NEW ZEALAND METEOROLOGICAL SERVICE

TECHNICAL NOTE NO. 187

MODIFICATION OF RAINFALL FROM A WEAK SYNOPTIC SYSTEM BY TERRAIN AND DIURNAL HEATING - A CASE STUDY

A.A. Neale

Issued for limited distribution by:

The Director,
New Zealand Meteorological Service,
P.O. Box 722,
Wellington 1.

6 March 1970.

NEW ZEALAND METEOROLOGICAL SERVICE

MODIFICATION OF RAINFALL FROM A WEAK SYNOPTIC SYSTEM BY TERRAIN AND DIURNAL HEATING - A CASE STUDY

A.A. Neale

Abstract

The scattered light rain from a weak synoptic-scale cloud band passing over the northeast of the North Island in summer is accentuated over the windward slopes of a mountain range. A second rainfall maximum occurs downstream from the rain shadow that lies immediately in the lee of the range crest; this second maximum, induced by the range, is enhanced by the effects of diurnal heating to give a greater rainfall than occurs on the windward slope of the range.

Introduction

Synoptic-scale disturbances travelling in an airstream flowing over mountain ranges often produce little rain on the leeward side. However, in the warmest months of the year some such disturbances can trigger off violent convection in these leeward regions. The intensity of these disturbances need not be great. A small amount of cyclonic vorticity (and its accompanying area favourable for ascending motion) arriving over a leeward region in the midday or afternoon hours, when surface heating is producing the greatest de-stabilizing effect, can lead to the development of violent convection with thunder and hail.

This sequence of events has been noted by Neale (1964) in eastern parts of Otago and southern Canterbury when westerly airstreams affect the region. Obviously, with New Zealand lying within the prevailing westerlies, such afternoon and evening convection is to be expected from time to time in all east coast regions from Otago to Gisborne. Another area in which the effect can be experienced is the Bay of Plenty when the general wind flow is from the south. Revell (1969) has noted that in summer the Bay of Plenty is susceptible to increased shower frequency in the afternoon and evening, particularly when synoptic-scale features are weak.

...

This paper presents one case study of rainfall over the northeastern part of the North Island (including the Bay of Plenty) showing that the pattern of rain associated with a relatively weak synoptic-scale disturbance travelling in a south-southwesterly airstream was greatly modified by topography and diurnal heating.

Data

The data consisted of records from rainfall stations, charts from all automatic raingauges in the region, and the analysed National Weather Forecasting Centre charts of the troposphere. Photographs from weather satellite ESSA 8 were used along with a record of visual observations taken between Rotorua and Whakatane. Figure 1 shows the distribution of the rainfall stations and automatic gauges as well as place names referred to in the text.

Time sections were constructed for Auckland and Christchurch airports and for Waiouru. Although pressure, temperature and humidity values were available from Waiouru only half as frequently (24-hourly) as at the other two stations, the values fitted well into a cross-section closely resembling that for Christchurch. Such a result appears reasonable since Waiouru lay directly downstream from Christchurch during this period of predominantly south-southwesterly flow at most levels in the troposphere.

Discussion

A period of rain lasting several hours occurred over the northeastern part of the North Island on the evening and night of 25 January 1969; both the preceding and following days were dry except for isolated light showers (Figs 1b, 1c, 1d). Figure 2a shows that this rain was the first significant fall at Whakatane in nineteen days. Comparison of the isohyets in Fig. 1c with the location of high ground (shaded in Fig. 1a) shows that the rain on 25 January occurred principally in two belts, one over and south of high ground (with reported falls up to 0.40 in.), and the other some distance to the north over the lowlands and coast (with reported falls up to 0.50 in.). These two rain belts were separated by a lane where little or no rain fell immediately north of the range crest.

The automatic raingauge record from Opotiki (Fig. 2b) shows that 0.47 in. fell in a little over four hours, and that in the middle of this period the rate of fall exceeded 0.15 in. in 30 minutes, thereby qualifying as heavy rain. From the author's personal observation at Whakatane, the rainfall showed marked variation in intensity and was occasionally heavy; it had a character

...

that strongly indicated a convective origin. Figure 2c relating the rainfall periods at automatic raingauge stations to their distance north of a fixed east-west line, shows that the rain belt moved northward across the region.

During the several days up to 26 January, the MSL synoptic analysis was dominated by a high pressure ridge over the Tasman Sea and a slow-moving trough near or eastward of 180° longitude. These produced a south-southwesterly airstream over the New Zealand region, and disturbances of a relatively minor nature travelled within this stream. One moved from west of southern New Zealand on 23 January to near Auckland at 0300 GMT 24 January (Fig. 3a); although small, it was discernible at all levels in the troposphere as a small cyclonic circulation (Fig. 3b), and appeared as a weakening vortical cloud pattern (marked V) in the satellite photographs on three successive days (Figs 4, 5, 6). Rain areas accompanying this disturbance did not affect the northeastern part of the North Island.

Time sections for Christchurch and Auckland (Figs 7,8) show that this weak circulation, preceded by a deep moist layer, made its closest approach to Christchurch at 1500 GMT 23 January, and passed Auckland some twelve hours later. Neither the three dimensional wind flow nor the potential temperature changes showed any distinct frontal character; a fact confirmed by the variations in potential wet bulb temperature (not shown) which were small and unorganised.

Although there was no decrease in stability behind the weak circulation, there was, in the lower half of the troposphere at both Christchurch and Waiouru (Figs. 7,9), a period of eighteen to twenty-four hours during which the stability (measured by the lapse rate of potential temperature) showed little variation. Also while the air had become drier than earlier, moisture persisted in middle levels about 500 to 600 mb. Study of the satellite photographs taken between 1919 and 2108 GMT 24 January revealed that this moist layer was apparently associated with a cloud band, consisting of stratiform and cumuliform elements, extending west-northwest to east-southeast across Christchurch (Fig. 5).

From the Waiouru cross-section, it was concluded that temperature and humidity fields were being advected in the south-southwesterly airstream with only slow modification; this enables time changes in the elements to be converted into distance changes. From such a conversion we can infer that stability in the lower half of the troposphere (as measured by the lapse rate of potential temperature)

...

was fairly constant in the region ahead (north) of the cloud band of the previous paragraph, and that stability increased southwards across the band accompanied by a lowering of the top of the moist layer. A more precise estimate of the degree of stability (or instability) of the clear pre-cloud band air can be made objectively by use of an index suggested by Boyden (1963). This index can be applied in trough or frontal conditions, and Table 1 lists the values of the index at Auckland, Waiouru and Christchurch.

