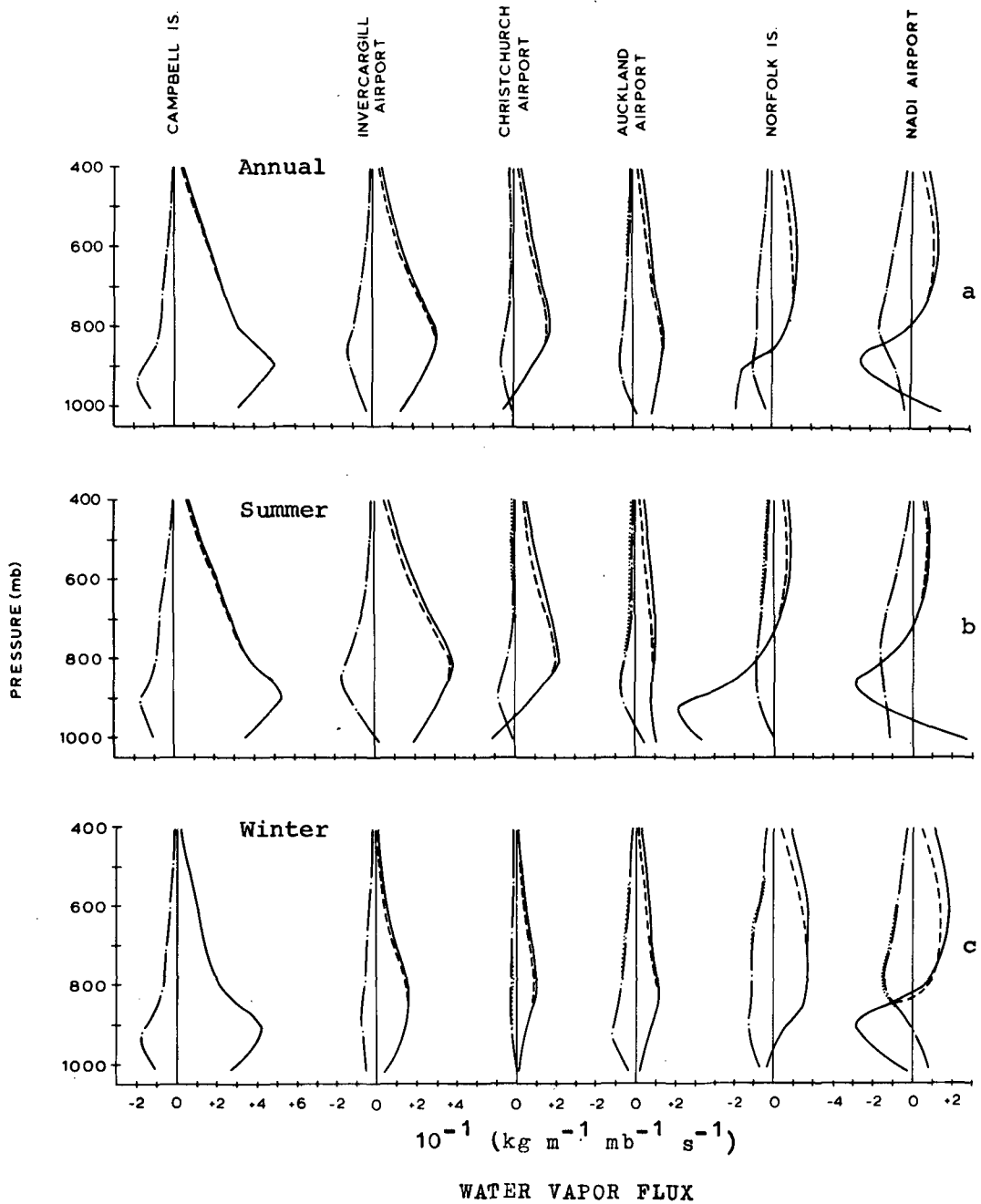
FIG. 2. Mean zonal transport of water vapor across 175°E from 1960 to 1973: (a) annual, (b) summer and (c) winter. Units are 10^{-1} kg m^{-1} mb^{-1} s^{-1}.

