THE SOUTHLAND FLOOD OF JANUARY 1984

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Abstract

The large-scale ascent of a deep layer of very humid air produced extremely heavy rain over Southland and Fiordland during 26 and 27 January 1984 and resulted in serious flooding in many parts of the region. This was the third time in seven years that a major flood had affected Southland, and it can be concluded that this has been the most serious flooding event to affect much of the region during the period for which records are available.

1. INTRODUCTION

This publication consists of two parts; first a discussion of the synoptic situation and the dynamics of its development, and second the rainfall observations and their analysis.

The broad-scale meteorological factors leading to the Southland floods of late January 1984 had all the classical characteristics of a heavy rain-producing situation. The dynamic processes favoured strong upward motions over a sufficiently long period, and included an important orographic contribution. Also, exceptionally moist air was available. Moreover, appreciable antecedent precipitation had occurred in the western high country only two to three days previously. Previous occurrences of heavy flood-producing rains in southern New Zealand have arisen in a similar way as, for example, that of 1978 affecting Southland and Otago, discussed by Hessell and Lopdell (1979) .

Extremely heavy rain fell over a large part of Southland during the 36hr period from midnight on 25/26 January until about midday on the 27th. As a result, river levels rose rapidly and floodwaters inundated much of Invercargill, Otautau, Tuatapere and Otatara. Floodwaters rose to around 3 metres deep over Invercargill Airport and many homes were evacuated. The extent of the flooding in some coastal parts of Southland can be seen in Fig. 1. The overall cost of damage due to the flooding has been estimated to be around $46 million (The Dominion, 28 March 1984).

2. SYNOPTIC AND DYNAMIC ASPECTS

2.1 The Development of the Situation.

In the day or two prior to 25 January 1984 an anticyclone

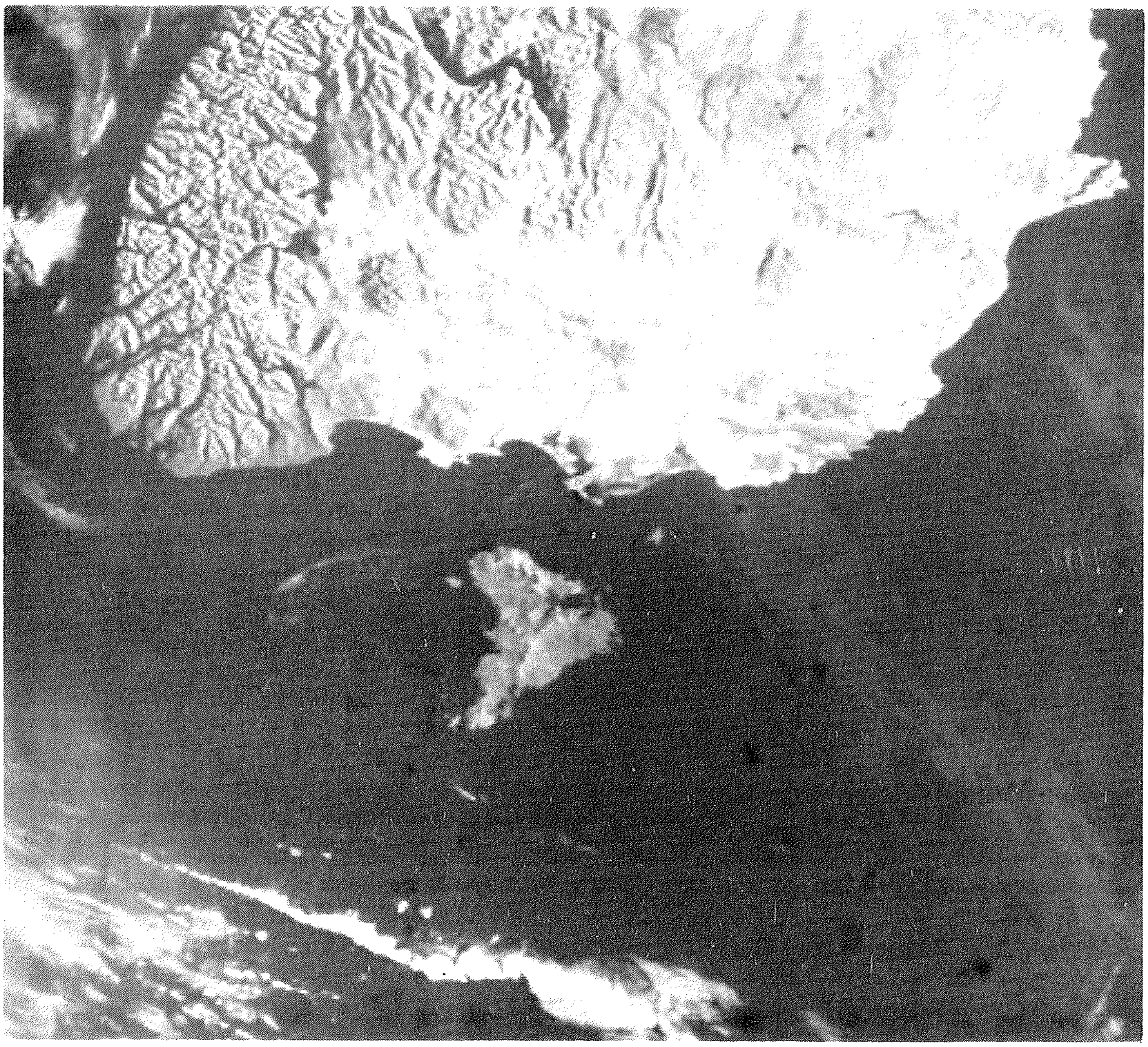


Fig. 1: This picture, taken from a height of 850km, highlights the differences between forest, grasslands and water surface. The dark areas immediatly northwest of Invercargill indicate the extent of the flooding. The swollen Aparima, Oreti, Waihopai and Mataura Rivers can also be readily seen.

had slowly intensified as it moved eastnortheastwards from the Bass Strait area toward northern New Zealand, being centred over the latter by midday 26 January. At the same time, a depression was moving eastsoutheast over the Southern Ocean south of the Great Australian Bight, near latitude 50°S. The sea-level map for midday NZDT 25 January is shown in Fig 2. (All times and dates employed will be NZDT which is GMT + 13 hours.) This depression was typical of many such systems over the Southern Ocean, essentially a cyclonic vorticity advection system with little evidence of much thermal advection, with a lower tropospheric cold front, as described by Hill (1980). On the lower latitude side of this depression and almost separated from its frontal cloud , there lay over the Australian continent another cloud band with westnorthwest-eastsoutheast orientation readily seen in the satellite imagery. Fig. 3 is a nephanalysis derived from this imagery from satellite passes over Australia between 0200 and 0800 hours NZDT 25 January. The cloud pattern is therefore that which existed about 6 hours prior to the time of the sea-level chart, Fig 2. This sea level map, for midday 25 January, showed there was a lower-level discontinuity associated with this cloud band lying from the inland north-western part of South Australia to Victoria, mostly along its northern edge. At the ground level this is seen to be a line of change of temperature and also of wind direction .

Although the middle latitude depression and the cloud band over Australia are related in that they both lay downstream of the one major upper trough, they may best at this stage be regarded as separate features. Figure 4 is the map of the streamline-isotach analysis on the 250 hPa constant pressure surface (near 11 km) close to the level of the maximum wind in the jet-stream. It shows that at midday 25 January there was a strong northwesterly wind maximum over the Tasmanian area on the downstream side of the upper trough. The extensive cloud system over Australia is seen to lie in the lower latitude entrance region to this wind maximum which also, being downstream of the cyclonic curvature of the upper trough, was a region of considerable cyclonic vorticity advection and hence of upward motion. The radiosonde observations over Australia in the air in the ascending regime indicated deep layers with wet bulb-potential temperatures about 18°C and stations along the line from Giles (west of Alice Springs) through Woomera to Melbourne all had very high values of the total precipitable water of 35 to 40 mm. The total precipitable water is the equivalent rainfall which would fall out if all the water vapour carried in the air column were condensed out by sufficient cooling, for example, by adiabatic cooling with large-scale lifting. While this will not likely be completely realised in the real atmosphere the concept of precipitable water is a useful indication of the potential for rainfall. This air appears to have come from the tropical areas northwest and north of Australia. Even in summer, air with such high moisture content will inevitably have had its origin in low

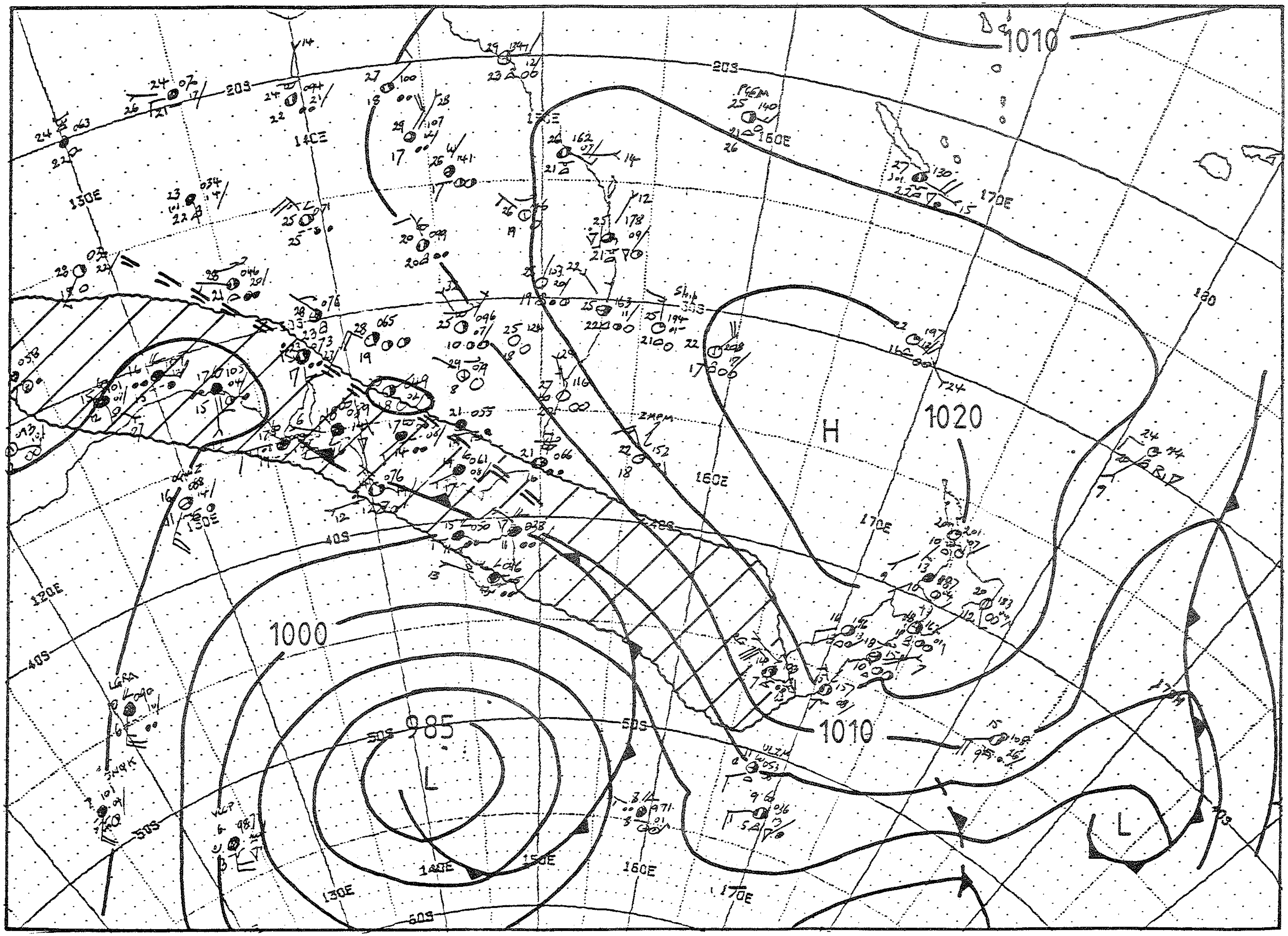


Fig. 2: Sea level analysis, midday (NZDT) 25 January 1984.