Table 1

Boyden Instability Index

	23 Jan.		24 Jan.		25 Jan.		26 Jan.
	0000Z	1200Z	0000Z	1200Z	0000Z	1200Z	0000Z
Auckland	89	93	93	93	-	91	93
Waiouru	95	-	94	-	95	-	93
Christchurch	94	95	94	96	94	90	93

These values range from 94 to 96 at both Waiouru and Christchurch in the period from 23 to 25 January; the peak values of 96 at Christchurch and 95 at Waiouru occur at times which correspond to their being found in the clear air just ahead of the cloud band. Tests conducted in England give a 60 to 70% probability of thunderstorms when the index was equal to or greater than 95. Thus the Boyden instability index indicates the probability of intense convection at a time when the Bay of Plenty would be likely to experience considerable diurnal heating of the lowest layers of the troposphere before the arrival of the cloud band towards evening.

Stability started to increase from about 0000 GMT 25 January in the Waiouru area (Fig. 9) with a drying of the moist layer from above. Further north in the Bay of Plenty such conditions would have been experienced later in the afternoon. At Auckland both the Boyden index and the time section (Fig. 8) show that the process of stabilization and drying of the atmosphere had begun the previous day, giving rise to a marked increase of stability westwards across the Bay of Plenty on 25 January; this shows up in Fig. 1c as an abrupt western edge to the rain. At Rotorua, in the rainless area, the author noted that on the afternoon of 25 January, dark towering cumulus clouds continually spread out into stratocumulus before precipitation occurred.

Riehl (1962) has shown that ascent of air and surface cyclogenesis are to be expected on the downstream side of an upper level trough whenever a speed maximum within the upper level flow passes across the trough axis. From Fig. 3 an upper level trough is located east of New Zealand, while the observed increase in contour gradient which occurs between the South Island and Chatham Islands (about 44°S, 176°W) in the 24-hour period from 0000 GMT 25 January indicates that an area of high speed wind is advancing northwards toward the trough axis. At the time of the satellite photograph in Fig. 5, this speed increase would lie southeast of Christchurch (C in Fig. 5) and the large, dense, irregularly-shaped cloud mass, M, lies in the locality designated by Riehl as favourable for ascending motion. Twenty-four hours later this cloud mass, M, has become much more organised (Fig. 6) and consists of a synoptic scale band, broad toward the southeast, narrow toward the northwest and becoming weak in the longitude of the Bay of Plenty; the appearance of a large area of cumulus clouds on the southwest side of the cloud band is consistent with cyclogenesis having taken place to the east of New Zealand.

The effect of topography on the rainfall pattern may be considered by comparison with a computer simulated dynamic model for orographic precipitation over the western Ghats of India (Sarker, 1967). This model assumes an idealized mountain profile and a simplified atmosphere. While the height of the western Ghats is similar to that of the ranges between Bay of Plenty and Gisborne, 3000 ft, there is an appreciable difference in the latitudes of the two places; nevertheless the results from the model could apply in a qualitative manner to our present case. The model shows (1) that the rainfall on the windward coast is little affected by the orography, (2) that there is a rainfall maximum on the windward slope of the range, (3) there is a minimum of rain just downstream from the ridge crest, and (4) there is a secondary rainfall maximum 15 miles downstream from the ridge crest.

In our case this would mean (see Fig. 1c) that the weak synoptic scale trough (accompanied by the weak cloud band) was producing only scattered light rain such as fell on the coast about Gisborne. A rainfall maximum of up to 0.40 in. did occur over the windward slope of the ranges, while little or no rain fell immediately downstream from the range crest. Twenty miles further downstream there was a second rainfall maximum, however its magnitude (up to 0.50 in.) was greater than that which fell in the windward slopes of the range. It is proposed that, as suggested in the dynamic model, there was a region favourable for rainfall that acted as a trigger to release the

...

instability which had built up during the afternoon through diurnal heating of the lowest layers of the atmosphere; in this way greater rainfall totals occurred downstream from the ranges than over the upwind slopes.

Conclusions

One case study of a summer situation over the northeastern part of the North Island shows that:-

(1) A synoptically weak disturbance within a south-southwesterly airstream, producing scattered and mainly light precipitation, can have this rainfall pattern markedly modified by the effects of terrain and diurnal heating.

(2) The effect of the terrain, in the form of a mountain range, is to intensify the precipitation on the windward slopes, and cause a rain shadow with little or no precipitation immediately downwind from the range crest. A second belt of precipitation, lighter than on the windward slopes of the range, may be favoured further downstream from the range crest.

(3) Within this second belt, the increased instability of the atmosphere resulting from diurnal heating of the ground downwind from the ranges, can intensify the rainfall to the stage where it is greater than that falling on the windward slopes.

References

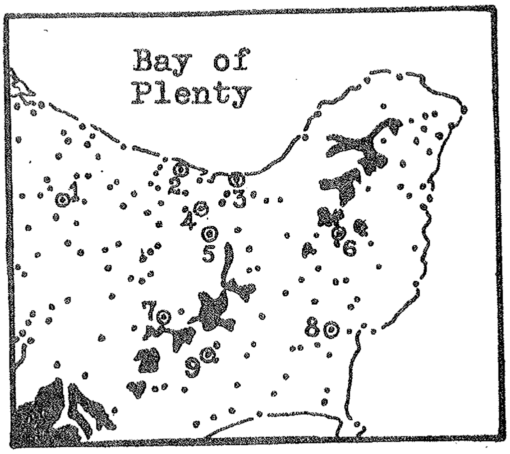
Boyden C.J., 1963: A simple instability index for use as a synoptic parameter. Met. Mag. 92, 198.

Neale A.A., 1964: Meteorology of inland and south-western parts of the South Island. N.Z.Met.S. Tech. Note No.152. (Unpublished).