FIG. 3. Vertical distribution of mean zonal and meridional water vapor transfer at the six stations from 1960–1973: (a) annual, (b) summer and (c) winter. A negative value for zonal or meridional component in this and subsequent figures indicates that it is from the east or north, respectively. Units are 10^{-1} kg m^{-1} mb^{-1} s^{-1}.
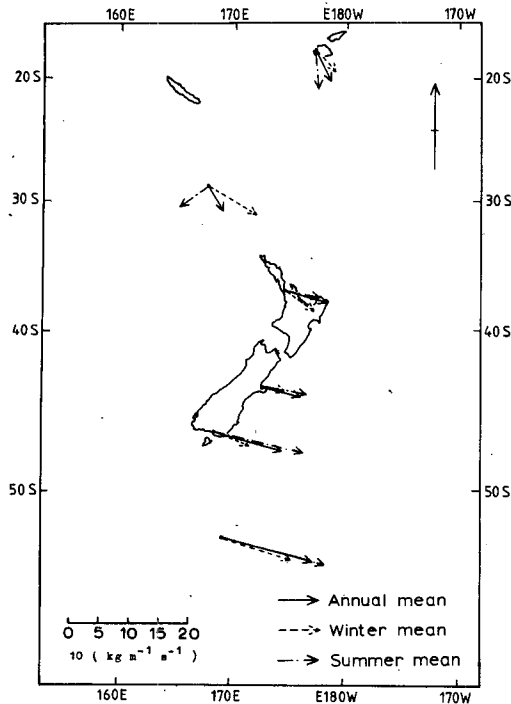
FIG. 4. Annual and seasonal means of vertically integrated vector transport of water vapor from 1960 to 1973. Units are 10 kg m^{-1} s^{-1}.

Bjerknes (1969). When a station is sheltered by mountain ranges from moist prevailing winds, the patterns of the low-level transfer are modified, as at Nadi and Christchurch.

The zonal vapor transfers vary markedly with the seasons. In the winter months (June, July and August), the westerly component of the transfer plays a more dominant role than the easterly component. By contrast, during the summer months (December, January and February), the easterly component of the flow enlarges at the expense of the westerly component. Mean annual zonal transfer is determined by the summer pattern, except that the center of the subtropical easterly component is situated about 10° farther north, and is weaker.

b. Meridional transfer

The contribution of the meridional transfer (values of $Q\phi_L$) to the total water vapor transfer of the Southwest Pacific is smaller than that of the zonal transfer (Fig. 3). At all latitudes, the meridional transfer is predominantly northerly in component and generally more developed in summer.

c. Vector transfer of water vapor

Analysis of vertically integrated vector transfer shows that the flux Q over the midlatitude region is mainly from the west (Fig. 4), with little variation in direction from season to season at Campbell Island, Invercargill and Christchurch. At these stations, the standard deviation of the direction of annual transport is less than 7°, compared with 16° at Auckland, 33° at Norfolk Island, and 18° at Nadi. Thus over the subtropics, seasonal variations of direction are more marked. In summer, the mean vector flux is predom-

TABLE 3. Vertically integrated precipitable water (10 kg m^{-2}) for wet and dry periods compared with average conditions for 1960–73. I = inclusive value, E = exclusive value.

Station	Year			Summer			Winter		
	Wet	Dry	Average 1960–73	Wet	Dry	Average 1960–73	Wet	Dry	Average 1960–73
Nadi									
I	4.01	4.00	4.08	4.37	4.68	4.64	3.60	3.58	3.50
E	3.84	3.81	3.93	4.27	4.53	4.54	3.39	3.38	3.28
Norfolk Island									
I	2.45	2.61	2.55	3.32	3.06	3.01	1.84	1.96	2.07
E	2.37	2.54	2.48	3.24	2.98	2.92	1.79	1.87	2.01
Auckland									
I	1.98	2.05	2.00	2.93	2.25	2.38	1.61	1.53	1.55
E	1.84	1.89	1.85	2.76	2.06	2.19	1.46	1.40	1.41
Christchurch									
I	1.57	1.58	1.59	2.12	1.93	1.99	1.17	1.03	1.18
E	1.47	1.46	1.49	2.02	1.81	1.87	1.06	0.91	1.06
Invercargill									
I	1.60	1.53	1.57	1.91	1.82	1.88	1.16	1.18	1.19
E	1.53	1.44	1.49	1.81	1.75	1.79	1.09	1.09	1.10
Campbell Island									
I	1.33	1.29	1.33	1.42	1.35	1.51	1.16	1.11	1.16
E	1.33	1.29	1.32	1.42	1.35	1.50	1.16	1.11	1.16

inantly from the north or northeast, while in winter, a northwest flow prevails. Significant changes in the flow patterns occur between latitudes 30°S and 37°S,

