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TECHNICAL NOTE 207

INTERACTION BETWEEN DIFFERENT SCALES OF MOTION IN A NORTH ISLAND SUMMER SITUATION

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INTERACTION BETWEEN DIFFERENT SCALES OF MOTION IN A NORTH ISLAND SUMMER SITUATION

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Abstract

Diurnal changes in the patterns of surface wind flow, cloud and precipitation are described in relation to a weak synoptic system over the North Island of New Zealand. The analyses made show how convection is modified by meso-scale patterns of convergence brought about by land-induced wind systems.

1. Introduction

The topography of New Zealand causes certain recurring patterns of wind and weather which are characteristic of a particular region but differ from those in other regions. These patterns vary in detail from day to day with changes in the broad-scale flow over the country. In conventional forecasting practice, allowance is made for the simple blocking action on wind flow and the accompanying rain shadow effects brought about by mountain barriers. Other important orographic influences, however, have received little consideration in New Zealand until recently but are now being increasingly recognised although no systematic studies have been reported.

One of the commonest land-induced winds is the sea breeze sometimes considered as a merely local phenomenon accompanying summer anticyclones. This simple type of 'pure' sea breeze is, however, comparatively rare, and is usually of short duration.

In the spring and summer months particularly, when differential heating is greatest, sea breezes are entrained into more extensive wind systems affecting a region sometimes as large as the whole of the North or South Islands. These latter systems result from an adjustment between the general air flow and the circulation associated with meso-scale heat lows. The development of such regional circulations with accompanying large-scale anabatic flow therefore involves the three-dimensional motion of large volumes of air. This is accompanied by important changes in the pattern of mass divergence and by the occurrence of definite discontinuities in the wind field. These circulation systems are observed to have a marked influence on patterns of convective precipitation. Moreover they interact with synoptic-scale weather systems, especially when these are in a degenerate stage, resulting in well-defined 'zones of convergence'.

An example of an interaction of this kind is described here. Local time is used throughout the report and the locations of places mentioned in the text are shown in Fig. 1.

2. Synoptic Situation

A weakening cold front passed off the North Island at midday on 7 January 1970 as a second front advanced quickly northwards over the country. The second front, followed by an airstream originating in high latitudes, crossed central New Zealand on the morning of 7 January with the characteristics of a line squall. During the night it became slow-moving and weak over the north of the North Island. At the same time pressures rose over the country as an anticyclone spread from the west (Fig. 2).

By midday on 8 January the general south to southwest wind flow on the eastern flank of the high had swept the decaying frontal cloud to the north of New Zealand. This was confirmed by detailed analysis and by satellite picture. The National Weather Forecasting Centre working analysis in Fig. 2 gives only a broad interpretation of the situation. However an active cloud mass remained over the seas to the east of Northland and to the north of the Bay of Plenty in a region where the surface wind flow had turned easterly.

At the same time a shallow pressure trough extended from Northland southwards near the west coast to Taranaki. A clearly defined wind discontinuity existed within this trough and south of Auckland it possessed the characteristics of a sea breeze front, the air on the western side being clear of cloud while broken cumulus lay to the east arranged mainly in streets along the wind. The detailed pattern of wind flow over the North Island at 1800 hrs on 8 January is shown in Fig. 3. The dominance of sea breeze circulations is evident.

The discontinuity passed eastward overnight and by the morning of 9 January had reached the position just off the Coromandel Peninsula still occupied by active cloud and from which heavy rain was then being reported. (Its structure is discussed in the next section). The system then remained quasi-stationary for about 48 hours during which period marked diurnal changes occurred in the weather of the Bay of Plenty region. Thunderstorms broke out on the night of 9 January and again on the 10th affecting mainly a narrow coastal strip in central Bay of Plenty and the high ground of the Urewera country to the south. Finally on 11 January, influenced by increasing westerly broad-scale flow, the system moved to the east being still detectable in satellite pictures as a broad cloud band extending northwestward from about East Cape.

3. Structure of the Discontinuity

Air approaching northern New Zealand from between south and southwest as on 8 January becomes partially blocked in the lower levels and tends to flow around the North Island. Two typical trajectories of air at the surface are drawn in Fig. 4.

Air following trajectory A passes over relatively warm water, being well mixed by small-scale convection and becoming increasingly moist. Wind flow in the middle and upper troposphere is outlined in Fig. 5. This flow possessed considerable cyclonic relative vorticity over the north of New Zealand in the form of curvature in the lower middle troposphere and lateral shear in the upper troposphere, a condition which favours deep convection. Air entering the trough from the east at midday would have been subject to these influences for some 6-12 hours. On the other hand air flowing on path B has followed a more direct route from the source south of New Zealand. It is also closer to the main anticyclone to the west. Initially dry, this air would have tended towards increasing stability under the anti-cyclonic influence west of the upper trough over northern New Zealand.

Soundings were made at Auckland International Airport within air which had followed these respective paths (Fig. 6). While dry bulb temperatures in the two original soundings agreed to within 1°C at all levels except close to the surface there is clearly a density discontinuity in the trough as shown by the disparity in virtual temperature. This is accounted for by the difference in moisture between the two airstreams. The noon sounding, A, revealed relative humidity 80% or more up to about 11,000 ft in a marginally unstable environment while the air sampled at midnight, B, was dry and absolutely stable. The airflow entering the trough from the west could therefore be expected to undercut the less dense air initiating ascent at the discontinuity. From kinematic considerations the inflow would have had most effect in the Auckland district (Fig. 3) intensifying the existing convection along the discontinuity and this convection was potentially strong because of the factors mentioned above in the discussion of trajectory A.

Observations on the 8th at midday showed that the trough was centred over the Kaipara and Manukau Harbours. There were aircraft reports at the time of towering cumulus tops reaching 20,000 ft in the Auckland area but further south towards the middle of the North Island the highest tops were only 7,000 ft.

From the available evidence it is reasonable to conclude that the discontinuity developed in a region of confluence between two airstreams which had been modified by external factors while flowing northward from a common source. The upper level contour and thickness pattern remained weakly cyclonic over the region on the three subsequent days.