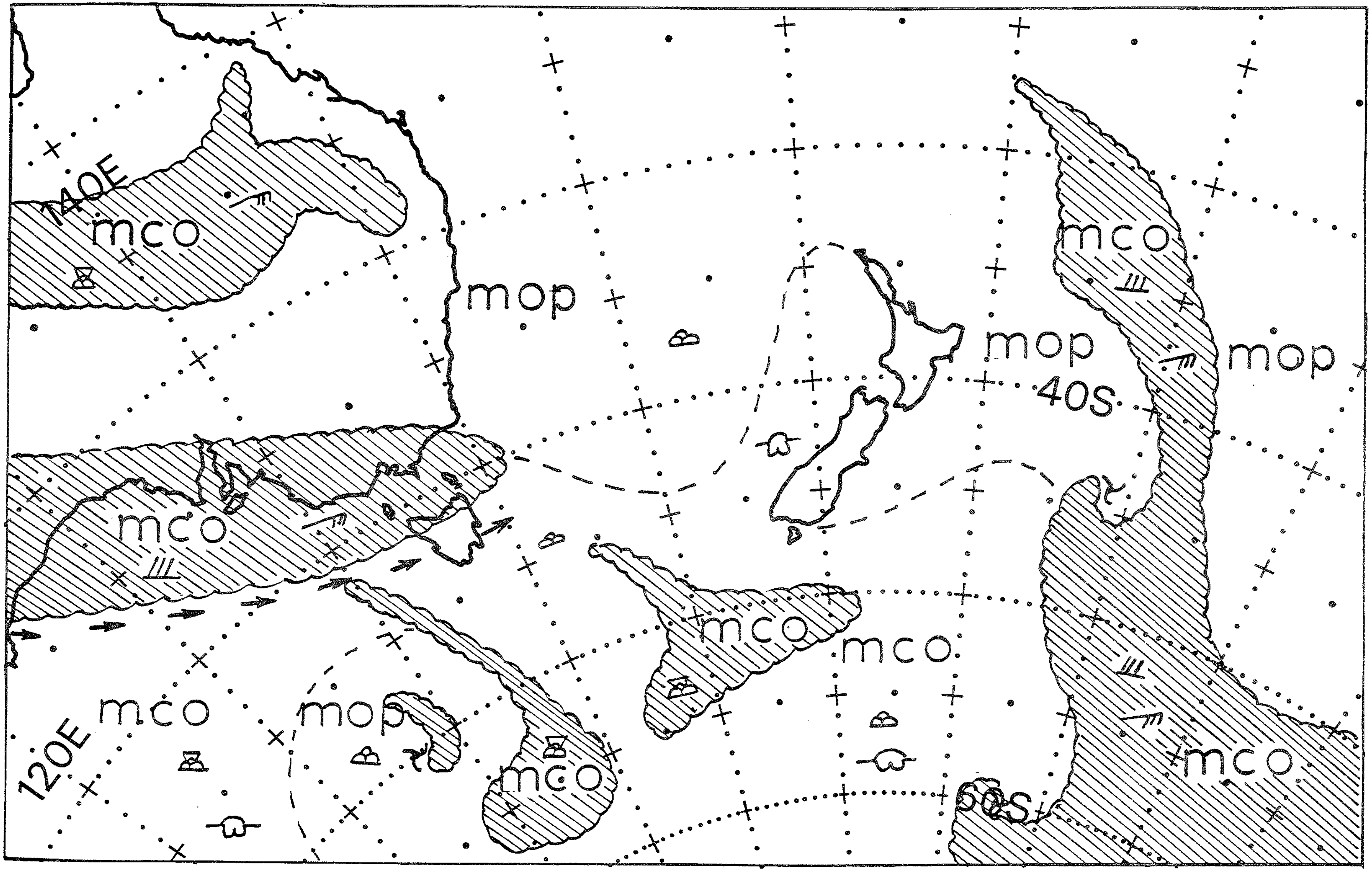


Fig. 3: Nephanalysis, 0200-0800hrs (NZDT) 25 January 1984.

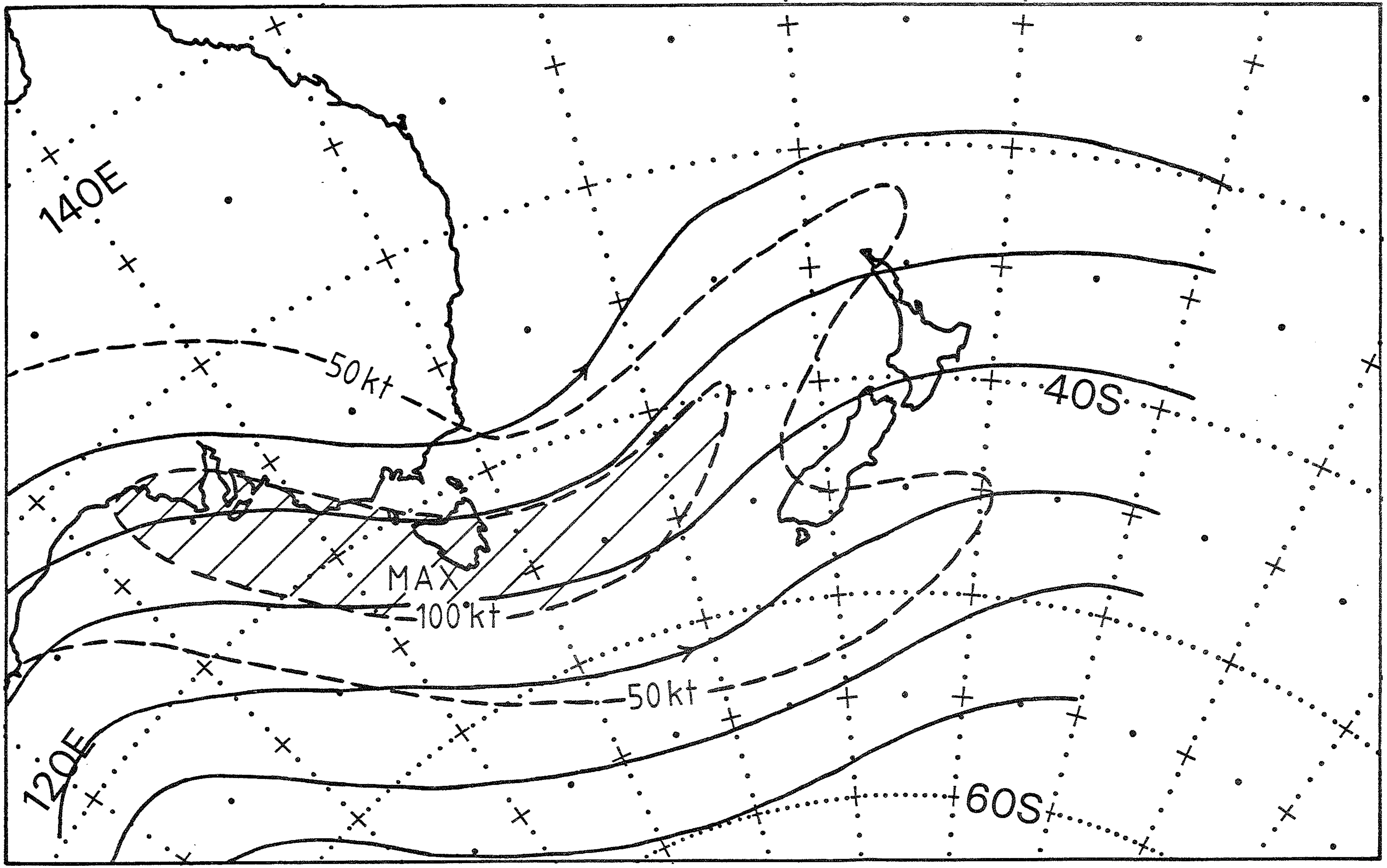


Fig. 4: 250hPa Streamlines and Isotachs, midday (NZDT) 25 January 1984.

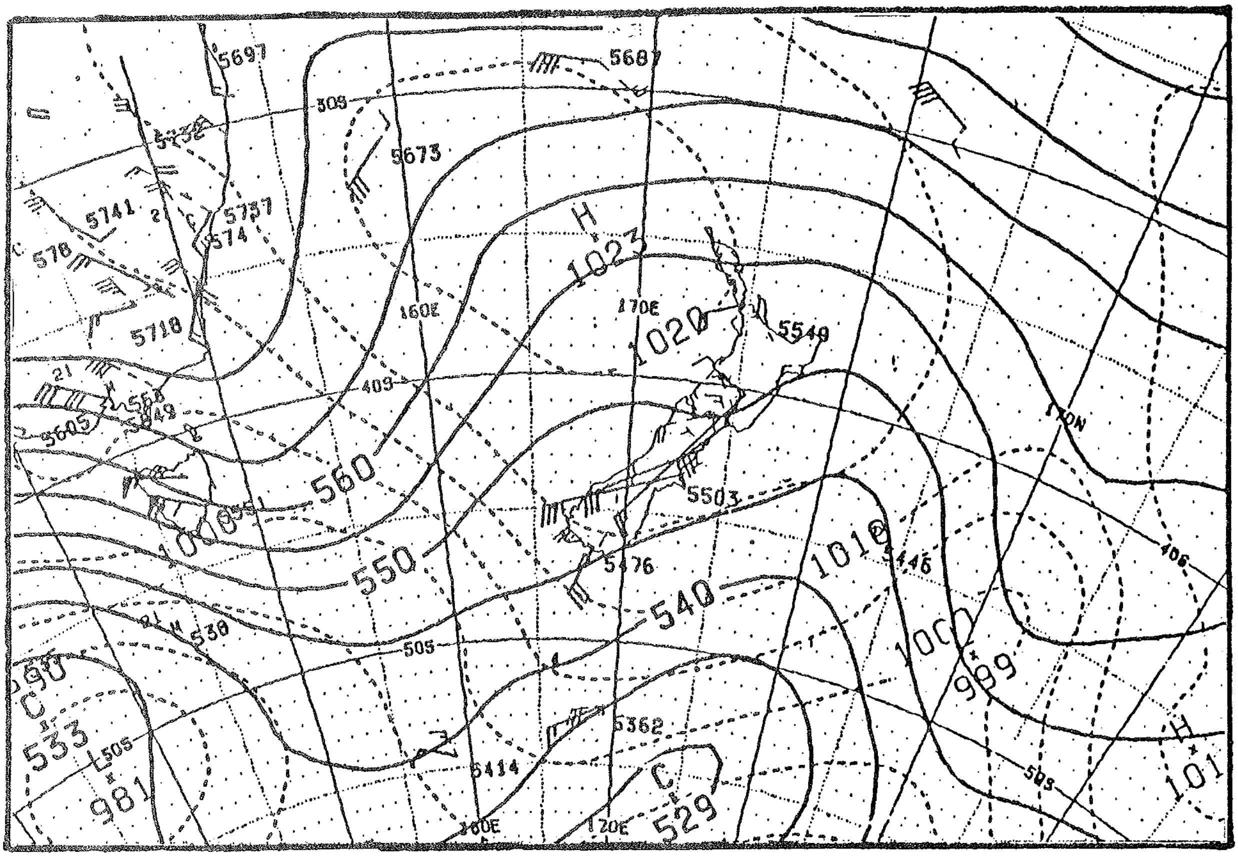
latitude oceanic areas. The air on the northern side of the ground-level convergence associated with the cloud band was very warm with surface temperatures already 25 to 30°C at 0900hr local Australian time. The 1000 to 500 hPa thickness in this air was 570 to 575 geopotential decametres (Gdam). The upper trough axis lay at this time northnorthwest-southsoutheast through the central part of the Great Australian Bight. By midday 26 January the trough in the 1000-500 hPa thickness field (Fig 5a,) and also that on the 250 hPa constant pressure surface (Fig. 6,) had moved eastwards and lay just west of Tasmania and Victoria. The northwesterlies at the level of the jet stream (near the 250 hPa surface) were still very strong with 140 kn reported over Tasmania, the actual maximum wind lying further southeast over the far southern Tasman Sea southwest of the South Island. As early as midnight 25 January very strong upper westerlies had reached southern New Zealand,the winds over Invercargill having increased from 50 kn to 110 kn at 11 or 12 km since the previous midday. This increase over southern New Zealand reflected the eastwards spread of the upper tropospheric wind maximum into the area south of the country.