as the trade winds give way to the westerlies. This has also been noted by Reid (1982) in his analysis of surface wind frequencies along a similar transect. He
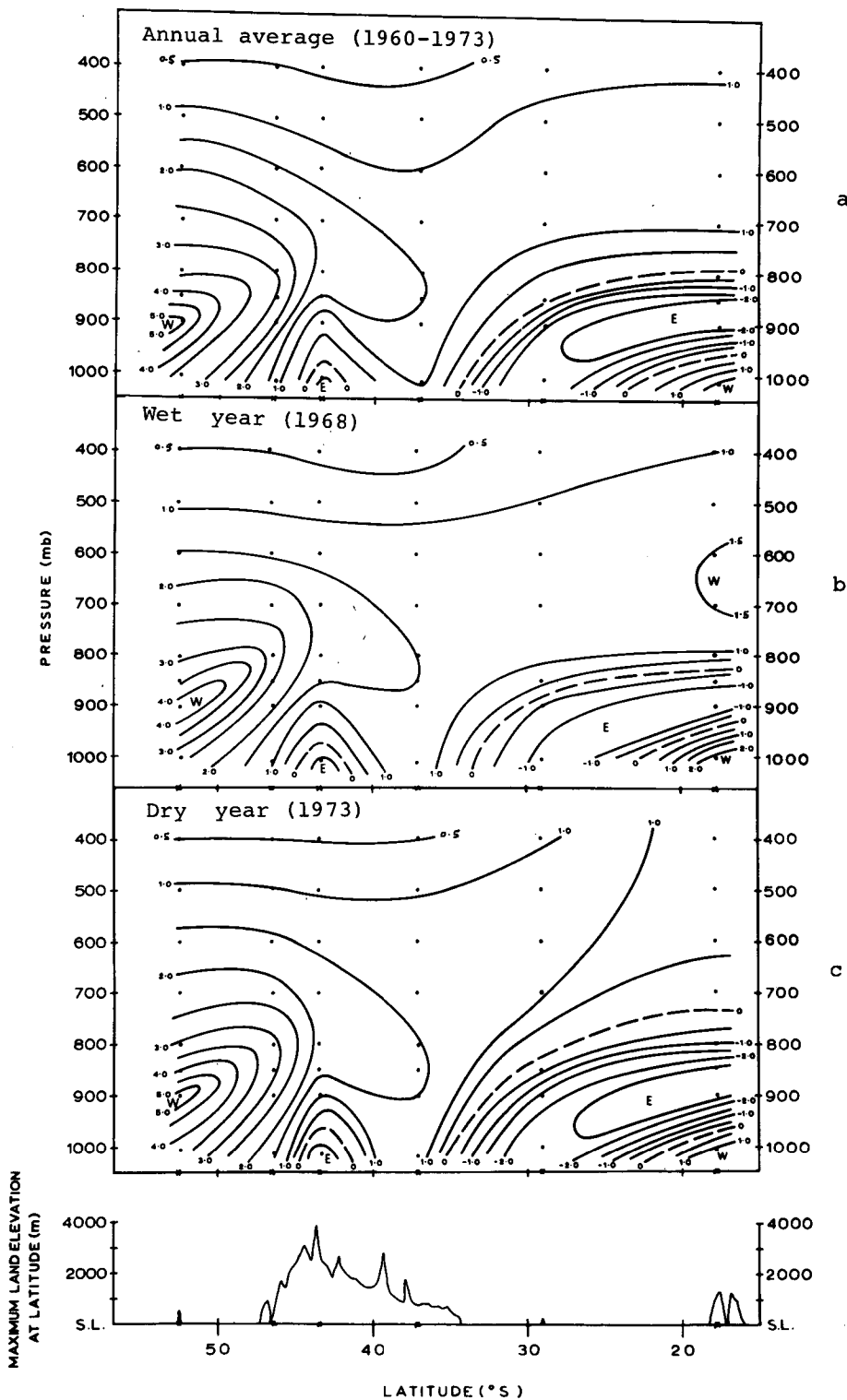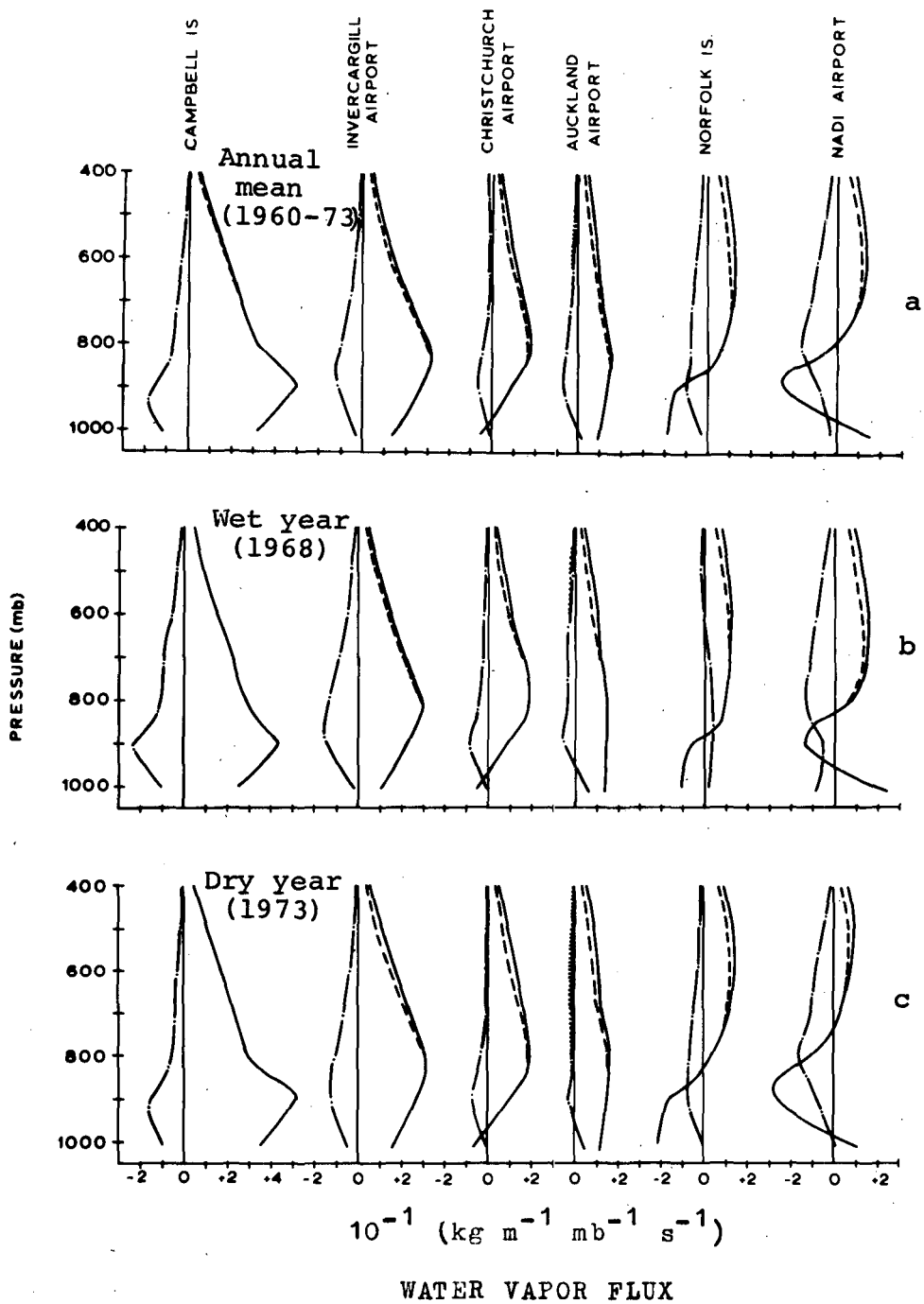