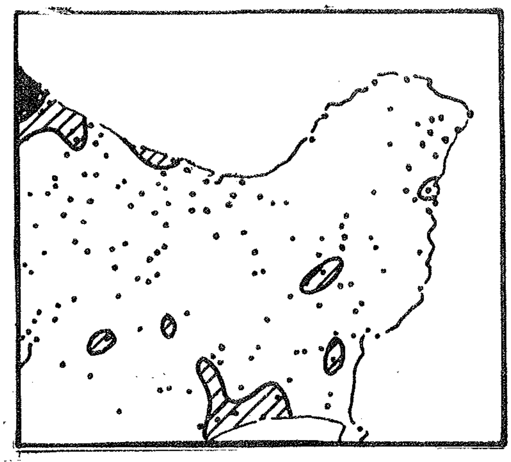
Revell C.G., 1969: A case study of meso-scale rainfall variations in northern New Zealand. N.Z.Met.S. Tech. Note No. 181. (Unpublished).

Riehl H., 1962: Jet streams of the atmosphere. Dept. Atmos. Sci. Colorado State Univ.: Tech. Rep. 32.

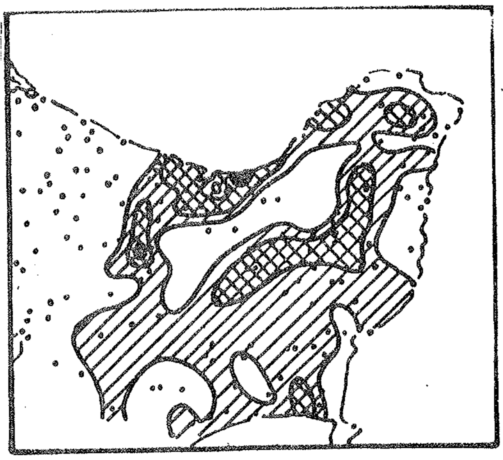
Sarker R.P., 1967: Some modifications in a dynamic model for orographic rainfall. Mon. Wea. Rev. 95, 673-684.



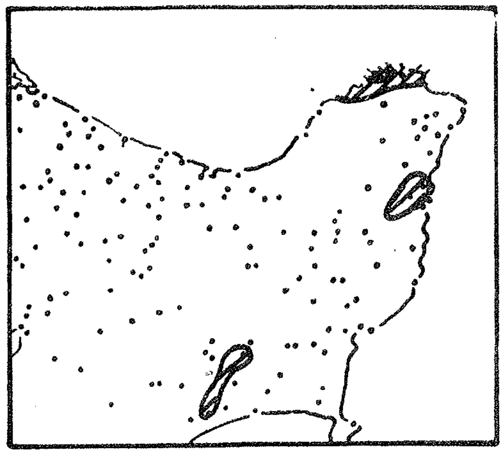
1a. Location map. Land above 3000 feet shaded.



1b. Rainfall for 24-hour period ending 2100 GMT 24 January 1969.



1c. Rainfall for 24-hour period ending 2100 GMT 25 January 1969.

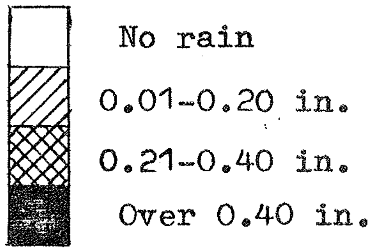


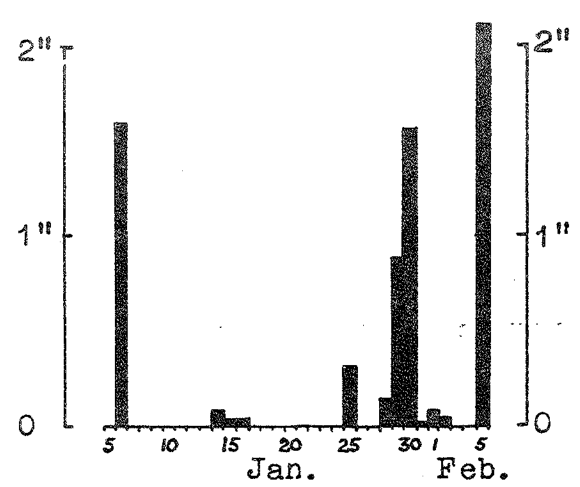
1d. Rainfall for 24-hour period ending 2100 GMT 26 January 1969.

Fig.1. Dots in 1a denote stations reporting rainfall. Circled and numbered dots indicate places referred to in the text.

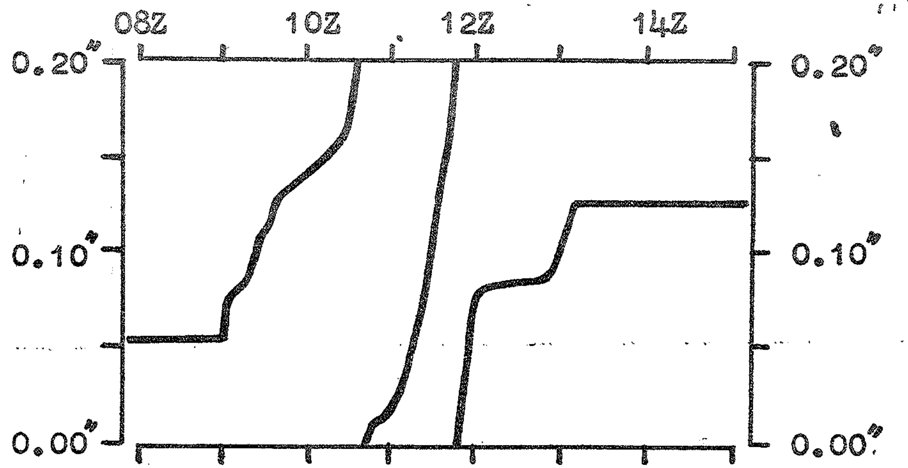
1. Rotorua: 2. Whakatane.
3. Opotiki. 4. Waimana.
5. Matahi. 6. Waipooa.
7. Tarapounamu. 8. Waerenga-O-Kuri.
9. Onepoto.

1b, 1c and 1d show 24-hour rainfall totals with isohyets drawn at 0.20 inch intervals.