2.2 The Changes with Time of the Vertical Structure over Invercargill, 25-27 January.

The wind and temperature regime over Invercargill are shown in the vertical section for that station, Fig. 7. After the increase of the upper tropospheric winds between midday and midnight 25 January there was not much further change till midday 26th. Between midday and midnight 26th there were no sucessful radar wind observations owing to strong rainfall echoes. At midday 27 January a sounding reached high levels and showed west-northwest winds of 150 kn around 11 or 12 km (250 to 200 hPa). The high tropospheric winds over southern New Zealand were probably at their maximum of over 150 kn overnight 26 to 27 January when the flow at those levels was going through an anticylonic phase between west-southwest, west and westnorthwest. During this period, therefore, there would have been large ascending motion with its accompanying thick precipitating cloud over those southern areas. The relationship of the vertical motions in the atmosphere to the vorticity advection and also the thermal advection discussed in the next section are explained by Hill (1980, op. cit.).

2.3 The Thermal Advection.

As significant as the extension of the great upper cloud sheet with the eastward spread of the higher level wind maximum was the net mass divergence also resulting from the cyclonic vorticity advection. This soon resulted in falling geopotential in the lower troposphere and is most readily seen in the falling sea-level pressures in the vicinity of southern New Zealand. In the 24 hours ending midday 26 January the pressures close to the southwest of the South Island fell at least 13 hPa, while in the the vicinity of central New Zealand on the southern flank of the



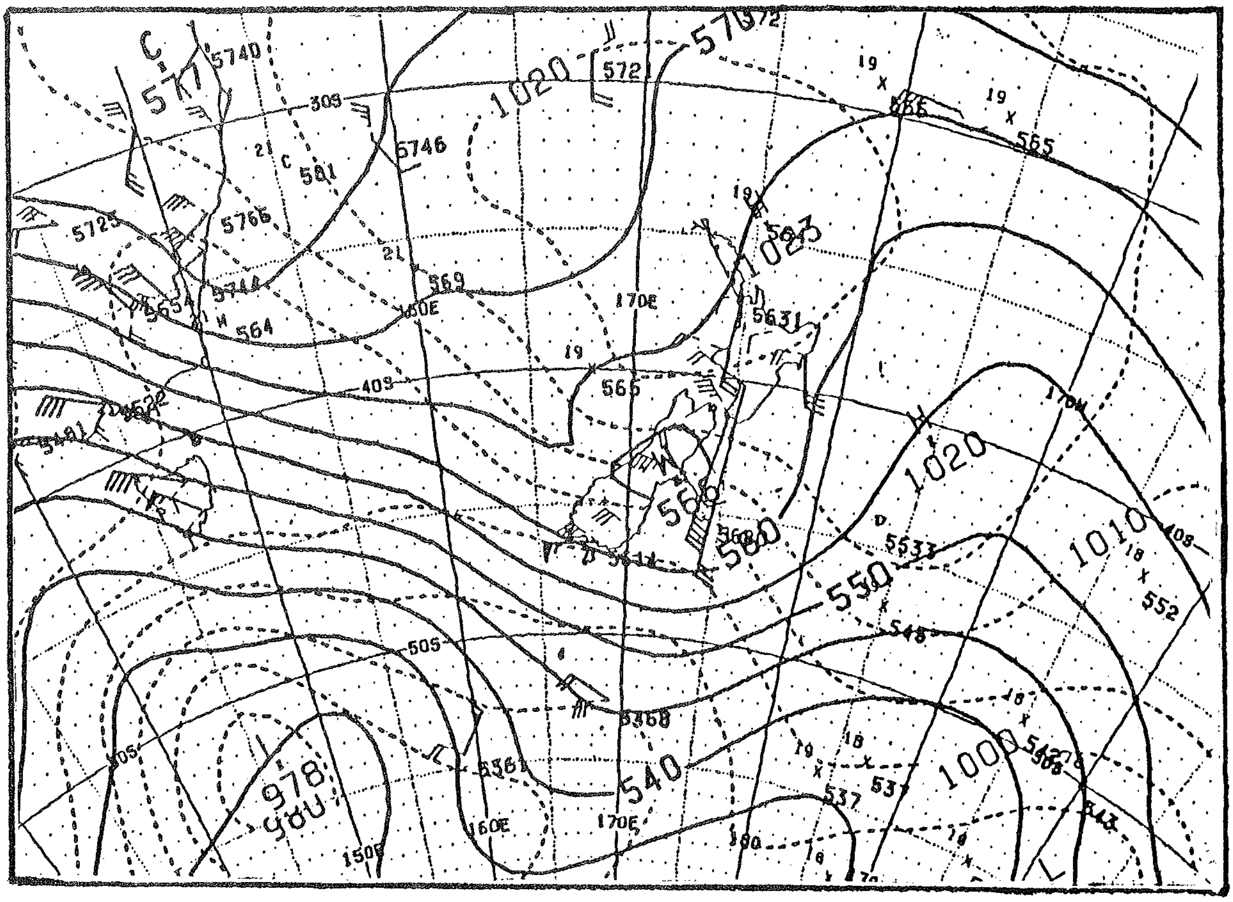


Fig. 5: 1000-500hPa (______) and surface (---) Analyses, for:

a. midday (NZDT) 25 January 1984.
b. midday (NZDT) 26 January 1984.

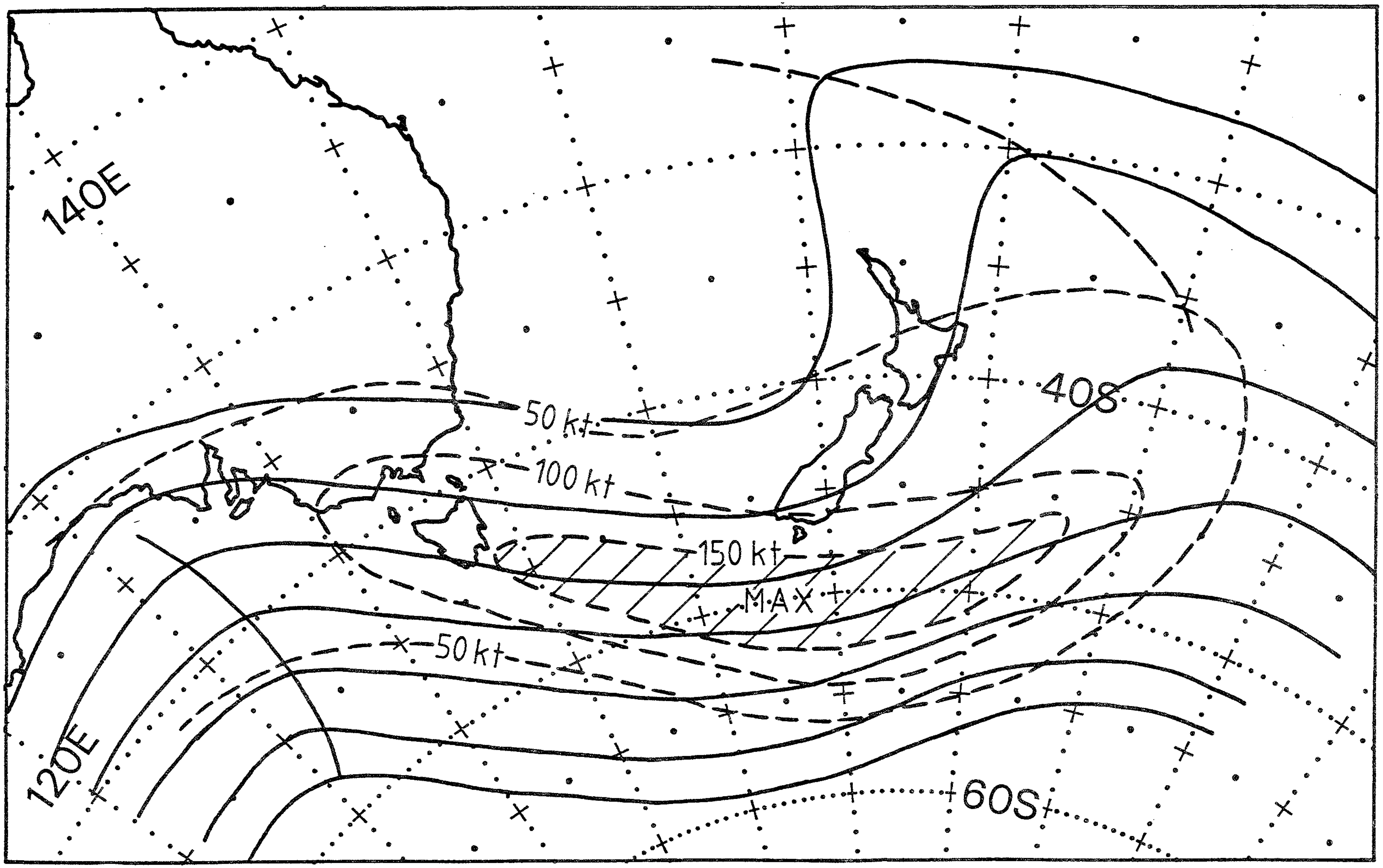


Fig. 6: 250 hPa Streamlines and Isotachs, midday 26 January 1984.