FIG. 5. Mean zonal transport of water vapor across 175°E for: (a) annual average (1960–1973), (b) wet year (1968) and (c) dry year (1973). Units are 10^{-1} kg m^{-1} mb^{-1} s^{-1}.

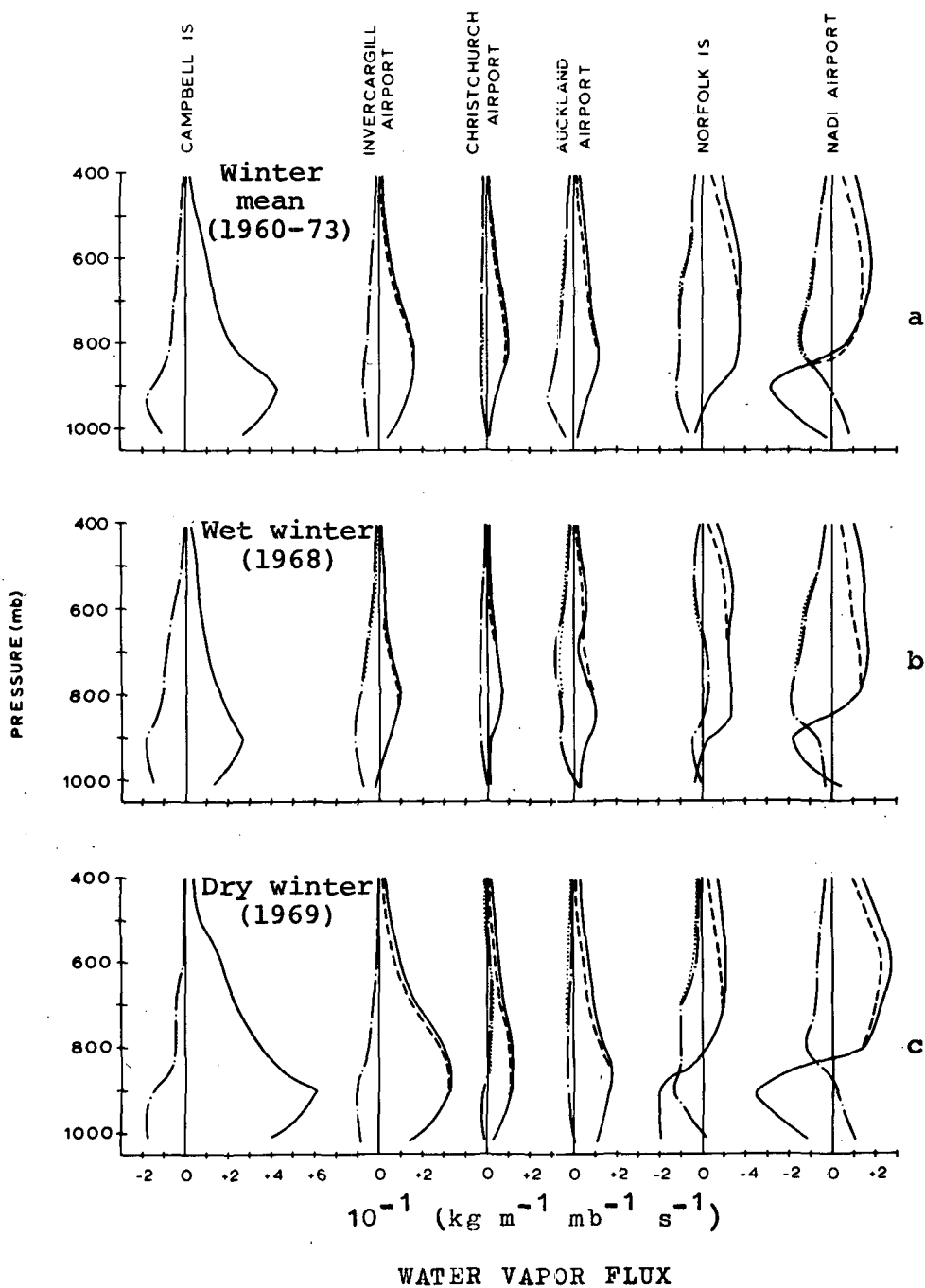FIG. 6. Mean zonal transport of water vapor across 175°E for: (a) summer average (1960–73), (b) wet summer (1965–66) and (c) dry summer (1972–73). Units are 10^{-1} kg m^{-1} mb^{-1} s^{-1}.

FIG. 7. Mean zonal transport of water vapor across 175°E for: (a) winter average (1960–73), (b) wet winter (1968), and (c) dry winter (1969). Units are 10^{-1} kg m^{-1} mb^{-1} s^{-1}.

FIG. 8. Vertical distribution of mean zonal and meridional water vapor transfer at the six stations for: (a) annual average (1960–73), (b) wet year (1968) and (c) dry year (1973). Units are 10^{-1} kg m^{-1} mb^{-1} s^{-1}.