4. Detailed Analyses

The development and subsequent behaviour of the discontinuity described in the previous section was studied by means of a series of detailed analyses of surface wind flow. For the time of each weather surveillance radar observation at Auckland Airport surface wind data were extracted from the anemograms at 12 stations and were supplemented by winds reported from synoptic stations for the observation time nearest to that of the radar sweep.

Precipitation echoes traced from the PPI display were also plotted. Fifteen maps were prepared for the interval 0430 hrs on 8 January to 0030 hrs on 10 January. Only four are reproduced in this note (Figs 7, 8, 9, 10). Precipitation echoes on the 8th were initially aligned in bands nearly parallel to the front (Fig. 7). During late morning the pattern changed into a north-south arrangement of echoes, some coincident with the wind discontinuity, and a close association with this feature was apparent in the afternoon and evening. At 1930 hrs extensive echoes appeared also in the approaches to the outer Hauraki Gulf where a weak trough appeared to form within the easterly wind regime. The pattern of surface wind and radar-observed precipitation at 2230 hrs on 8 January is shown in Fig. 8.

At 0630 hrs on 9 January (Fig. 9) the early morning flow pattern had reached full development, the wind discontinuity having moved off the land areas and become associated closely with the area of precipitating cloud to the east. A weak vortical pattern was discernible in the cloud north of Great Barrier Island in a satellite picture taken 2 hours later. The resemblance between the shape of the radar echo and the configuration of the neighbouring coastline is a noteworthy illustration of orographically-induced convergence.

Daytime heating resulted in reversal of the flow across the eastern coastline with development of anabatic motion over land and the convergence zone over the sea weakened or disappeared. This daytime pattern was near its peak at 1430 hrs (Fig. 10). Few radar echoes were seen but showers were reported near the sea breeze convergence zone along the Kaimai Range, thunder was heard at Kawerau and Rotorua and hail was observed near the latter station.

Afternoon wind speeds averaged 15 to 20 kt in many coastal regions which was considerably higher than would have been experienced over the adjacent seas in the very feeble pressure gradients which prevailed.

Rain echoes reappeared over the sea northeast of the Coromandel Peninsula and became more extensive over central Bay of Plenty during the evening at the stage when the daytime circulation pattern gave way to the land breeze regime characteristic of the night hours. By 0030 hrs on 10 January both flow and echo patterns were almost identical with those which existed early the previous morning (Fig. 9). A weak cyclonic eddy was detectable over central Bay of Plenty (compare area west of Rotorua in Fig. 10) but at 0100 hrs flow with a southerly component extended across the coastline at least as far east as Whakatane.

5. Rainfall in Bay of Plenty 9 Jan. 1970

While most of the Auckland province enjoyed fine weather on 9 and 10 January parts of Bay of Plenty as well as islands in the eastern approaches to the Hauraki Gulf received substantial falls of rain ranging up to about 100 mm in a few places, including Great Barrier and Cuvier Islands.

While detailed distribution of convective rainfall is notoriously difficult to account for, the broad pattern can be inferred from the available data and in the following discussion an attempt is made to relate this to the features already described. It should be noted that much of the rain was occurring out of range of the Auckland surveillance radar and was not detected.

As described in section 4 the wind discontinuity with its associated cloud system moved eastward on the night of 8 January. It merged with the precipitating cloud to the east of Coromandel Peninsula in the early hours of 9 January and rain in inland areas died out by 0600 hrs. At that time cloud cover in western Bay of Plenty was thin and broken but further east was dense with embedded cumulonimbus from which rain fell intermittently. Insolation soon heated the ground in the west where sea breezes developed and cloud dissipated. This cloud-free area then appeared to act as a nucleus for further cloud dissipation, particularly at its eastern edge. Gradually the change spread eastward along the coast.

The sequence of events at places equipped with recording instruments confirms that a discontinuity existed at this cloud edge. The final shower at Whakatane stopped at 1130 hrs and a northeast breeze developed simultaneously and abruptly while a similar change followed at Opotiki at 1300 hours.

During the course of the day the sea breeze-anabatic flow system became very extensive. Growth of this circulation with subsiding motion in the seaward branch where convection is suppressed accounts for the commonly observed clearance of cloud in coastal regions during situations favourable for vigorous sea breeze development. Successive satellite pictures 3-4 hours apart showed the effect clearly on this day as well as on 8, 10 and 11 January.

In the afternoon of 9 January there were two main zones of precipitation:

1. In a band parallel to the coast about 10-30 miles inland where strong cells were scattered and arranged irregularly.

2. Over the inland high country roughly parallel to the main mountain divide where anabatic winds converge.

Figure 10 indicates the extent of the regional wind system on this same afternoon. The western Bay of Plenty sea breeze flow appears to be separated from the anabatic flow over the central plateau in this situation.

Rain in the second of the above-mentioned zones did not become widespread until around nightfall and continued until near midnight. This rain clearly does not result from small-scale convection, i.e. local thermals, which stop at the end of the day. A possible explanation can be given in terms of the anabatic flow. This steady ascending motion is part of a large three-dimensional system possessing a certain amount of inertia. Although weak the vertical component acting for the greater part of a day leads to condensation and cloud formation over a large area. The air involved is likely to have had properties similar to that of sounding A discussed in section 3. Any conditional or convective instability is readily released resulting in further cloud growth which does not depend on sustained convection from ground level. Individual strong convective cells could be embedded within such a system. Nocturnal cooling and the gradual reversal of the vertical circulation results in dissipation of the system during the night.

After 1800 hrs 9 January rain again developed in some coastal places and at 2230 hrs the Auckland radar detected moderate echo extending from the area seaward of Whakatane across the coast in a spiral band into the Urewera country. Vivid lightning from this system was observed as far away as Auckland.

The landward part of the system dissipated soon after this but heavy rain continued in the coastal region where thunderstorms were occurring in the early hours of 10 January. By this time as noted in the previous section the nocturnal land breeze was fully established at the surface. While other factors are involved the interaction between this offshore flow and the gentle northerly flow over the Bay is considered to have augmented the low level convergence thus intensifying convection at the coast and seaward.