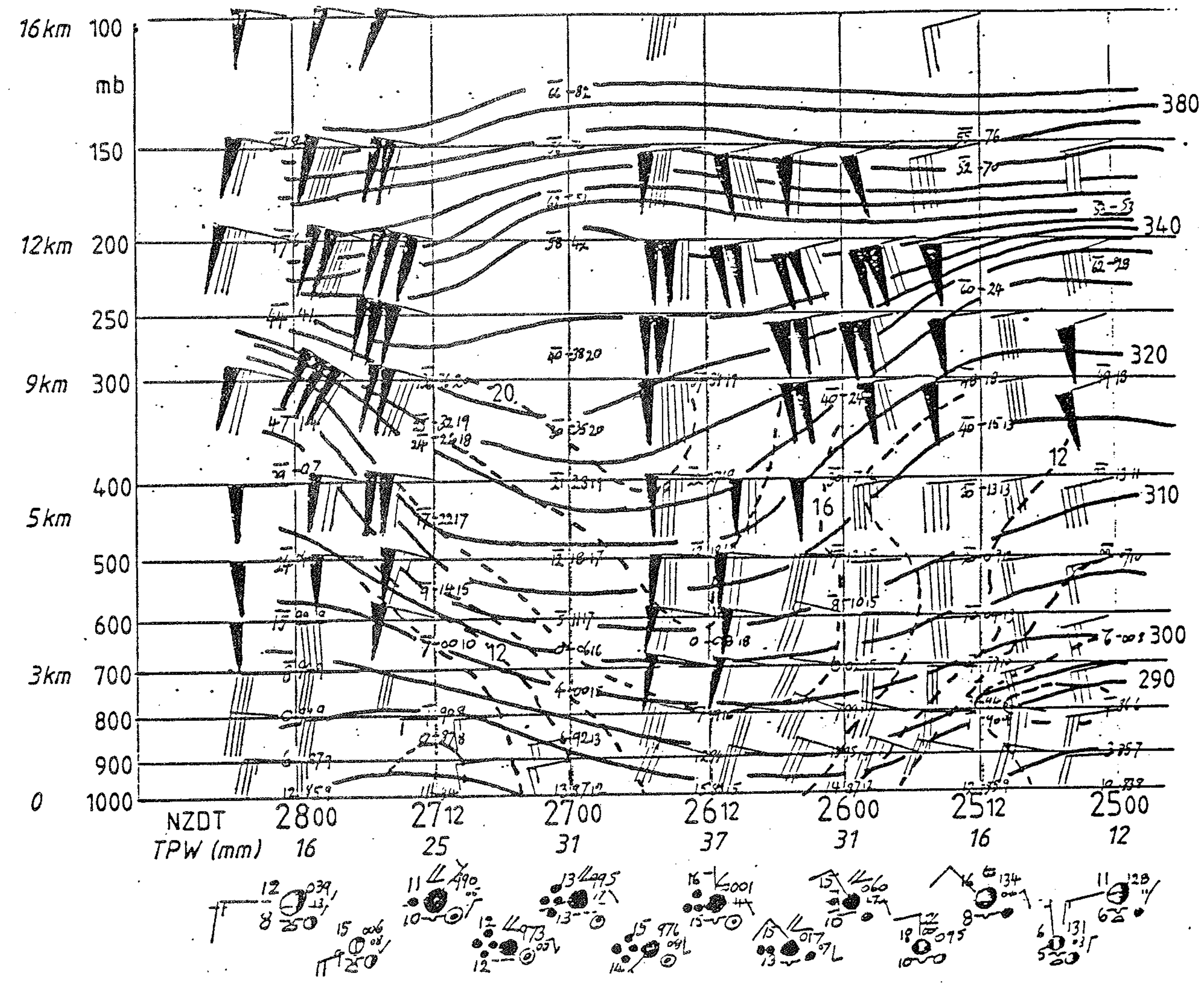


Fig. 7: Vertical Cross-Section for Invercargill, 25-28 January 1984.

Continuous heavy lines (_____) isopleths of potential temperature. Dashed lines (------) isopleths of potential wet bulb temperature. Small figures on ordinate above each observation time (in order left to right): temperature (°C), potential temperature (°K -hundreds digit ommitted), and wet bulb temperature (°C). Winds are shown with usual convention: arrow pointing downwards indicates northerly, arrow pointing towards the right indicates westerly. Triangles = 50 kn, long barb = 10 kn and short barb = 5 kn. Weather sequence at Invercargill Airport at each 6 hours corresponding to time on the ordinate above is shown in international code (see Appendix 2). Total precipitable water (TPW) calculated from each radiosonde flight is given in each relevent ordinate, values in mm.

anticyclone there was little change. In this period the pressure gradient over the southeast Tasman Sea increased markedly and there was a three-fold increase in the gradient along the western coast of the South Island. In association with this the lower tropospheric northwest winds likewise increased. The consequence of this was increasing thermal advection as the increasing northwest flow transported very warm air, in which the thickness values were high, from the western Tasman across the South Island. This can readily be seen from Figs 5a and b, the 1000-500 hPa thickness maps for 25 and 26 January respectively. In this 24-hour period the 560 Gdam isopleth moved from mid-Tasman, where it had lain through 40°S 160°E, to east of New Zealand, and the spot values of this thickness over Christchurch and Invercargill rose by 16 and 14 Gdam respectively. This represents a very large warming considering that, at the same time, there would have been considerable upward motion producing some compensating cooling.

The effects of the warming can be readily seen in the production by midday 26 January (Fig. 5b) of a strong warm ridge over the South Island and the consequent enhanced anticyclonic curvature in the thickness isopleths. This implies increasing cyclonic vorticity advection by the thermal wind, which was also contributing to the total vorticity advection and further enhancing the upward motion. Fig. 7 shows how strong was the warming over southern New Zealand, in steep downward slope from left to right of the potential temperature lines in the troposphere. In terms of the actual temperature changes at given pressure levels it will be seen that at 700 hPa (ca. 3 km) there was a rise of 9°C from -4 to +5°C and at 500 hPa (5.5 km) of 8°C from -20 to -12°C.

Fig. 7 also shows that equally impressive as the very deep tropospheric warming was the simultaneous large increase in the humidity. At midday 25 January the potential wet-bulb temperature over Invercargill was largely 10 to 12°C but by midday 26th this had increased to 17 to 19°C from 700 hPa (3 km) upwards. These are high values for the latitude. Moreover, the total precipitable water in the air-column above Invercargill rose from 12 mm rainfall-equivalent to 37 mm between midday 25th and midday 26th and remained as high as 25 to 30 mm to at least midday 27 January. These very high values are indicated below each sounding. They are of the same order as those which had occurred the previous day over southern Australia in air of low latitude oceanic origin.

2.4 <u>The Sea-level Situation during the Time when the Heavy Rain was occurring</u>.

The sea-level map for midday 26 January is shown in Fig. 8. By then the depression in the higher latitudes had moved into the area west of Macquarie Island and a newly developed centre lay southwest of Campbell Island. The cold front of this depression

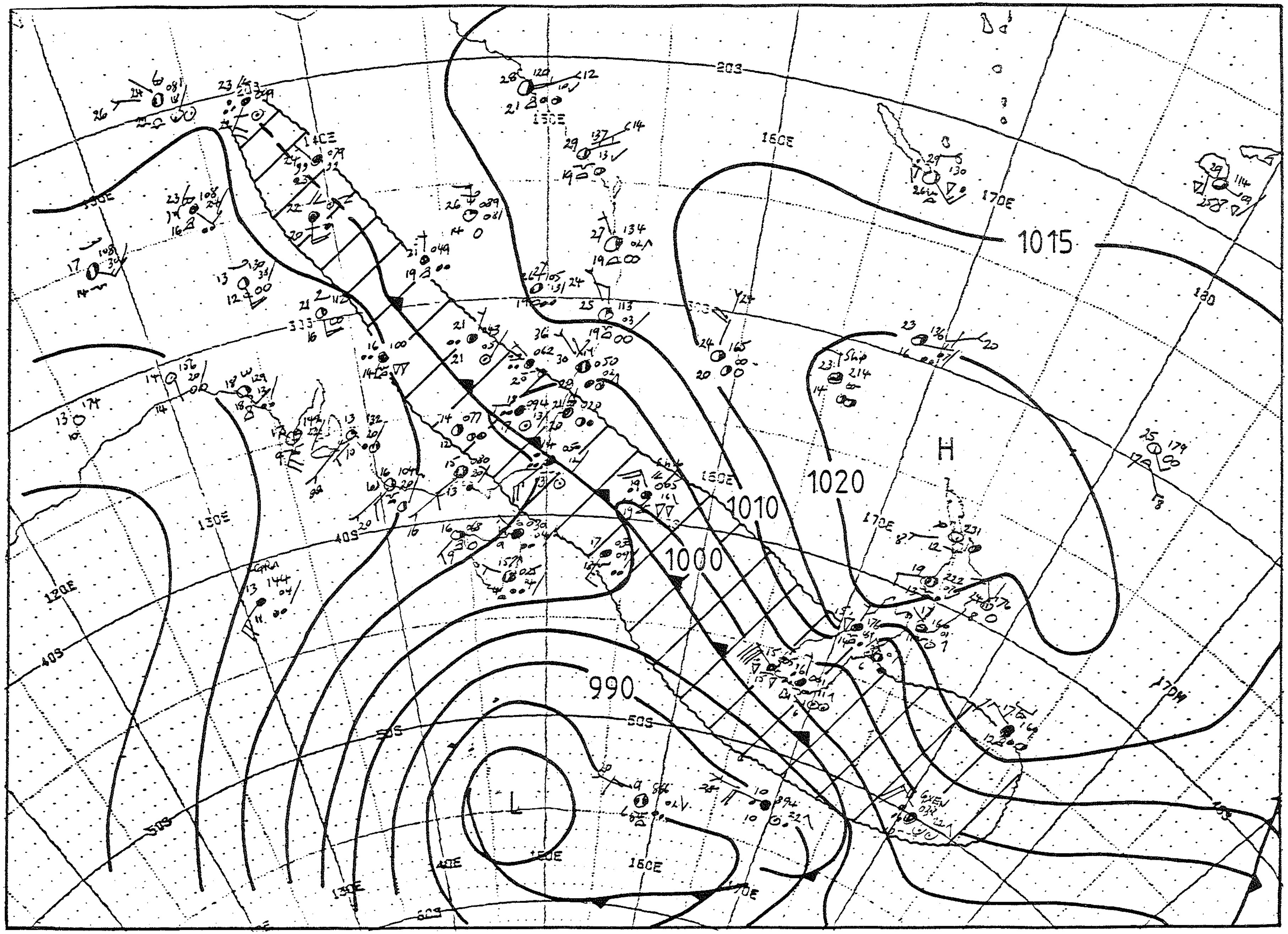


Fig. 8: Sea level analysis, midday (NZDT) 26 January 1984.

had passed to the east of Campbell Island. It can be seen in the satellite imagery (Fig. 9) as a rather narrow cloud band lying southwest- northeast. It passes under the much wider, deeper, nearly west-east oriented cloud band, associated with the large-scale dynamic processes of the jet stream and thermal advection. This is why there is a sharp "dog-leg" appearance in the cloud system. There was, however, under the major cloud system a sea-level discontinuity of wind and temperature arising from low-level convergence between the warmer air on its northern side and the colder less humid air from the Southern Ocean. This boundary lay always south of the South Island through the period of the heavy rain as is evident from Fig. 7. It will also be seen to lie between the ships at 39°S and 42°S in the western Tasman Sea in Fig. 8.