found the broad scale change from tropical easterlies to midlatitudes occurred near the latitude of Auckland. The magnitude of the mean water vapor vector transfer Q along the transect varies both with latitude and season (Fig. 4). The transfers at the latitudes of Campbell Island and Invercargill are considerably
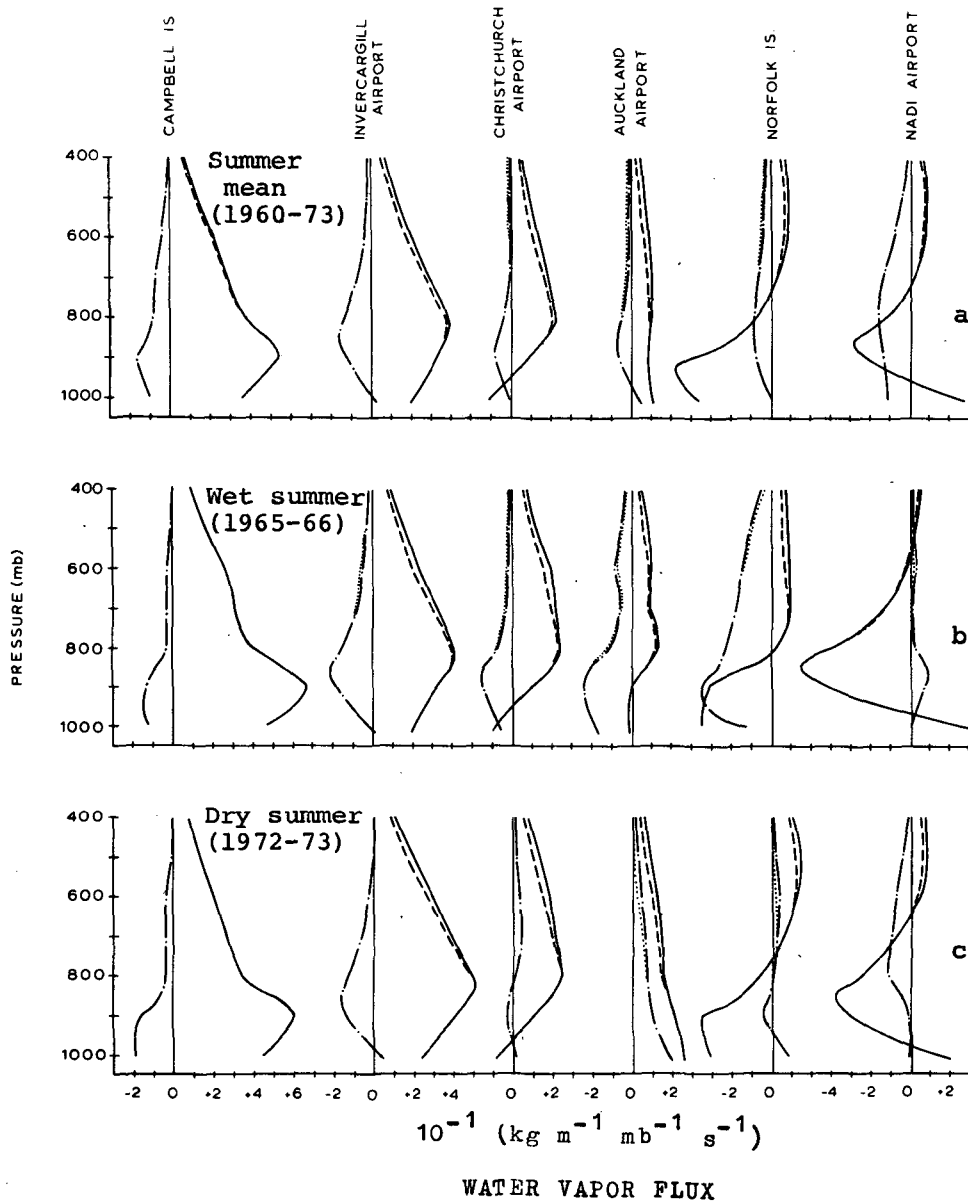
WATER VAPOR FLUX

Zonal water vapor flux

——————— inclusive values

— — — — — exclusive values

Meridional water vapor flux

— · —— inclusive values

· · · · · · exclusive values

FIG. 9. Vertical distribution of mean zonal and meridional water vapor transfer at the six stations for: (a) summer average (1960–73), (b) wet summer (1965–66) and (c) dry summer (1972–73). Units are 10^{-1} kg m^{-1} mb^{-1} s^{-1}.

FIG. 10. Vertical distribution of mean zonal and meridional
water vapor transfer at the six stations for: (a) winter average
(1960–73), (b) wet winter (1968) and (c) dry winter (1969). Units
are 10^{-1} kg m^{-1} mb^{-1} s^{-1}.

larger than those at more northerly latitudes, consistent with the overall increase of wind speed with latitude. The standard deviation of the magnitude of the annual transport ranges from 14% of the mean for 1960–73 at these two southern stations, to as large as 31% at Norfolk Island.