A similar cycle of events occurred on 10 January, thunderstorms developing over the Urewera country in the evening and at Opotiki at midnight.

6. Discussion and Conclusions

While this report is not intended to give a complete explanation of the phenomena described it can be concluded that the features discussed contributed in large part to the observed weather sequence.

Growth and decay of the sea breeze circulation which is often part of a large scale anabatic system, with accompanying changes in low level convergence, causes a diurnal variation in the sign and intensity of vertical motion particularly in a zone at the coast and at the sea breeze 'front'. The degree and extent of convection changes correspondingly.

This effect is distinct from that of frictionally-induced convergence in the surface layer which is enhanced by change of friction at the coast. However the two are probably related. The latter mechanism is also linked to the daily heating cycle through variations in turbulent mixing with corresponding changes in the 'effective' frictional stress. From the literature to date it appears that no satisfactory physical picture of the diurnally varying boundary layer is yet available.

The essential features of this situation can be summarised as follows:

A weak tropospheric trough became quasi-stationary. It contained an area of moist cloudy air which was marginally unstable. The upper wind flow across the trough possessed a sharp gradient of cyclonic relative vorticity in a narrow zone. Surface winds on the eastern side of the trough were easterly to northerly, the northerlies being weak over the Bay of Plenty. The coastal air-circulation system then acted within this framework with a 'tidal' or 'pumping' effect to modify the patterns of windflow and precipitation in the manner observed. The features of this system are shown schematically in Fig. 11, for the near-surface layer.

Orographic modification of this kind occurs throughout New Zealand. Apart from their intrinsic interest and general effect on weather such systems are of special importance in connection with yachting, gliding, forest burning-off and other activities where the development of convection and associated wind changes have to be assessed in arriving at tactical decisions.

Appendix

Relative vorticity of upper wind flow over northern New Zealand.

Two aircraft approaching Auckland from the north on the morning of 9 January reported winds of 275° 125kt at 34°S, 176°E or about 180 miles north of Auckland. The maximum wind was probably near the flight level, just below the 200mb surface. The maximum wind reported at Auckland in the midday sounding was 275° 80kt near 200mb. The minimum value of horizontal shear at the jet stream level between 34°S and Auckland was therefore about 8×10^{-5} sec^{-1}, approximately equivalent to the Coriolis parameter at 35°S. There were no aircraft measurements on 8 January but the upper wind flow was similar to that on the following day. It was the Essa 8 satellite picture on the morning of 9 January in which a vortical pattern was discernible north of Great Barrier Island (section 4).

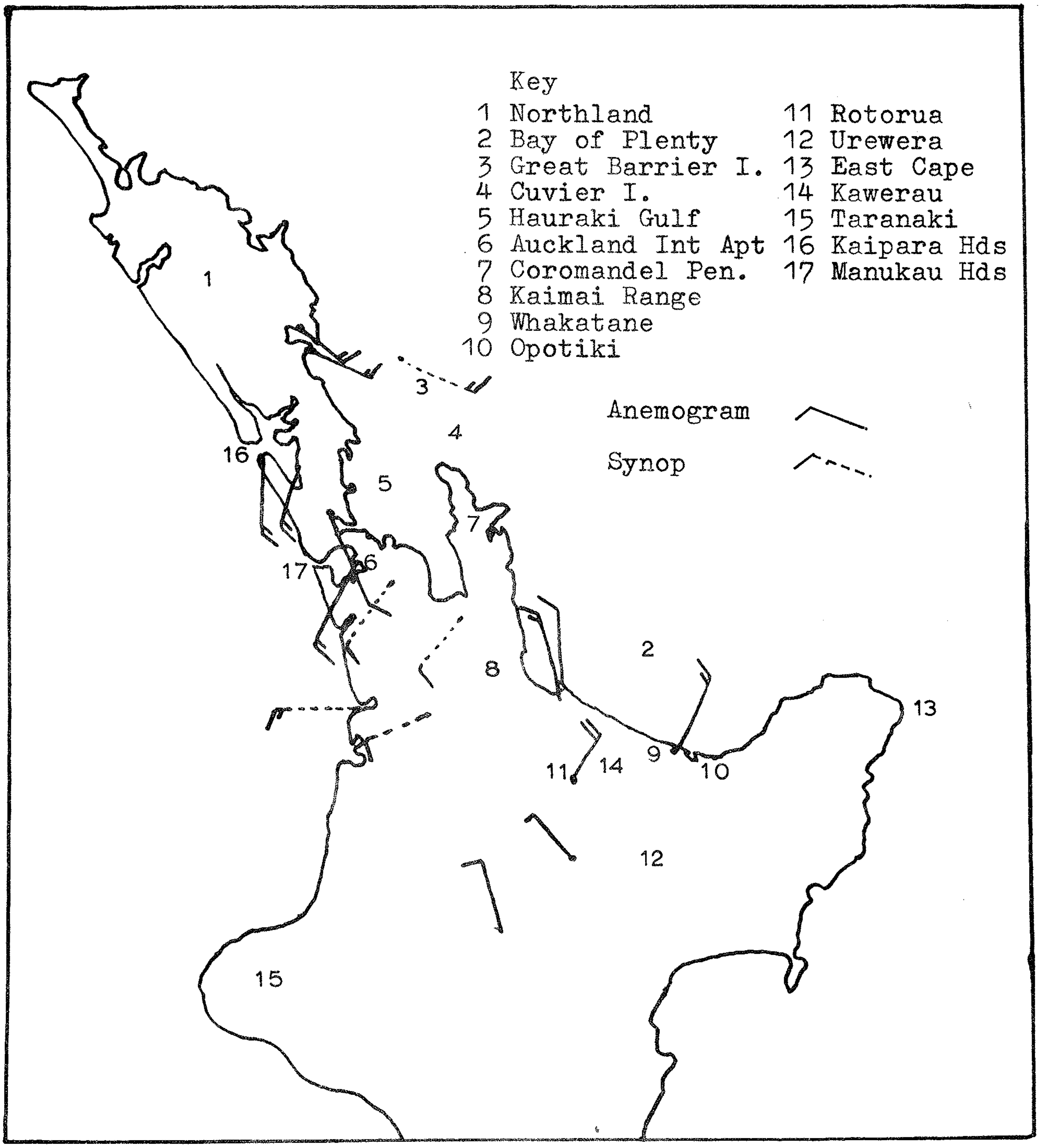

Fig. 1 Map showing location of places mentioned in text.
Winds used in analysis of Fig.10.