2.5 The Orographic Precipitation.

Independently of the larger synoptic scale dynamics, in an area such as the southwest of the South Island where there is bold orography, there is another aspect that cannot be neglected, and that is in this case the orographic enhancement of the precipitation. There must have been a large spill-over of the rain across the ranges into the headwaters of rivers rising in the far west. This would have caused peaks in the river-flow downstream coinciding with the accumulation of rainfall in the lower reaches. With the anticyclone moving only slowly east-northeast toward northern New Zealand and the falling sea-level pressures over and in the area west of southern New Zealand, an increasing pressure gradient developed over the South Island. This was already discussed in connection with the thermal advection in Section 2.3. In the 24 hours 25 to 26 January the pressure fell about 13 hPa in southern New Zealand and the northwest flow in the lower layers began to increase. This was evident in an increase of the pressure gradient at sea level between Hokitika and Puysegur Point from 6 to 17 hPa and from 4 to 10 hPa from Hokitika to Christchurch in that period. It has already been shown how wet was the air streaming onto southern New Zealand in the west to northwest flow, and the orographic ascent which would certainly have been greater than the mere height of the Fiordland mountains could easily release a large amount of rain independently of the large-scale dynamic processes. It will also be seen from Fig. 7 that the temperatures were high. From 25 January until after midnight 26th, the freezing level over southern New Zealand was continuously above 3 km, so that there was no likelihood of any of the precipitation reaching even the highest mountains as snow and thus being prevented from becoming run-off. The importance of the orographic contribution can be judged from the very large rainfalls measured in Fiordland which are discussed below.

By midday 27 January (Fig. 10), the discontinuity at ground level had reached a line from southern Westland to North Otago and drier air was spreading over southern New Zealand. From then

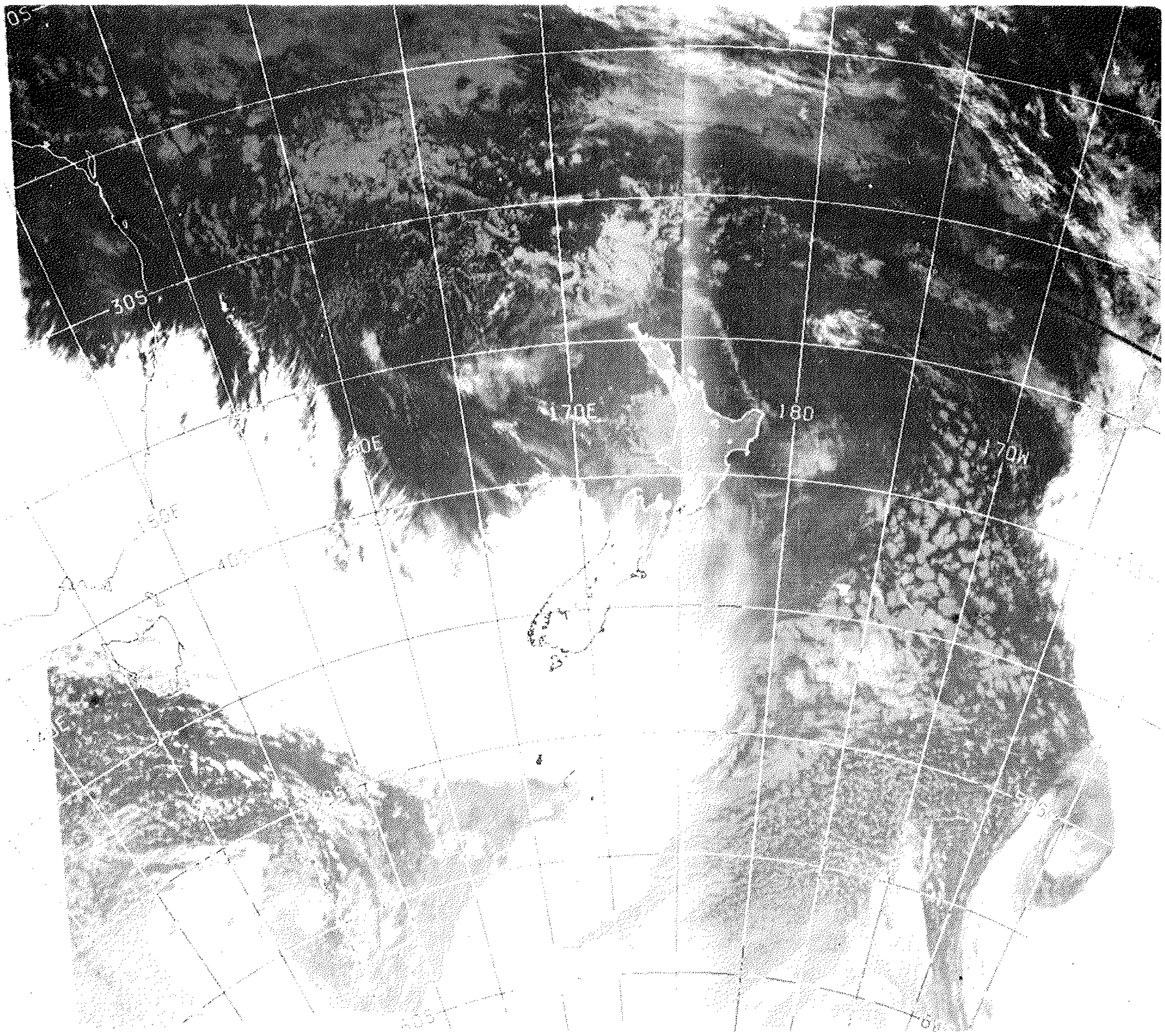


Fig. 9: Satellite image, 0500hrs (NZDT) 26 January 1984.

on the upper tropopspheric winds, which had been so very strong, decreased and the rain eased. By midday 28 January these winds were only half their previously high speed; they were also backing westerly as the axis of the upper trough passed, and skies over Southland cleared.

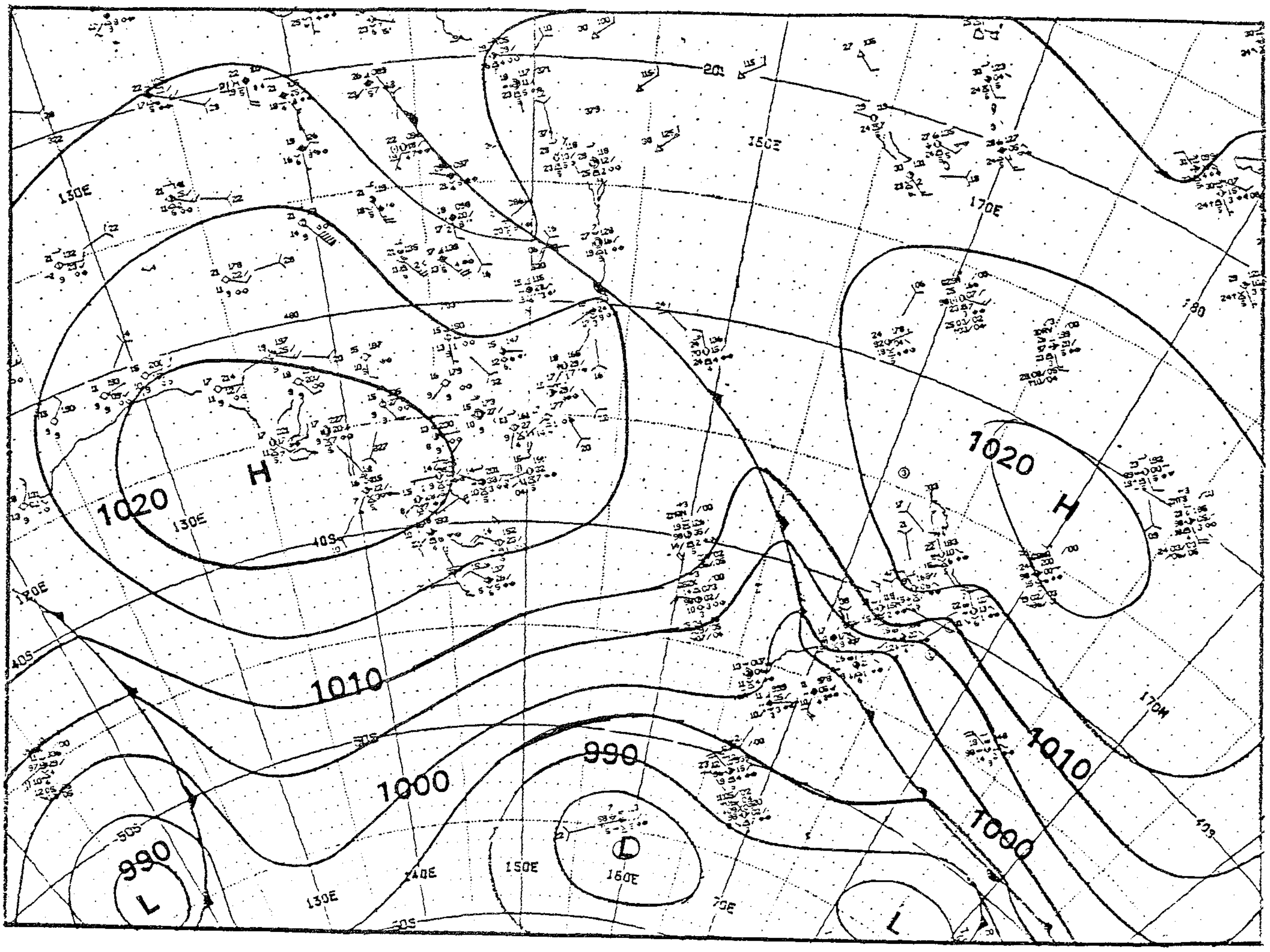


Fig. 10: Sea level analysis, midday (NZDT) 27 January 1984.

3. RAINFALL

3.1 The Observations

The New Zealand Meteorological Service maintains an extensive network of rainfall stations throughout the country. Most of the gauges are read daily by voluntary observers and it is largely through their efforts that a detailed knowledge of New Zealand's rainfall has been acquired. The observers read their gauges at 9am each morning and the 24-hour rainfall thus obtained is credited to the previous day. For example, when the rain-gauges were read at 9am on January 27th the readings were regarded as being the rainfalls of the 26th of January. There is also a (considerably smaller) network of automatic raingauges which record rainfall on either daily or weekly charts. Charts from these instruments can be used to make detailed analyses of rainfall intensity and duration. Rainfall readings from a number of other sources have also been used in this study. They include readings made by the Southland Catchment Board, the Fiordland National Park Board and by various other organisations and individuals. The locations of stations used in this analysis are shown in Fig. 11.

A table of rainfall stations and their readings for the period 25 to 27 January 1984 forms Appendix 1 of this publication.

3.2 Rainfall Distribution and Intensity.

Isohyets of rainfall recorded during the three day period from the 25th to the 27th of January are shown in Fig.12. Although the analysis covers a 72-hour period the rainfalls can, for all intents and purposes, be regarded as 36-hour rainfalls since over the whole of the effected area the rain was confined to the period from about midnight on January 25th/26th to midday on the 27th.