Except at Norfolk Island, the water vapor flux is greater in summer than in winter, the most notable seasonal differences being at Invercargill, where the summer flux is 128% of the mean and the winter flux just 51% of the mean. Such seasonal changes reflect some combination of changes in both wind speed and humidity, the latter being seen in the seasonal variation of precipitable water (Table 3). Precipitable water is larger in summer than in winter, varying from 10% about the average for the year at Campbell Island up to 25% at Christchurch. The majority of the summer increase in vapor flux and about half the winter decrease can be explained by changes in moisture at Campbell Island, Invercargill, Christchurch and Nadi. At Norfolk Island and Auckland seasonal wind speed variations are more important in controlling the magnitude of the flux. The three southern stations of the transect have higher average 900–400 mb wind speed and precipitable water in summer than in winter. On the other hand, the three northern stations have a winter maximum of wind speed, and a summer maximum of precipitable water, so the relationship between vapor flux and these parameters changes with latitude.
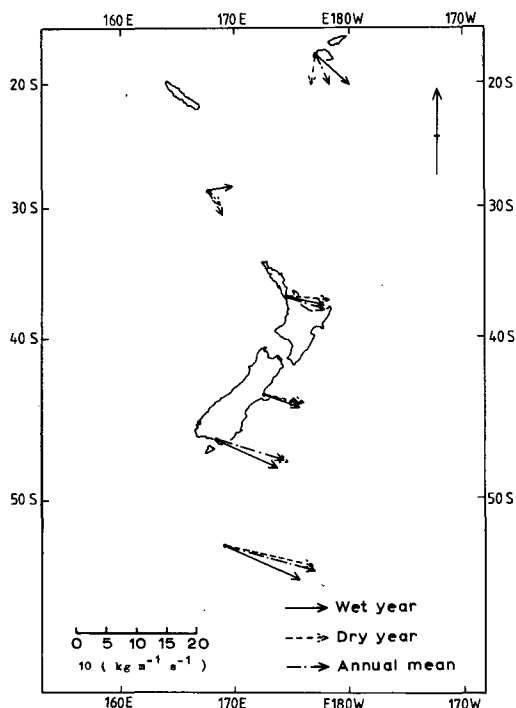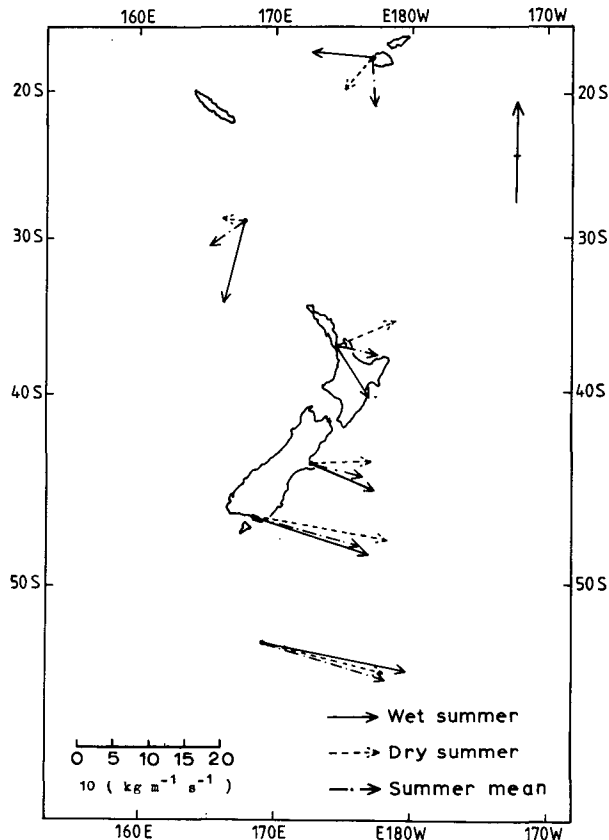

FIG. 12. Mean vertically integrated vector transport of water vapor for: summer average (1960–73); wet summer (1965–66), and dry summer (1972–73). Units are 10 kg m^{-1} s^{-1}.

4. Water vapor transfer characteristics during wet and dry rainfall periods over New Zealand

The low-level easterly component of zonal water vapor transfer extends farther south during wet periods than it does during dry periods, or during the mean period 1960–73. This phenomenon is particularly marked in summer (Figs. 5–7). Conversely, during dry periods, the westerly transfer is more dominant.

During wet periods of 1960–73, the meridional water vapor transfer tends to have a stronger northerly component than is the case for dry periods. This phenomenon is most pronounced over the New Zealand region (Figs. 8–10), which appears to be especially sensitive to the effects of shifts in the influence of the westerlies and trade winds.

The differing magnitudes of the northerly and westerly components are also evident in the directions of mean vertically integrated vector vapor transfers (Figs. 11–13). However, no consistent pattern of variation is apparent in their magnitude, or in precipitable water for wet and dry periods (Table 3). On the basis of those observations, both droughts and wetter periods in New Zealand tend to be related more to the direction of water vapor transfer, and
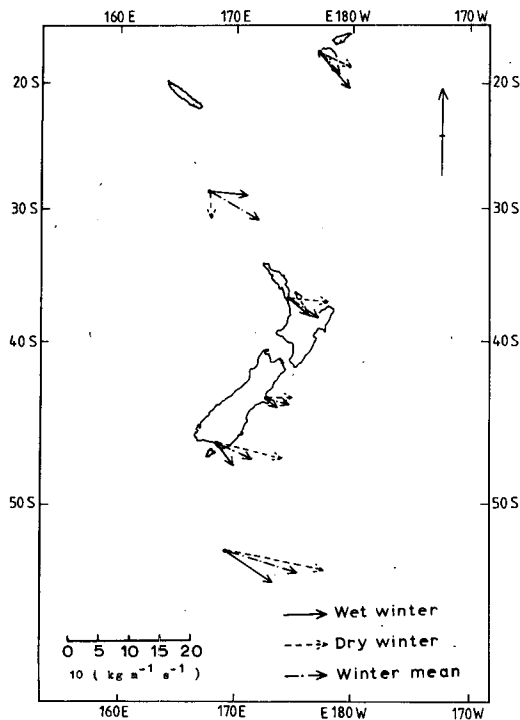

FIG. 11. Mean vertically integrated vector transport of water vapor: annual average (1960–73); wet year (1968) and dry year (1973). Units are 10 kg m^{-1} s^{-1}.