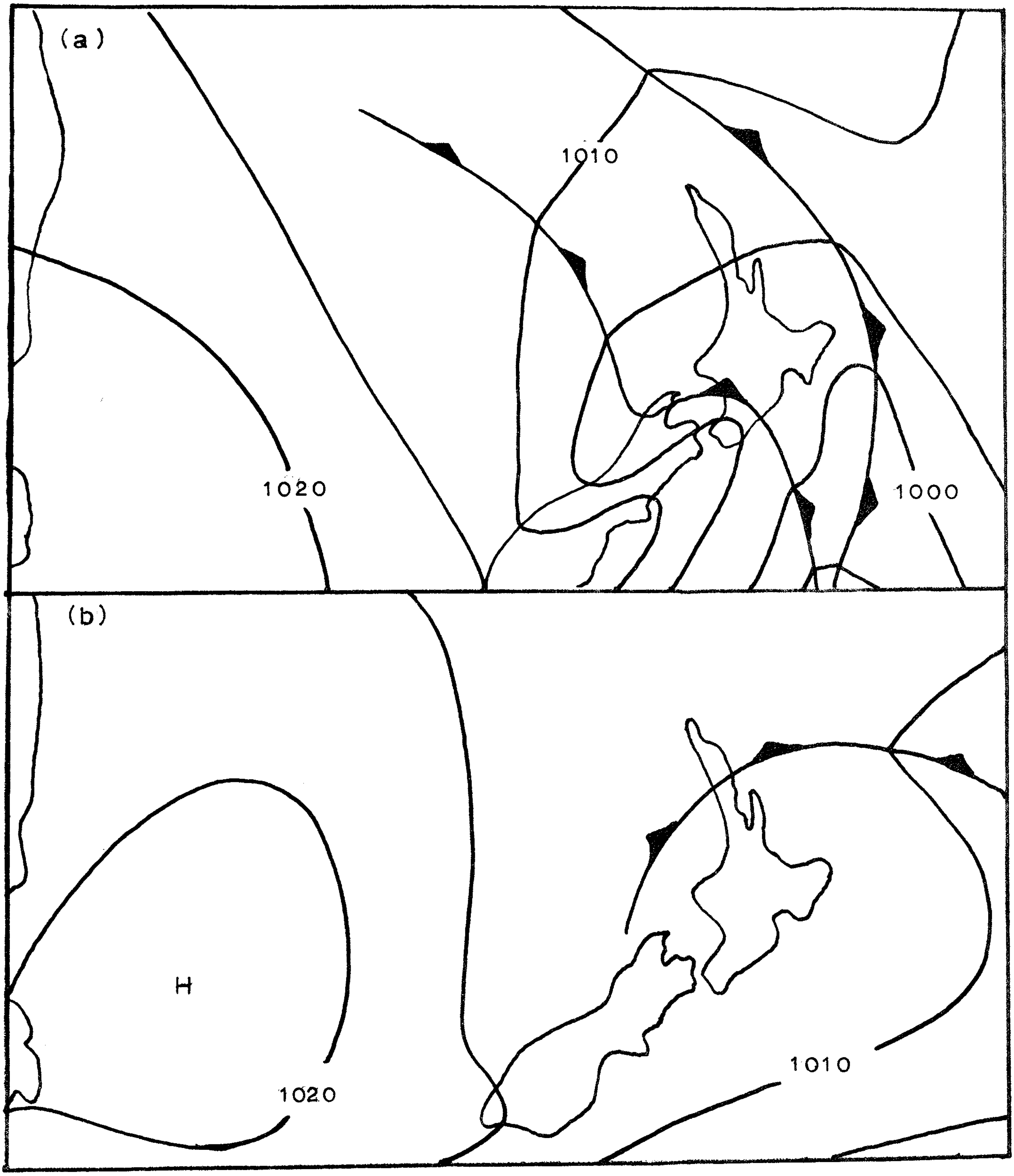

Fig. 2 M.S.L. analysis (a) 1200 N.Z.S.T. 7 January 1970
(b) 1200 N.Z.S.T. 8 January 1970