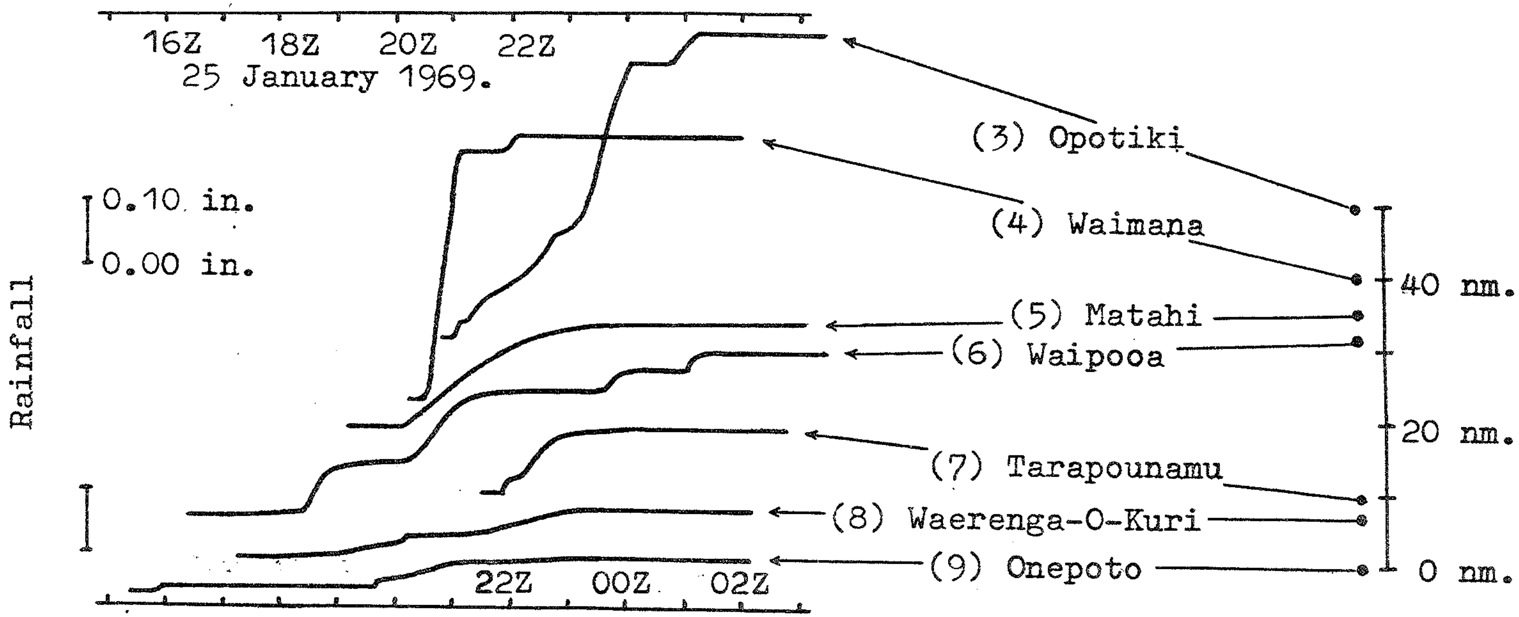




2a. Daily rainfall Whakatane.



2b. Continuous record of rainfall at Opotiki on 25 January 1969.



2c. Records from stations having automatic rainfall gauges. Stations arranged in order from north to south; distances north of an east-west line through Onepoto are shown on the right.

Fig. 2.

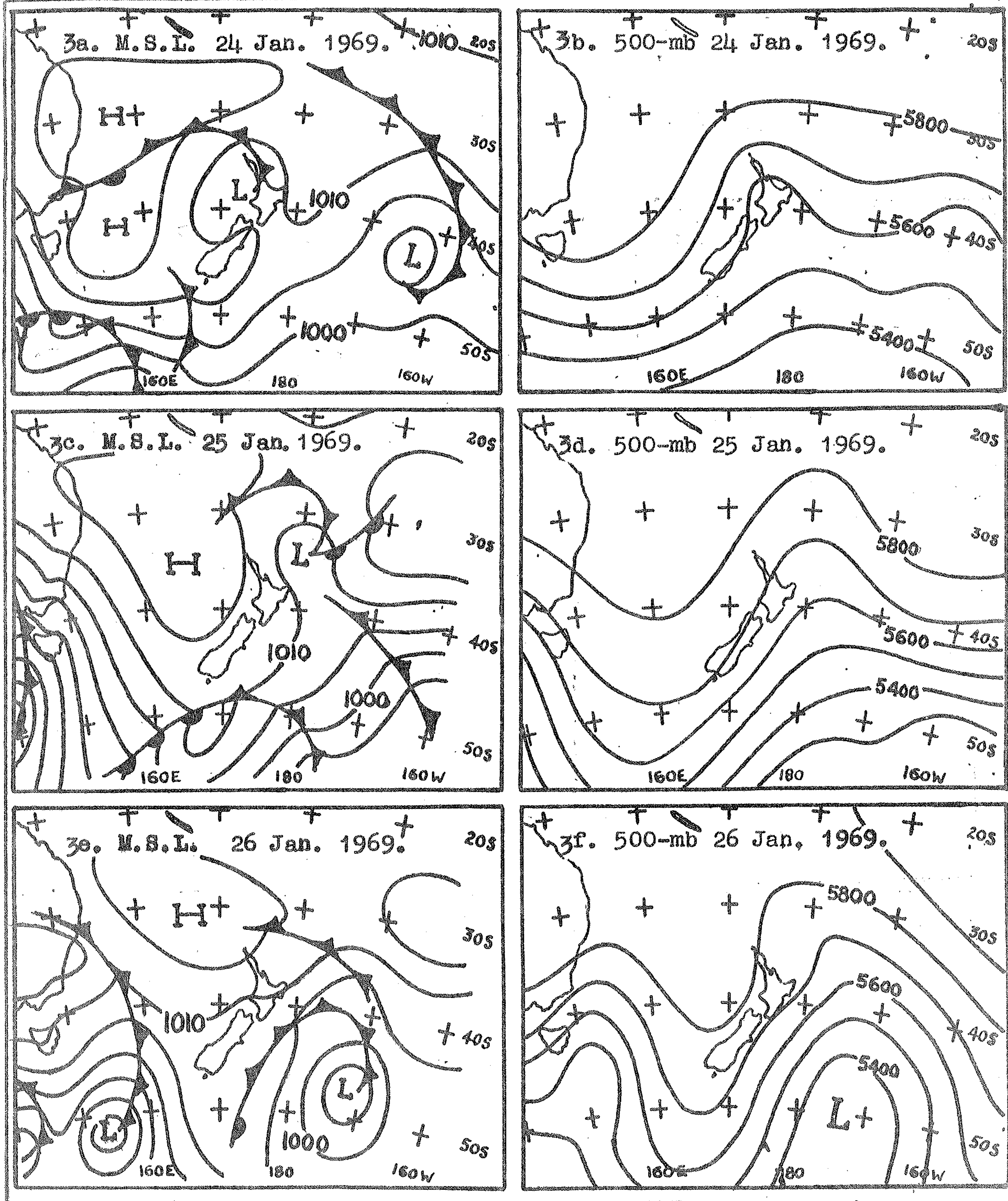


Fig. 3. M.S.L. and 500mb analyses for 0000 GMT. Pressures in millibars, heights in metres.