FIG. 13. Mean vertically integrated vector transport of water vapor for: winter average (1960–73); wet winter (1968) and dry winter (1969). Units are 10 kg m^{-1} s^{-1}.

hence wind field changes, especially in summer, rather than to the magnitude of these transfers.

These points are illustrated further in Fig. 14, where the low level water vapor transfer vectors are plotted for individual summers at Auckland. Auckland data was chosen because the area is little influenced by orography and it is located in the latitude band especially sensitive to shifts in the large scale circulation patterns. The wet summer (1965–66) and dry summer (1972–73) plot in contrasting sectors of the diagram, and the data points are the farthest apart. The flux vectors of the wettest and driest summers differ from the less extreme ones in a consistent and clearly identifiable way.

5. Discussion and conclusions

The overall patterns of water vapor transfer established by the present analysis verify those established earlier by Starr et al. (1969), Peixoto (1972) and Peixoto et al. (1976). However, the magnitude and location of the various transfer centers, here defined by more observations and over a longer period, differ considerably. Daily wind and humidity data used in earlier studies were restricted to four or five pressure levels (1000, 850, 700, 500, and in some cases 300 mb) rather than the eight or more considered here. In particular, the patterns of zonal transfer differ markedly from those of zonally averaged transfer

during the IGY as obtained by Peixoto et al. (1976) for a meridional cross section of the Southern and Northern Hemispheres. They indicated that the zonally averaged subtropical easterly transfer was more developed in winter than in summer. This is also suggested for the New Zealand longitudes in their Figs. 1 and 2, a fact not confirmed by the present analysis, which demonstrates that over 1960–73 the subtropical easterly transfer is strongest in summer. In addition, the center of the midlatitude westerly transfer is 10° farther poleward than that indicated by Peixoto et al. Consequently the line of zero zonal flux, which separates the subtropical easterly transfer from the midlatitude westerly transfer, is also located at higher latitude than that given by Peixoto et al. These results therefore support Taljaard (1972) and Trenberth (1981) who note that there are anomalies in the circulation of the Australian-Western Pacific region.

Rosen et al. (1979) discovered a wide range of interannual variability in atmospheric water vapor transport in the Northern Hemisphere, which is here shown to extend southward into the west Pacific. Over New Zealand, wet periods are produced by a wider latitudinal distribution of low-level easterly wind regimes and vapor transfer, or expansion of the Hadley cell. Dry conditions are accompanied by a weakening of the Hadley cell and strengthening of the Ferrel cell as represented by the westerly wind regime and vapor transfer.

The wet and dry periods during 1960–73, were accompanied by only small changes in the magnitude of the water vapor flux and humidity, but by large
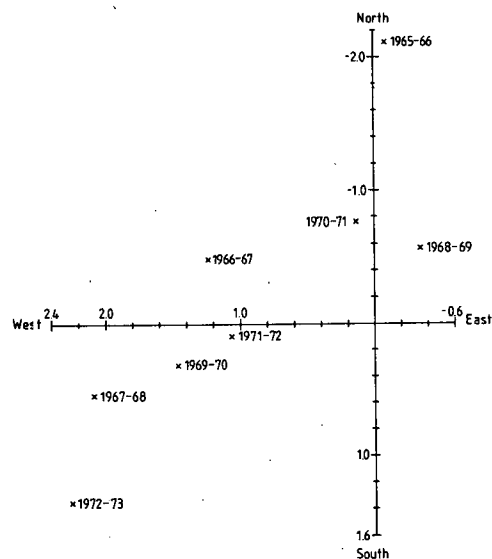

FIG. 14. Vector diagram of the mean of the surface and 900 mb zonal and meridional water vapor transfer over Auckland for each summer from 1965 to 1973. Vector is obtained by drawing the line from the cross to the origin. Units are 10^{-1} kg m^{-1} mb^{-1} s^{-1}.

changes in the flux direction, especially in summer. These changes are produced mainly by changes in the large scale wind regime, with wetter summers associated with enhanced lower tropospheric northeast flow. These findings are consistent with current notions of the circulation changes that accompany wet and dry periods over New Zealand. Steiner (1968) and Salinger (1980) note that widespread, unsettled weather over much of north and east New Zealand is associated with easterly regimes. In contrast, dry conditions over eastern districts are often associated with the predominance of westerly regimes, with frontal disturbances separating migratory anticyclone cells (Hill, 1971; Salinger, 1980).

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