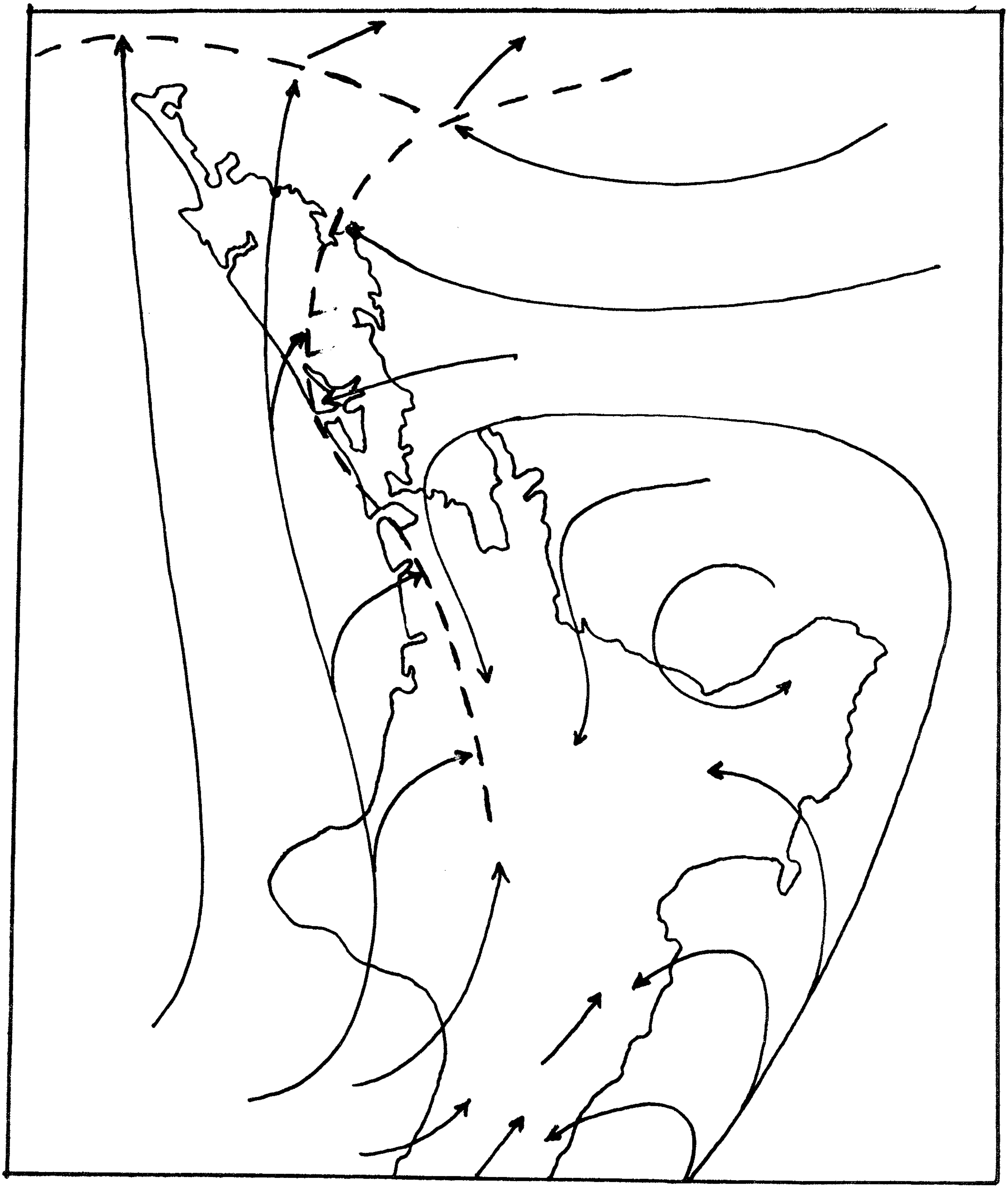

Fig. 3 Surface wind flow at 1800 N.Z.S.T. 8 January 1970.

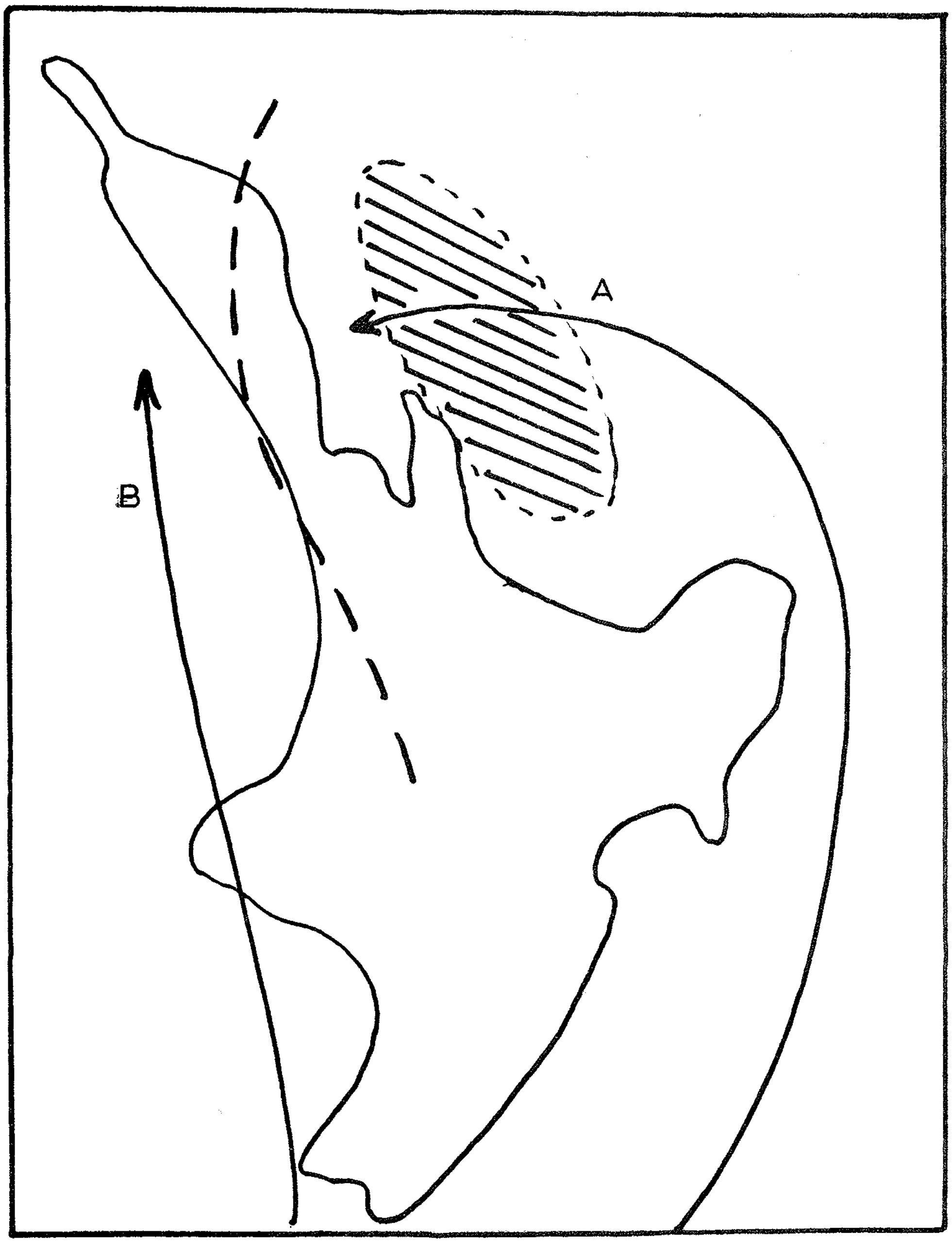

Fig. 4 Basic trajectories of low level air entering trough over northern New Zealand on 8 January 1970. (Hatched area signifies active cloud system over sea).