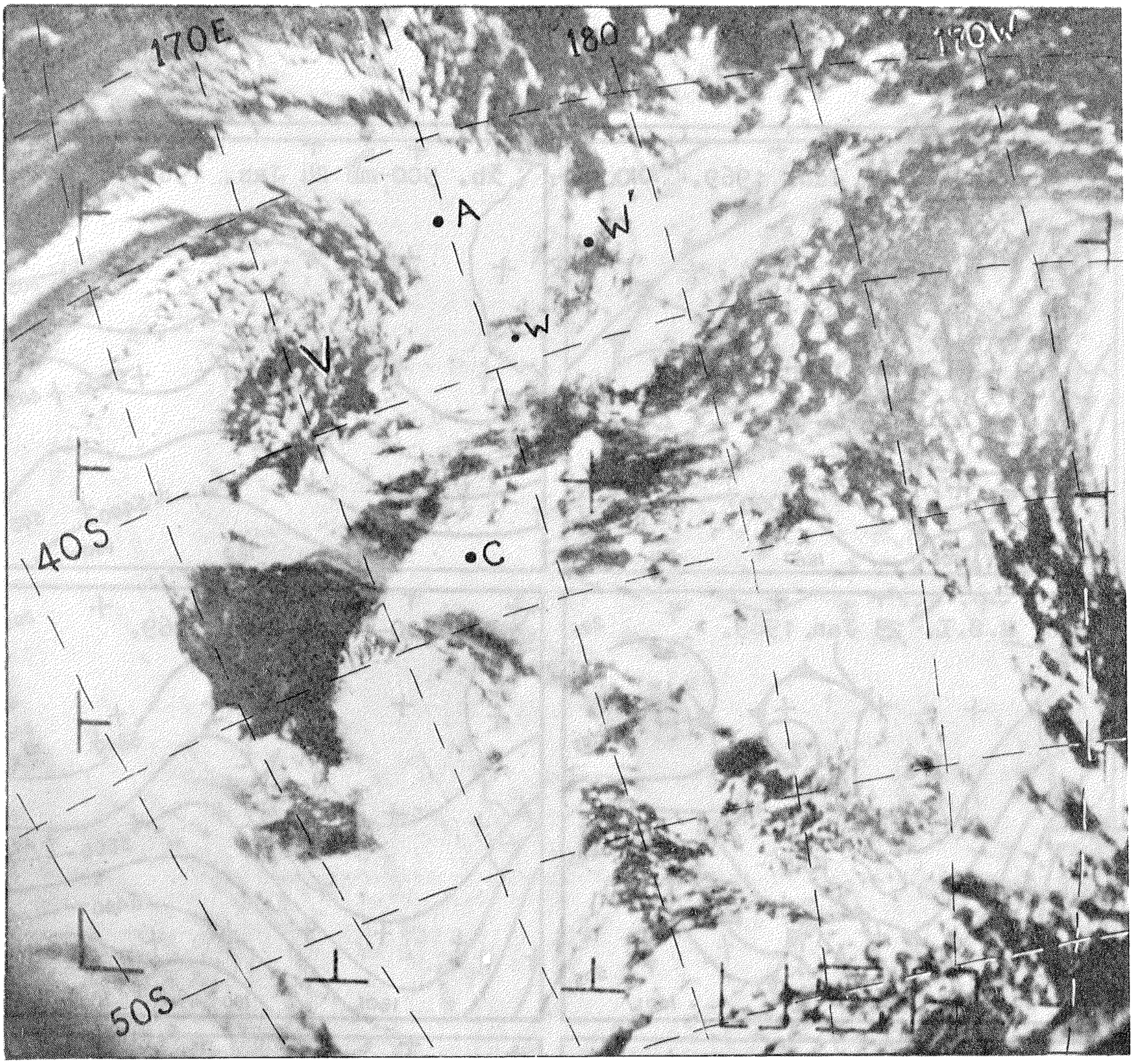


Fig. 4. Photograph taken by ESSA 8, 2023 GMT 23 January 1969 (orbit 491).

A - Auckland. C - Christchurch. W - Waiouru.

W' - Whakatane. V - vortical cloud pattern.