By far the highest rainfalls were recorded in the Fiordland mountains and would have had a significant impact on the level of the Waiau River. However, rainfalls of this magnitude are not unusual in that area and it was the rain over much of Southland which, although much less intense by comparison, was by far the most important. Many parts of the region recorded their highest-ever 24-hour rainfalls on the 26th and the widespread, prolonged and heavy rain produced serious flooding in the Waiau, Aparima and Oreti catchments, and to a lesser extent in the Mataura catchment.

Rainfall accumulation graphs, based on data from recording raingauges at West Arm, Invercargill Airport, Waimumu and Gore, can be seen in Fig. 13. and show the steady nature of the rain during the storm. Note that the heavy rain began earlier at stations in the west than in the east where the duration of the

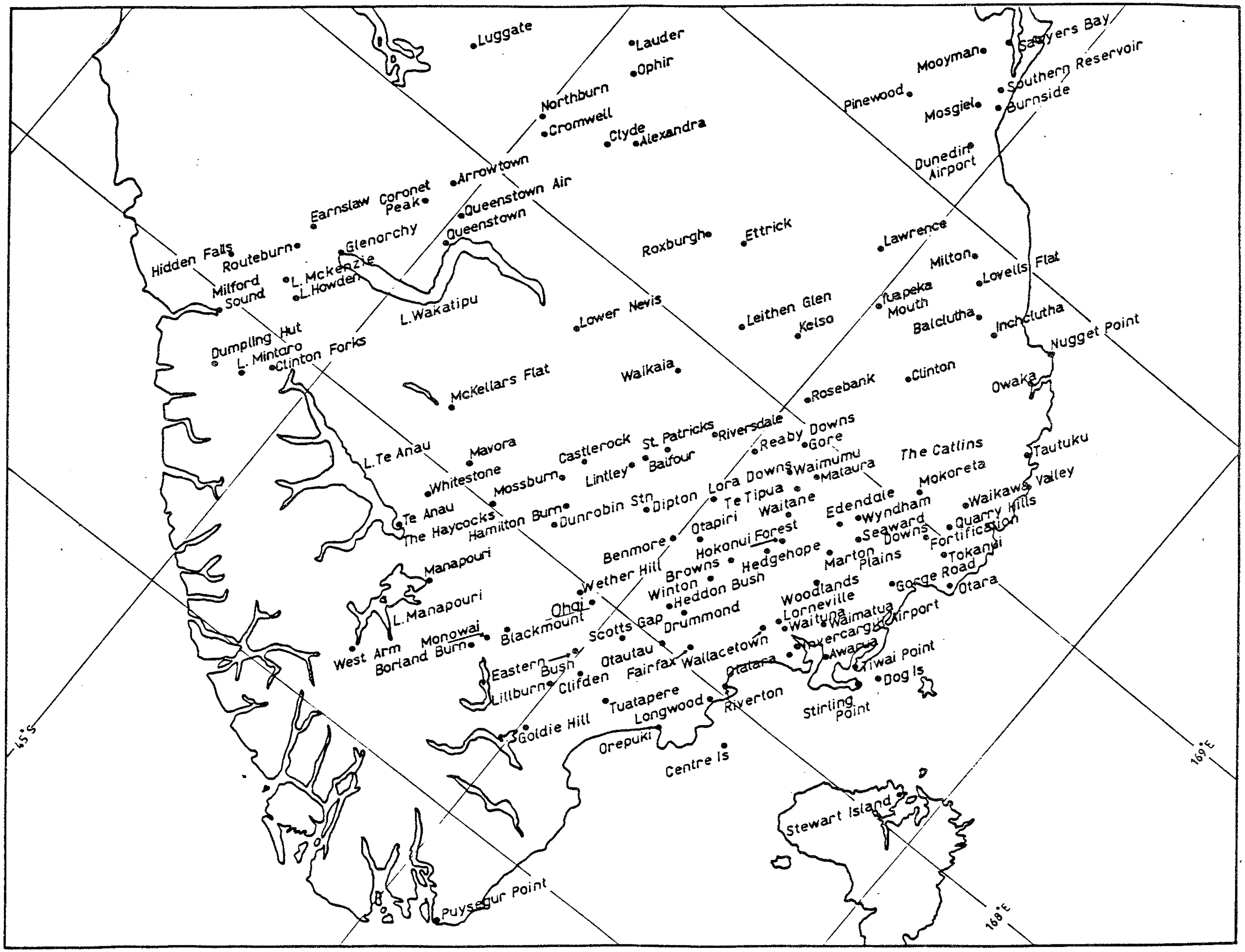


Fig. 11: Locations of stations used in analysis.

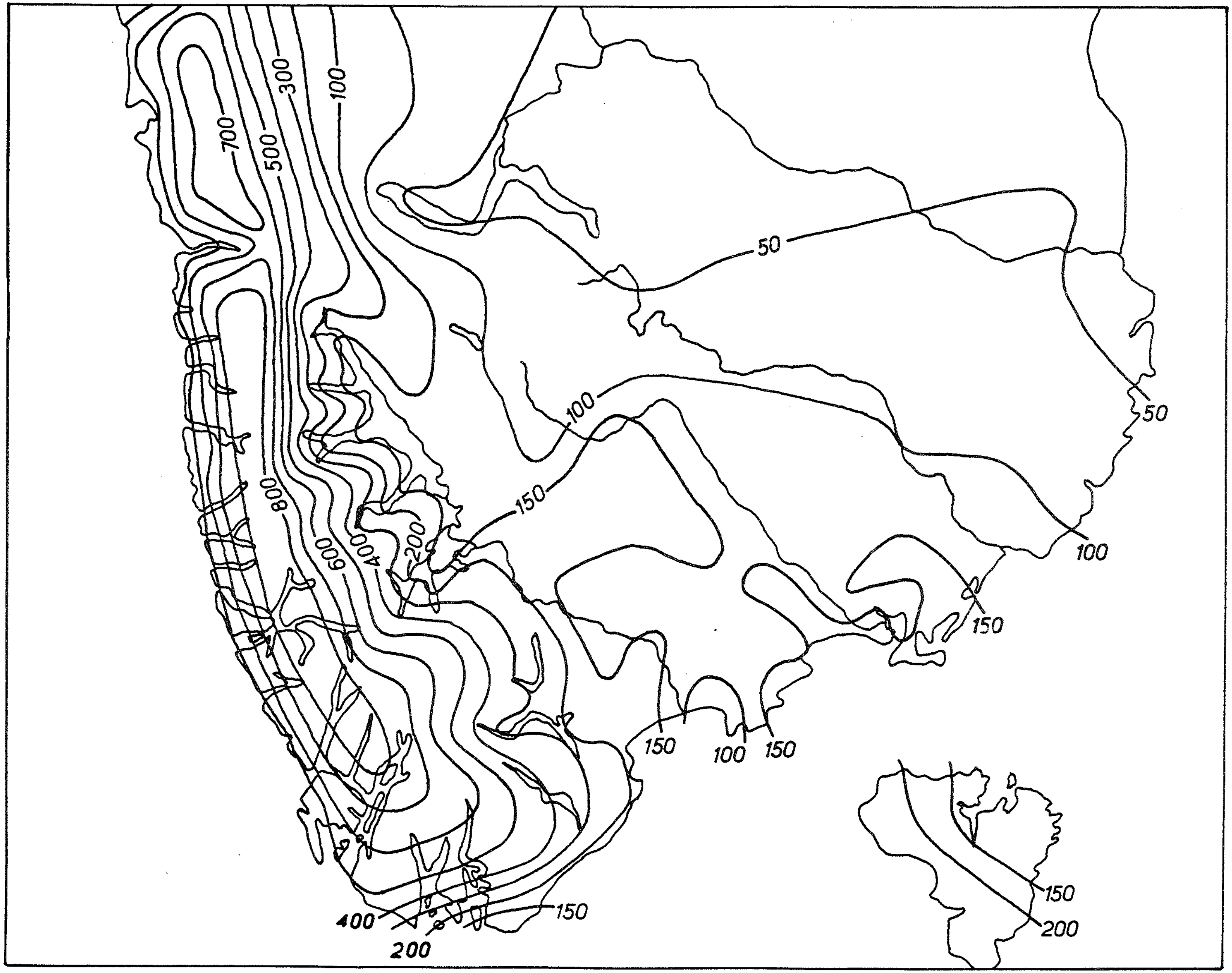


Fig. 12: Isohyets of 3-day rainfalls, 25-27 January 1984.

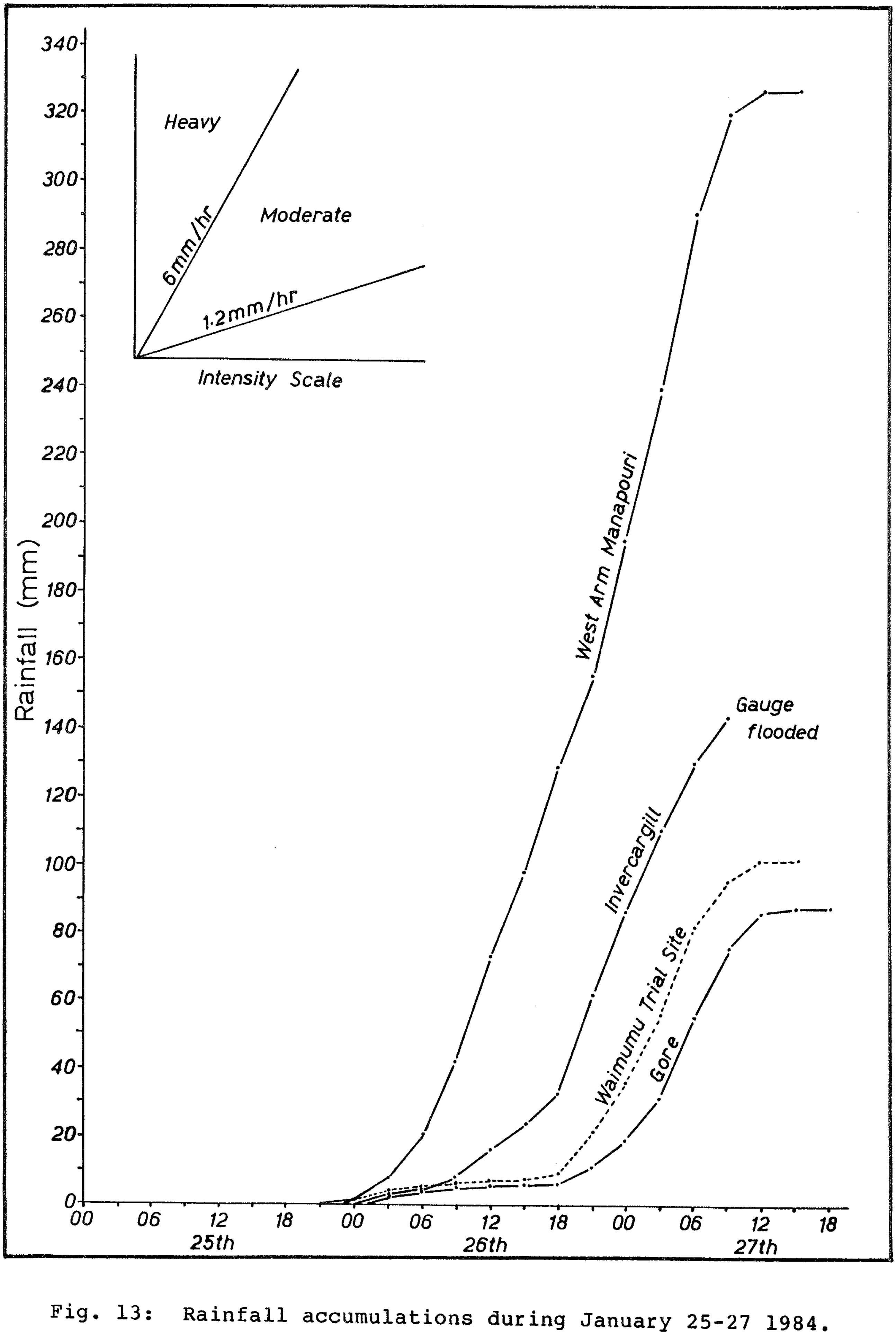


Fig. 13: Rainfall accumulations during January 25-27 1984.

heavy rain was considerably shorter.