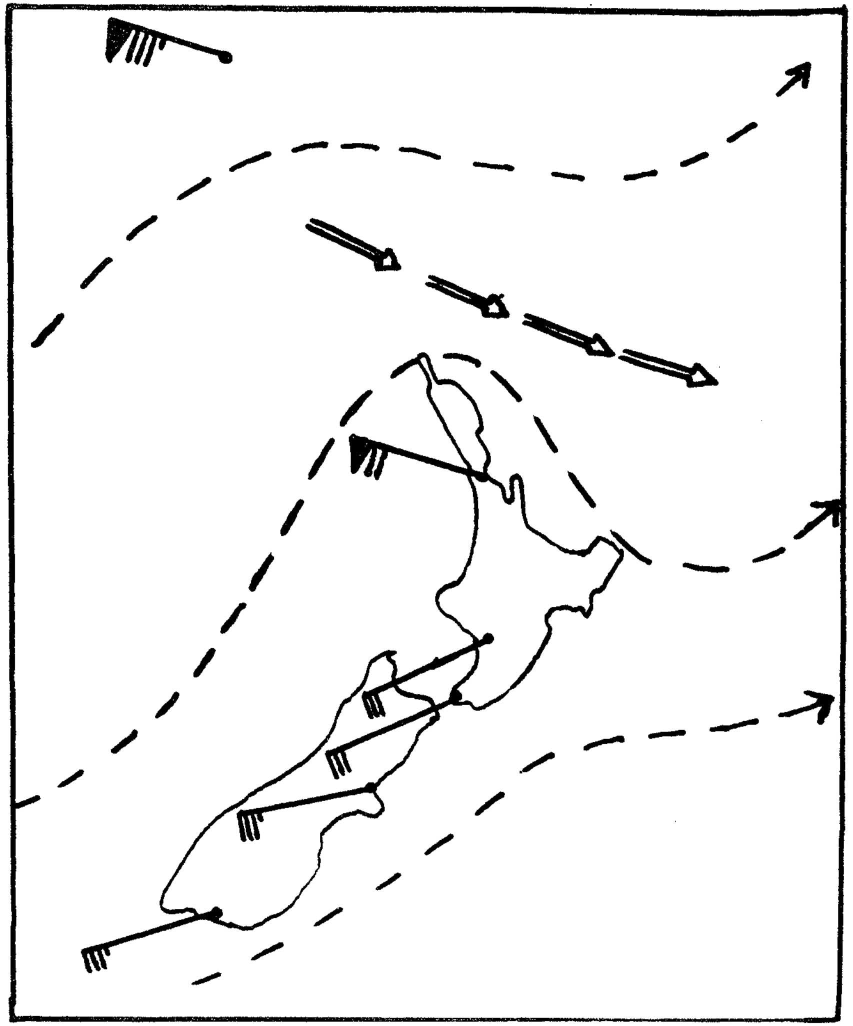

Fig.5 Upper flow 1200 N.Z.S.T. 8 January 1970.
Flow at 10,000ft (700mb) - - - →
Wind reports at 30,000ft (300mb): wind arrows
Estimated axis of jet stream ⟹⟹

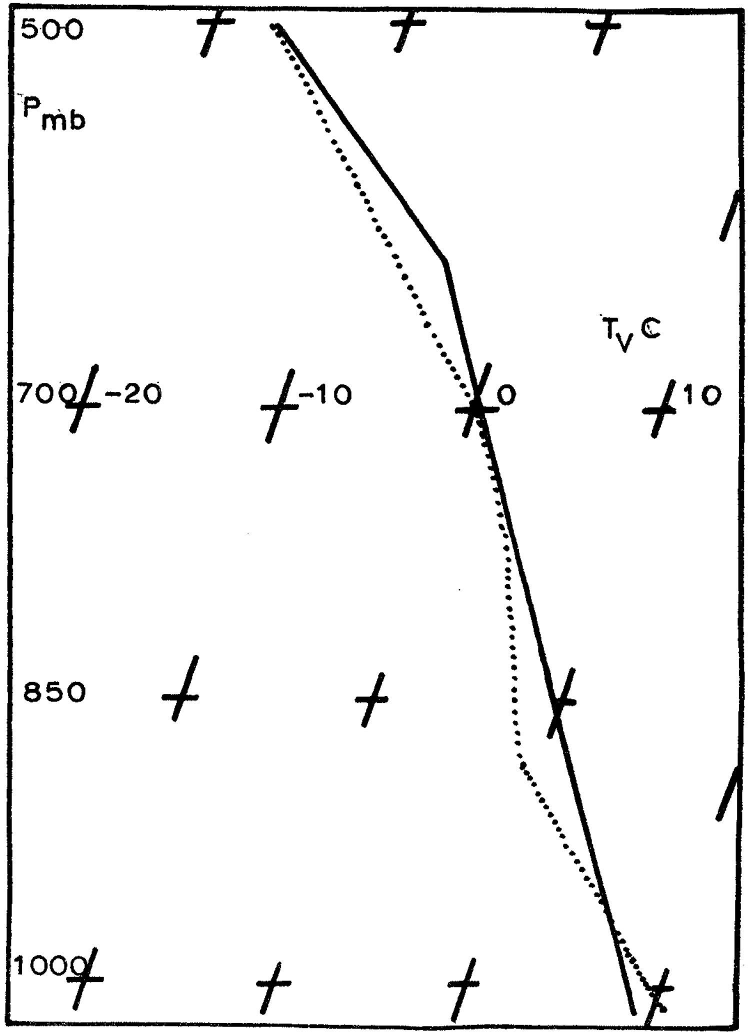

Fig.6 Soundings of virtual temperature in relation to pressure.
1200 N.Z.S.T. 8-1-70 ——— Trajectory A
2400 N.Z.S.T. 8-1-70 ········ Trajectory B