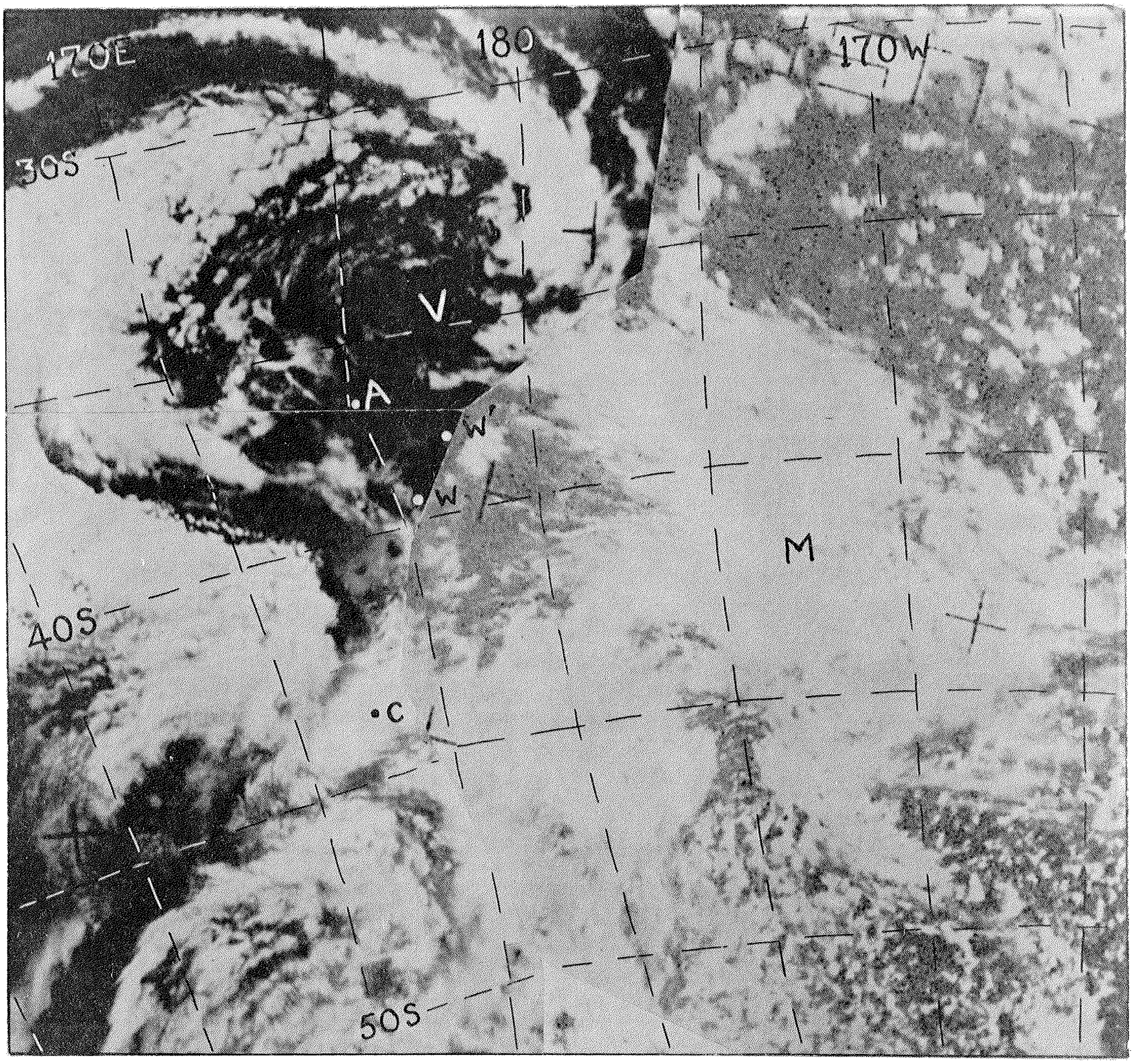


Fig. 5. Mosaic constructed from photographs taken by ESSA 8, 1919 to 2108 GMT 24 January 1969 (orbits 503 and 504).

A - Auckland. C - Christchurch. W - Waiouru.

W' - Whakatane. V - vortical cloud pattern.

M - developing cloud mass.

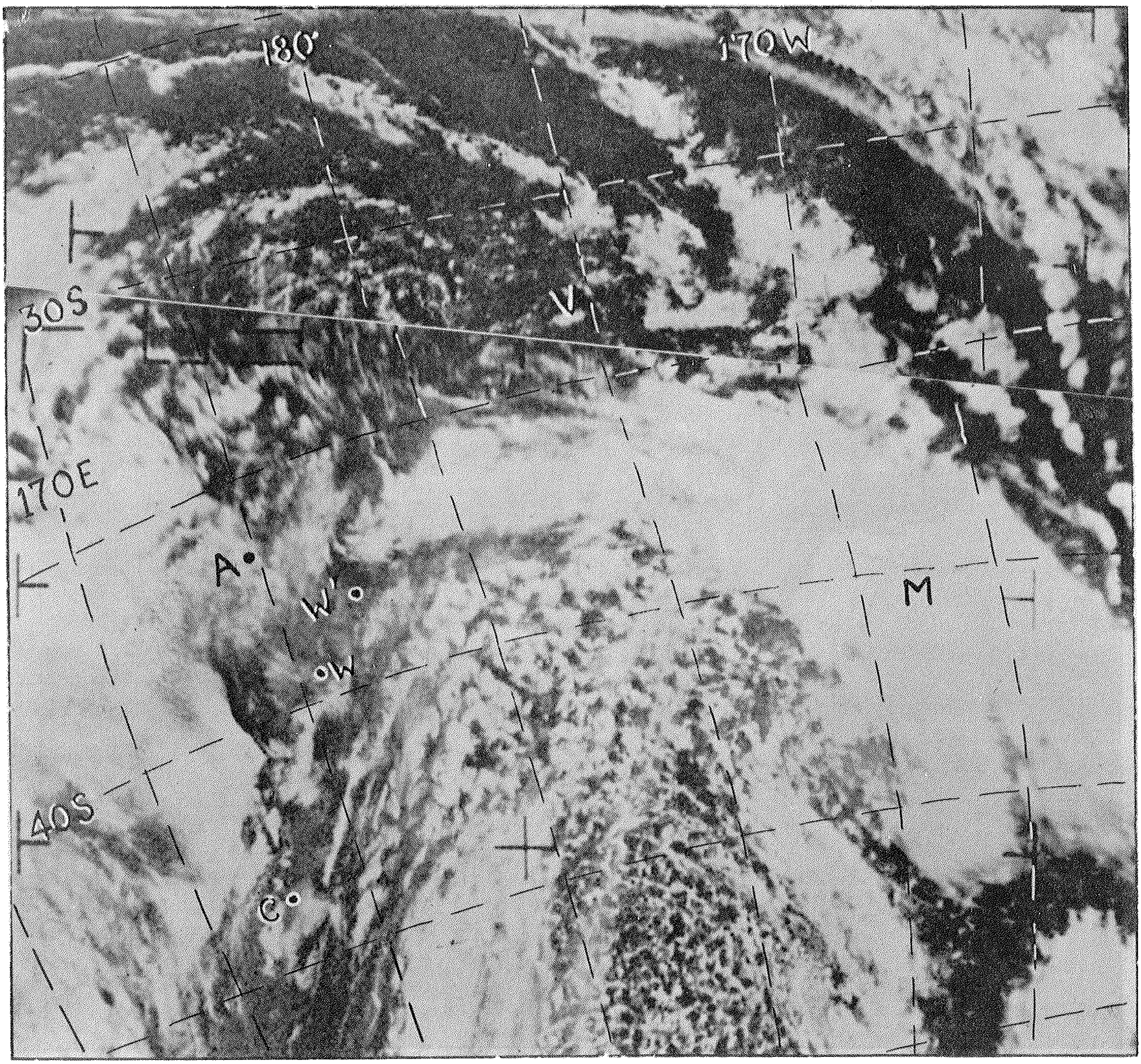


Fig. 6. Mosaic constructed from photographs taken by ESSA 8, 2005 to 2011 GMT 25 January 1969 (orbit 516).