Heavy rainfall events are often discussed with reference to their "return periods". These figures are calculated using a statistical method developed by Gumbel (1958). Return periods of the 24-hour rainfalls of 26 January have been obtained and are included in the appendix tables. These values have been mapped and the resulting analysis forms Fig. 14. Rainfalls over a large part of Southland exceeded the 100-year return period values, in some cases by a considerable margin. The very heavy rainfalls over the Fiordland mountains, however, were much less significant, with return periods generally between 5 and 10 years.

4. HISTORICAL PERSPECTIVE

It has already been noted that this was an exceptional event and that many places recorded their highest-ever 24-hour rainfalls (the previous 24-hour maxima are included in the appendix tables). In fact many parts of Southland recorded more than twice their previous maximum rainfalls. Although this has been the third serious flood in Southland during the past seven years the areas affected by the heaviest rain have been different in each case: the highest rainfalls associated with the 1978 event were recorded in the area east and northeast of Gore and the Hokonui Hills, while the heaviest rain during January 1980 occurred over an area southeast of Lake Wakatipu and over the Catlins Ranges. The heaviest rain associated with the floods of January 1984, however, was over the mountains of Fiordland and over southern and southwestern Southland; and rainfalls were, in general, much lower over the areas which received the most rain in the earlier events. The areas which recorded 24-hour rainfalls with return periods in excess of 50 years during each of these three events can be seen in Fig. 15.

The extent of the flooding in Invercargill during January 1984 has certainly been considerably greater than that associated with either the 1978 or 1980 floods. During the floods of October 1978 floodwaters on Invercargill Airport were about 1 metre deep, but in January 1984 the floodwaters at the airport were about 1.5 metres above the 1978 level (Southland Catchment Board, 1984). Western parts of Southland, such as the Tuatapere and Otautau areas were seriously affected during January 1984 but escaped the worst effects of the previous floods. On the other hand, other areas which were seriously affected by flooding in 1978 and 1980, namely Kelso, Mataura, Balclutha, Alexandra, Roxburgh, Beaumont, Riversdale and Gore, were not greatly affected in January 1984.

5. CONCLUSIONS

The ascent of very moist air, due to the combined effects of vorticity advection at the level of the jet stream and strong

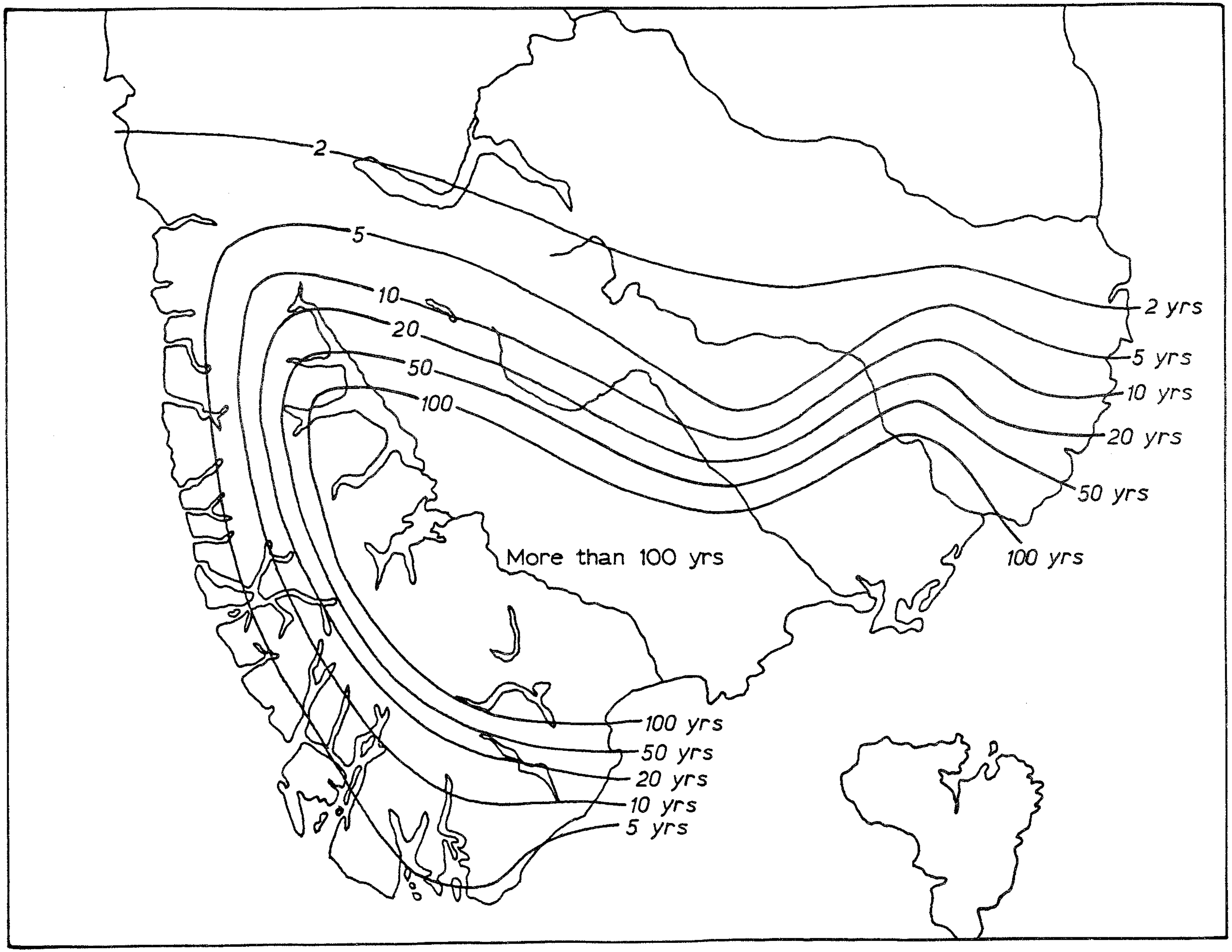


Fig. 14: Return periods of 24-hour rainfalls, 26 January 1984.

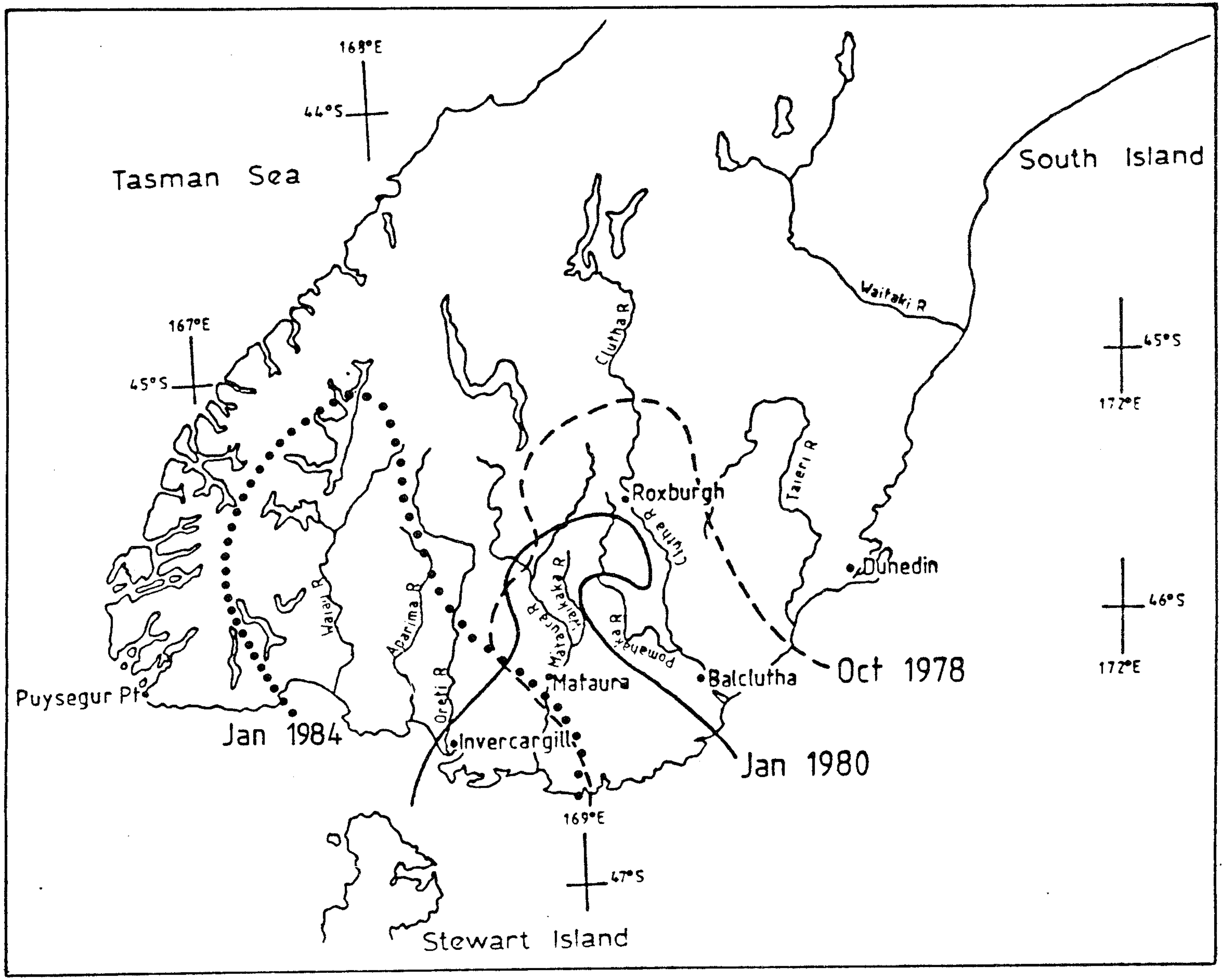


Fig. 15: Areas in which maximum 24-hour rainfalls exceeded the 50-year return period values for the storms of October 1978, January 1980 and January 1984.

warm advection, produced a 36-hour period of very heavy rain over a large part of Southland and Fiordland during the 26th and 27th of January 1984. Rainfalls in Fiordland were further enhanced by the orographic ascent of moist low-level air over the mountains. In many respects this has close parallels with the situation which produced the 1978 flood in Southland.