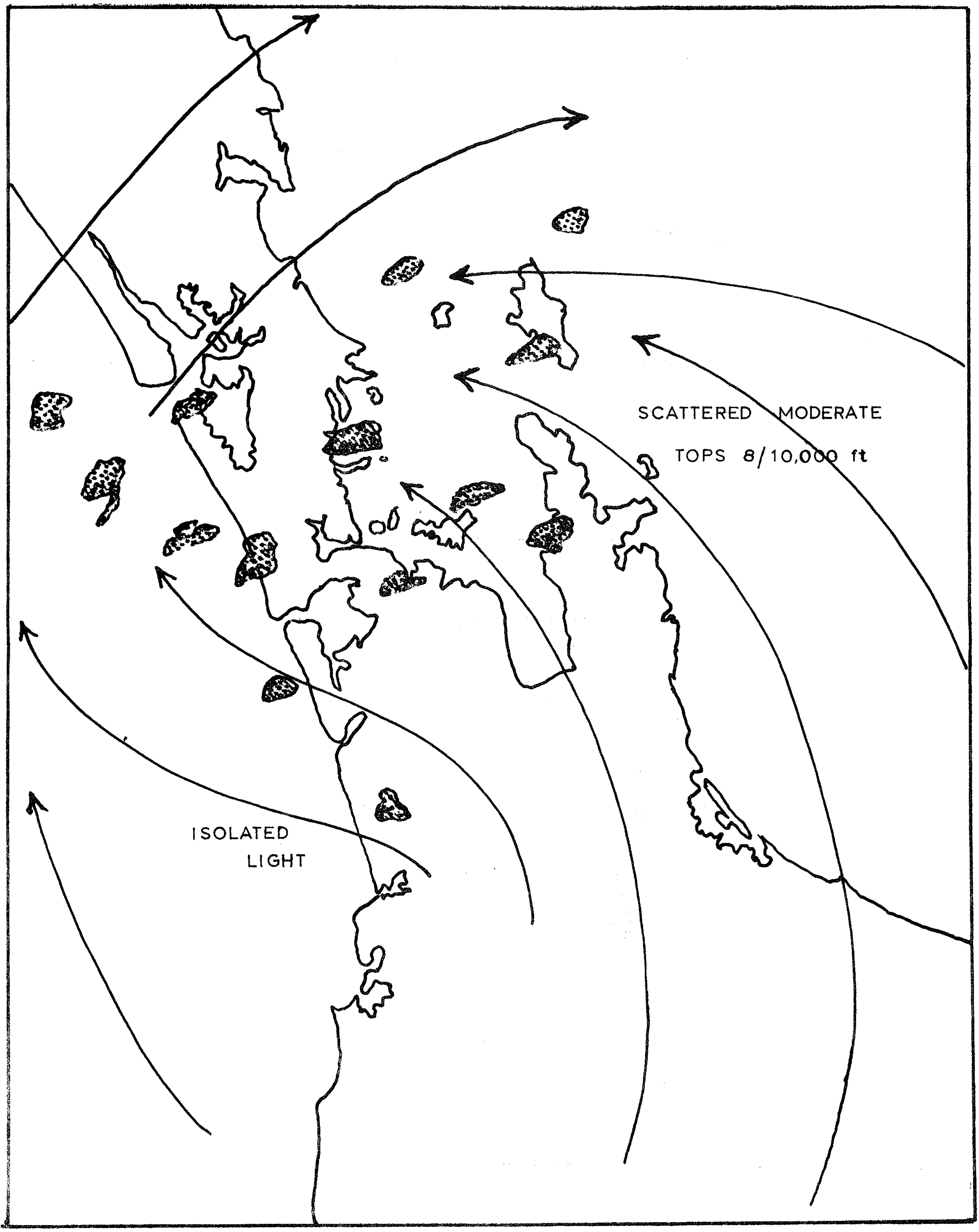

Fig. 7 Position of precipitation echoes at 0430 N.Z.S.T. 8 January 1970

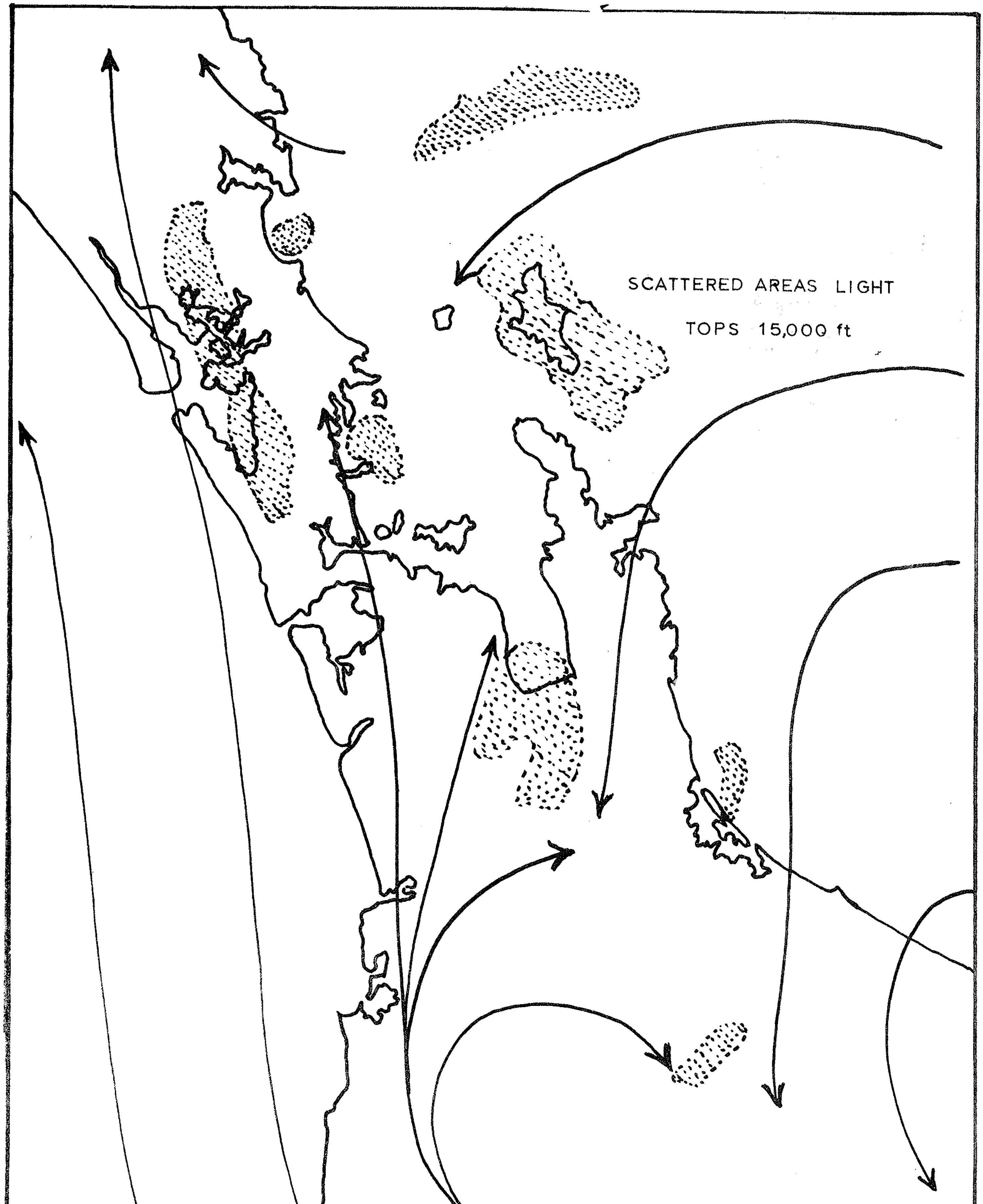

Fig. 8 Pattern of surface wind flow and