A - Auckland. C- Christchurch. W - Waiouru.

W' - Whakatane. V - dissipating remnants of vortical cloud pattern.

M - developing cloud mass.

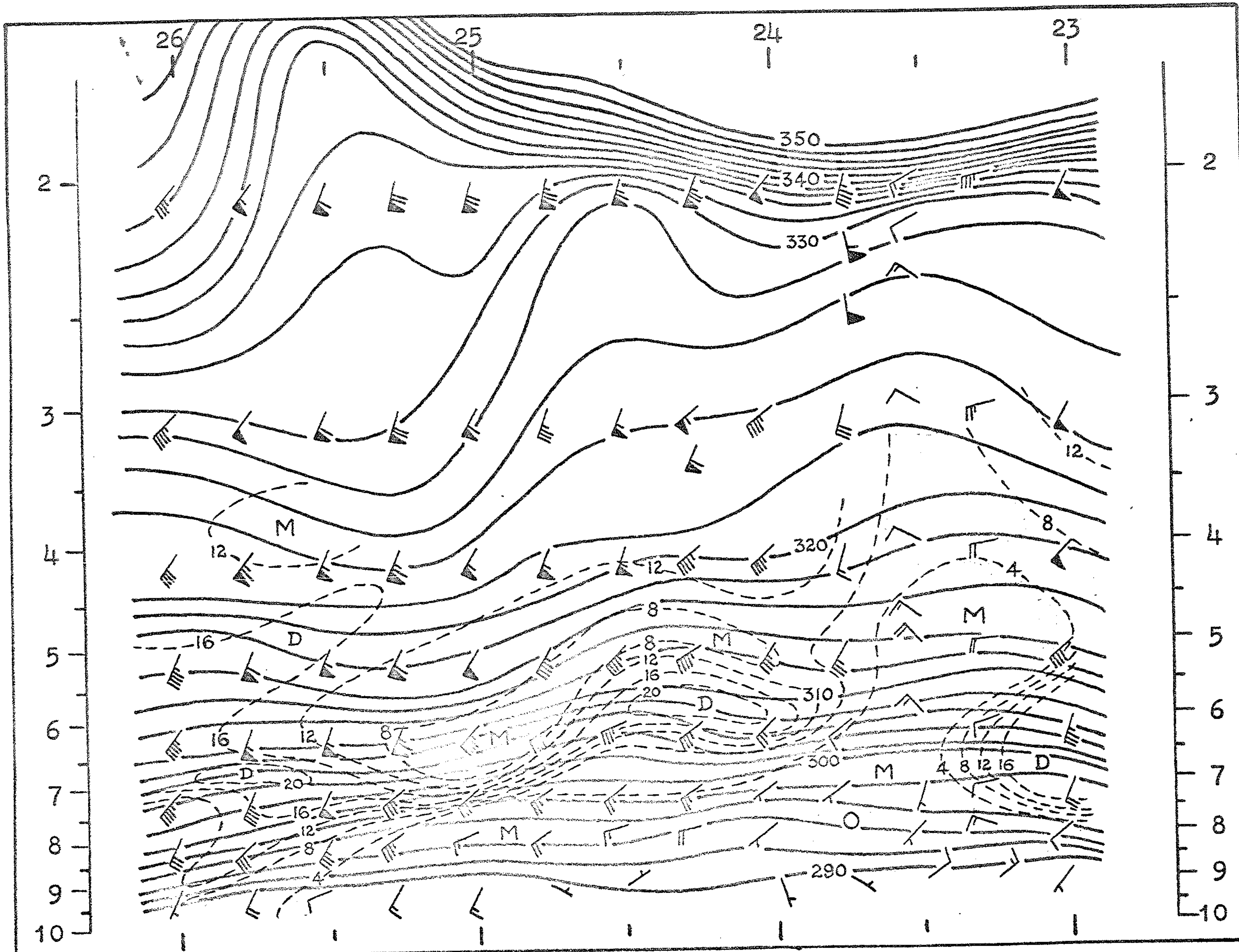


Fig. 7. Time section for Christchurch, January 1969.
Dates refer to 0000 GMT. Vertical scale in hundreds of millibars.
Solid lines - potential temperature in degrees K. Dashed lines - dew point depression in degrees C. Shaded area is moist air, depression < $8^{o}C$.