The rain during January 25th and 26th 1984 was by far the heaviest ever recorded in many parts of the region. The 100-year return period values were exceeded, in some cases by a considerable margin, over a very large area. As a result, large areas of Southland were swept by exceptionally high floods, causing damage estimated at around $46 million.

The extent of the heaviest rain and the severe flooding was somewhat different to that associated with the major floods which affected parts of the region in October 1978 and again in January 1980, making direct comparisons of the events somewhat difficult. Nevertheless, the effect of the January 1984 flood has certainly been much more serious than with any previous event.

6. ACKNOWLEDGEMENTS

This type of study would be impossible without the efforts of the many rainfall observers whose reports, often made under very unpleasant conditions, form the basis of our knowledge of New Zealand's rainfall patterns. We would like to convey our most sincere thanks to these people.

We are also indebted to the Southland Catchment Board, who provided a great deal of useful information.

Mr R. McGann, Liaison Meteorologist at Dunedin, assisted with the gathering of information, as did the staff of the Rainfall Section of the New Zealand Meteorological Service.

Our thanks also to Mrs C. Kreft and Mr A.W. Dyke, who drafted the figures.

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APPENDIX 1

RAINFALL TOTALS, JANUARY 25-27 1984

Station	25 Jan	26 Jan	27 Jan	25-27 Jan	24hr Return Period	Previous 24hr max
Haast	15.5	17.0	62.5	95.0	-	
Milford Sound	175.0	345.0	14.0	534.6	4.2	519.9 (1958)
Dumpling Hut	-	575.0	-	860.0*	-	
Clinton Forks	-	176.0	-	282.0*	-	
Lake Mintaro	-	523.0	-	837.0*	-	
Lake McKenzie	-	231.0	-	370.0*	-	
Lake Howden	-	223.0	-	357.0*	-	
Hidden Falls	-	398.0	-	637.0*	-	
Puysegur Point	8.7	110.2	4.9	123.8	5	
Routeburn	37.3	116.6	39.9	193.8	-	
Glenorchy	-	41.0	-	61.0*	-	
Earnslaw	20.1	77.2	19.7	117.0	2	167.0 (1978)
Coronet Pk.	-	40.0	-	70*	-	
Arrowtown	2.3	26.4	29.2	57.9	2	75.2 (1957)
Luggate	0.0	-	-	33.9	2	91.9 (1965)
Lower Nevis	-	26.0	3.0	29.0	-	
Pinewood	0.4	4.6	23.2	28.2	-	83.6 (1980)
Mosgiel	0.6	5.2	17.5	23.3	2	83.6 (1978)
Mooyman Homestead	0.2	2.1	27.3	29.6	-	
Sawyers Bay	2.3	Tce	1.8	4.1	2	
Dunedin Airport	1.0	8.0	23.0	32.0	2	86.1 (1968)
Burnside	Tce	1.8	2.8	4.6	2	190.0 (1923)
Southern Reservoir	1.5	0.0	31.7	33.2	2	97.1 (1980)
Green Island	1.6	7.2	25.9	34.7	-	98.5 (1980)
West Arm	39.4	278.6	17.3	335.3	100	160.0 (1977)
Te Anau	16.3	120.6	7.9	144.8	-	93.6 (1980)
Te Anau	24.0	116.5	0.0	140.0	-	
Te Anau	12.5	87.5	2.8	102.8	-	
Whitestone	8.0	98.5	6.0	112.5	-	
Borland Burn	80.2	120.0	11.2	211.2	-	
Blackmount	0.0	110.3	0.0	110.3	-	
Monowai	50.0	165.0	16.5	231.5	100	100.8 (1946)
Manapouri	14.0	140.0	0.0	154.0	-	
Eastern Bush	0.6	112.7	10.7	124.0	-	83.8 (1980)
Ohai	0.0	125.0	10.0	135.0	-	
Wether Hill	0.4	113.1	17.7	131.2	-	73.8 (1980)
Queenstown	9.0	36.2	21.2	66.4	-	121.9 (1949)
Queenstown Airport	2.1	27.1	19.7	49.0	2	78.0 (1980)
North Burn	0.0	18.3	20.8	39.1	-	

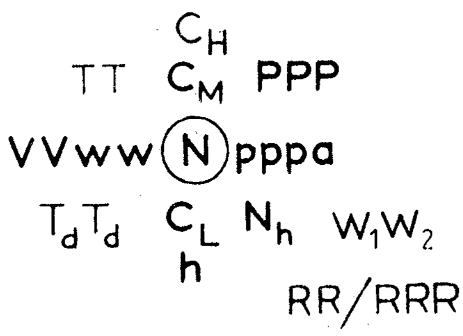
Station	25 Jan	26 Jan	27 Jan	25-27 Jan	24hr Return Period	Previous 24hr Max
Cromwell Sub Station	0.0	19.6	26.4	46.0	-	
Cromwell	1.3	18.7	29.3	49.3	-	64.0 (1969)
Lauder	0.0	6.4	30.1	36.5	-	
Ophir	0.0	8.6	28.8	37.4	-	93.5 (1978)
Clyde dam	0.0	13.0	36.6	49.6	-	
Clyde	0.0	23.7	24.1	47.8	-	
Alexandra	0.0	18.0	10.0	28.0	2	72.4 (1978)
Mossburn	9.0	130.0	17.0	156.0	-	
Hamilton Burn	28.2	123.0	8.5	159.7	-	
The Haycocks	27.1	61.2	10.0	98		
Dunrobin	4.2	146.1	1			
Balfour	0.0	96.7	3.9	100.6	-	
Waikaia	0.0	49.3	2.9	52.2	-	128.1 (1980)
Waikaia	0.0	40.0	35.0	75.0	-	
St Patricks	0.0	77.8	22.1	99.9	-	100.4 (1978)
Benmore	1.5	95.0	13.0	109.5	-	
Dipton	5.1	98.3	19.4	123.0	-	89.5 (1978)
Leithen Glen	1.5	44.0	16.5	62.0	-	115.5 (1980)
Roxburgh	0.0	18.0	12.0	30.0	2	97.0 (1978)
Lawrence	3.4	26.6	18.6	48.6	2	101.1 (1972)
Ettrick	0.0	32.0	18.0	40.0	-	
Goldie Hill	6.5	161.9	Tce	168.4	-	81.8 (1971)
Lillburn	1.2	125.3	3.2	129.7	100	79.0 (1960)
Clifden	1.3	199.3	0.0	200.6	-	60.2 (1971)
Tuatapere	13.0	100.0	25.0	138.0	-	
Tuatapere	Tce	122.0	0.0	122.0	-	
Orepuki	0.0	80.1	0.0	80.1	-	75.2 (1980)
Centre Island	7.4	136.2	11.1	154.7	100	101.6 (1909)
Longwood	5.0	135.0	12.0	152.0	-	
Lora Downs	0.0	107.4	14.1	121.5	-	117.8 (1980)
Otapiri	-	140.0	-	140.0	-	
Reaby Downs	3.2	78.7	13.8	95.7	-	101.9 (1978)
Riversdale	0.0	64.3	16.5	80.8	-	
Manderville	5.8	68.2	26.6	100.6	-	62.4 (1972)
Fairfax	2.5	110.0	28.0	140.5	-	
Otautau	2.0	128.1	8.2	138.3	100	106.1 (1977)
Scotts Gap	0.0	106.8	12.0	118.8	-	
Winton	2.7	131.2	9.2	143.1	100	67.1 (1978)
Heddon Bush	1.4	130.2	12.2	143.8	-	55.9 (1978)
Browns	5.0	128.0	3.0	136.0	-	
Winton	0.6	116.5	10.5	127.6	100	65.5 (1980)
Drummond	2.5	138.0	12.0	152.5	-	
Glendhu, Waimumu	5.6	95.2	12.6	113.4	-	98.9 (1978)
Waimumu	5.8	89.8	6.3	101.9	-	
Gore	5.3	71.0	13.0	89.3	-	93.5 (1978)
Waitane	-	127.0	-	139.0*	-	

	25 Jan	26 Jan	27 Jan	25-27 Jan	24hr Return Period	Previous 24hr Max
Te Tipua	4.5	98.1	8.2	110.8	-	76.7 (1978)
Hokonui Forest	4.3	115.0	3.7	123.0	-	
Hedgehope	3.3	127.4	5.9			(1978)
Mavora	12.7	71.2	14.8	98.7	-	
McKellars Flat	18.0	76.0	0.0	94.0	-	
Mataura	5.0	82.0	12.0	99.0	-	92.3 (1980)
Wallacetown	9.0	118.5	10.3	137.8	-	
Riverton	-	132.5	-	148.0*	100	
Waikiwi	7.0	119.0	7.5	133.5	-	
Woodlands	11.4	132.4	7.8	151.6	-	77.5 (1980)
Seaward Downs	10.0	95.0	20.0	125.0	-	
Wyndham	10.0	75.0	25.0	110.0	-	
Edendale	12.8	107.5	11.6	131.9	-	84.4 (1978)
Invercargill Airport	8.0	134.0	19.0	161.0	100	73.4 (1980)
Waimatua	16.0	50.0	67.0	133.0	-	
Awarua	6.5	131.0	10.1	147.6	100	91.4 (1937)
Otaratara	14.0	135.5	1.5	151.0	-	
Tiwai Point	6.4	132.5	11.7	150.6	100	72.4 (1970)
Morton Mains	9.5	122.5	11.5	143.5	-	
Gorge Road	7.9	115.7	11.3	134.9	-	66.1 (1980)
Tokanui	5.5	87.5	17.8	110.8	-	
Stirling Point	4.8	143.0	12.3	160.1	100	65.6 (1978)
Otara	6.0	104.0	17.0	127.0	-	
Dog Island	8.1	152.3	7.1	167.5	-	62.1 (1972)
Lorneville	5.0	138.0	15.0	158.0	-	
Stewart Island	10.8	131.6	3.8	146.2	100	
Rosebank	2.0	38.0	29.0	69.0	-	
Tuapeka Mouth	2.6	32.0	25.8	60.4	-	105.0 (1978)
Milton	0.5	18.3	11.9	30.7	-	104.1 (1972)
Clinton	8.4	43.9	8.9	61.2	-	
Clinton	7.7	41.1	12.6	61.4	-	
Balclutha	1.7	27.0	13.2	41.9	2	115.6 (1978)
Lovells Flat	5.1	31.4	14.5	51.0	-	
Inch Clutha	1.0	24.8	13.3	39.1	-	107.3 (1978)
Fernhill, Mokoreta	8.6	74.4	9.7	92.7	16	97.1 (1980)
Nugget Point	0.5	27.0	14.0	41.5	-	87.5 (1978)
Owaka	0.2	25.4	9.9	35.5	2	98.5 (1980)
Fortification	8.6	88.3	20.8	117.7	-	
Quarry Hills	8.1	72.5	10.0	90.6	-	147.1 (1960)
Waikawa Valley	7.0	65.3	7.6	79.9	-	
Tautuku	3.7	36.2	12.6	52.5	-	

* Record incomplete - 3 day rainfalls estimated.

APPENDIX 2

Surface observations plotted on the figures use standard meteorological plotting model:



Key to WW symbols:
- · light rain
- ∴ moderate rain
- ⁘ heavy rain
-]• recent rain