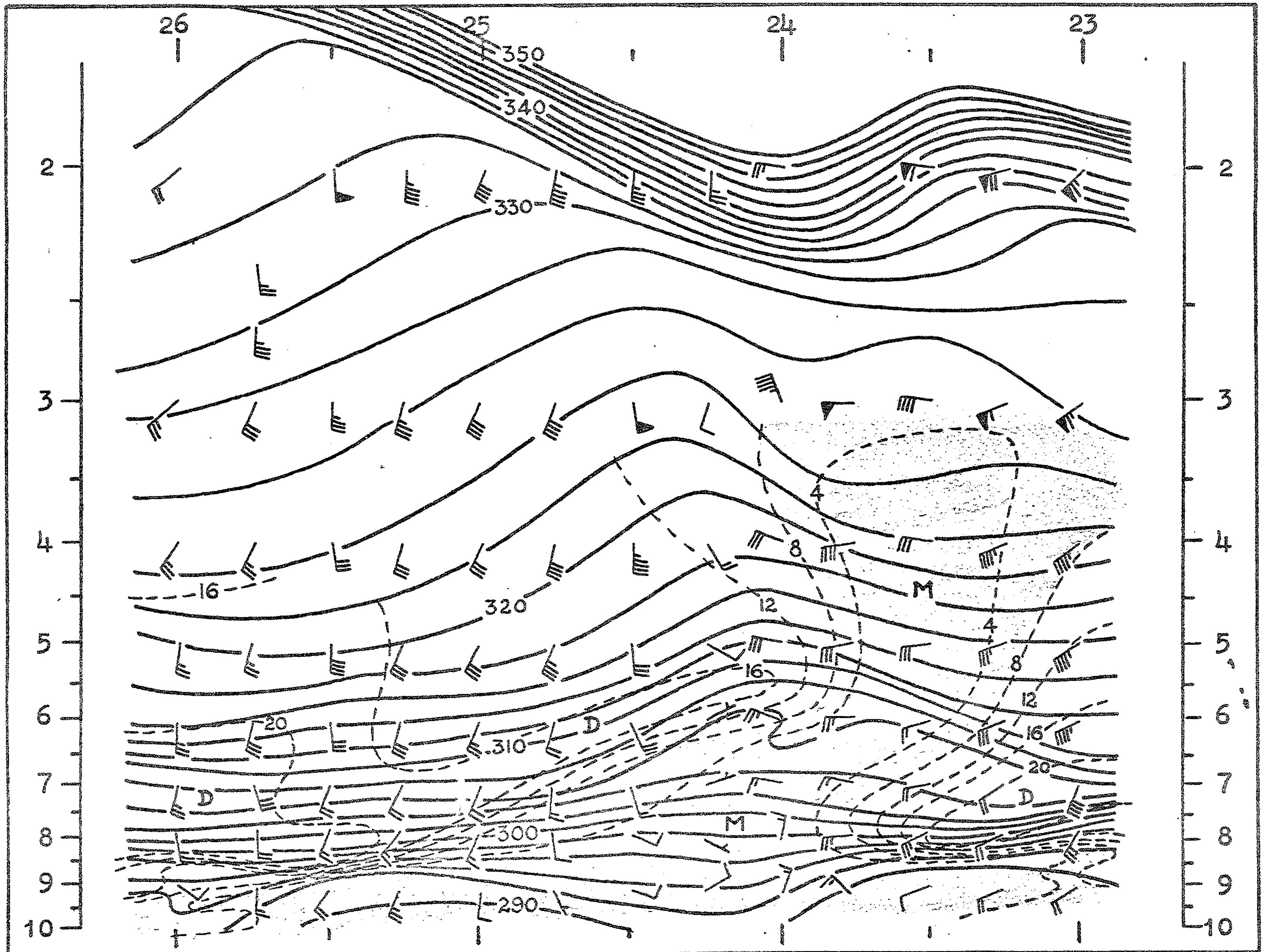


Fig. 8. Time section for Auckland, January 1969.

Dates refer to 0000 GMT. Vertical scale in hundreds of millibars. Solid lines - potential temperature in degrees K. Dashed lines - dew point depression in degrees C. Shaded area is moist air, depression $< 8^\circ C$.

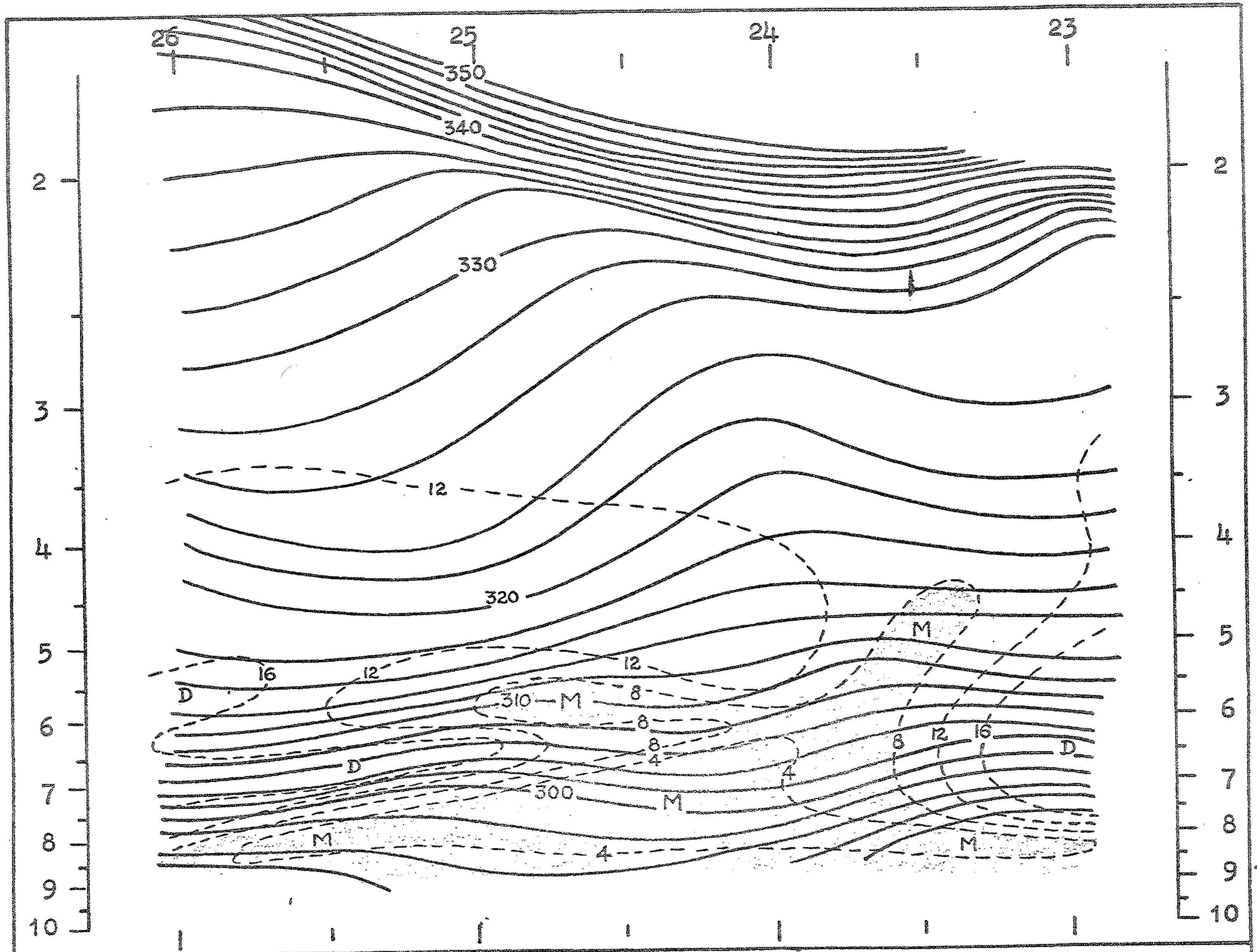


Fig. 9. Time section for Waiouru, January 1969.

Dates refer to 0000 GMT. Vertical scale in hundreds of millibars. Solid lines - potential temperature in degrees K. Dashed lines - dew point depression in degrees C. Shaded area is moist air, depression $< 8^{\circ}C$.