radar-observed precipitation at 2230 N.Z.S.T. 8 January 1970.

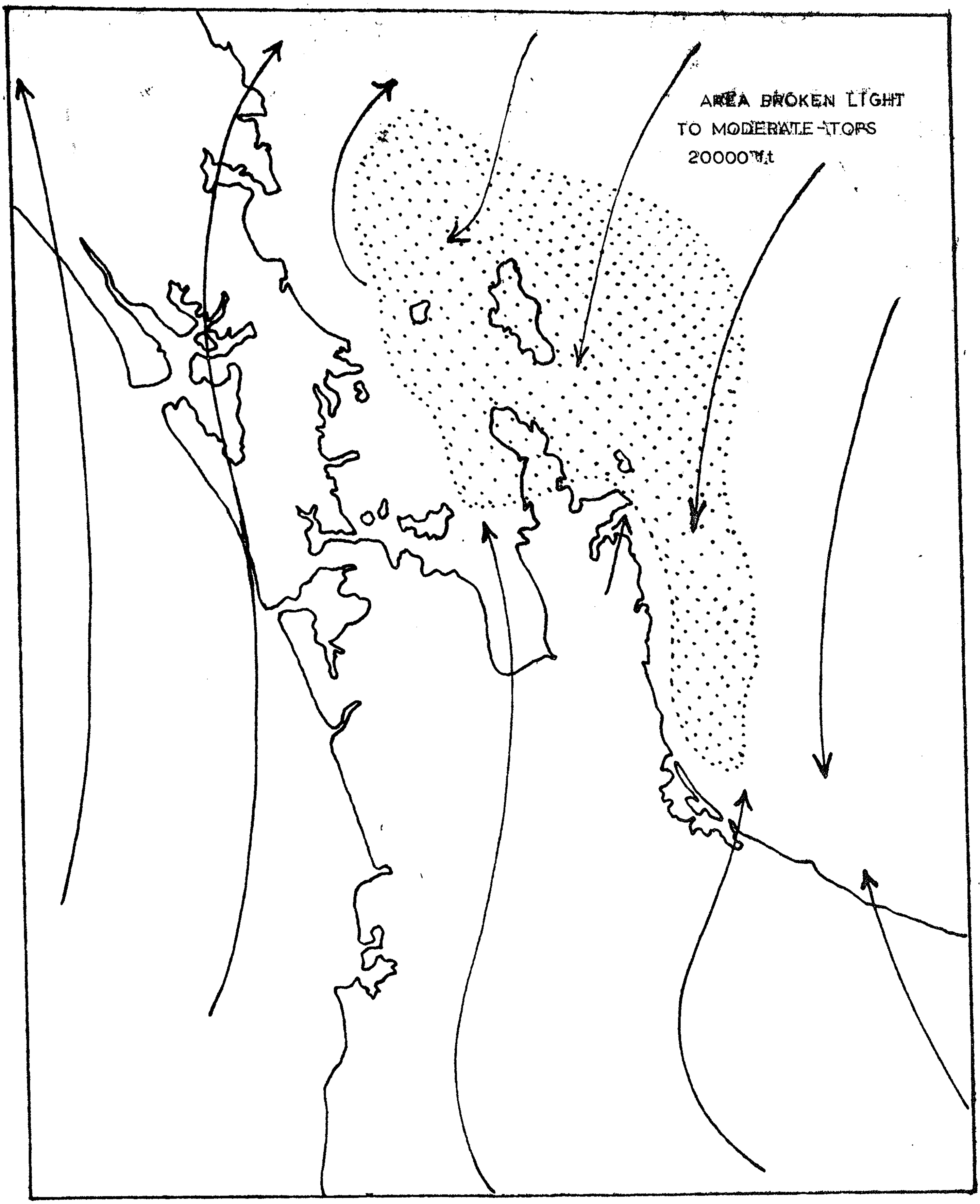

Fig. 9 Pattern of surface wind flow and radar-observed precipitation at 0630 N.Z.S.T. 9 January 1970.

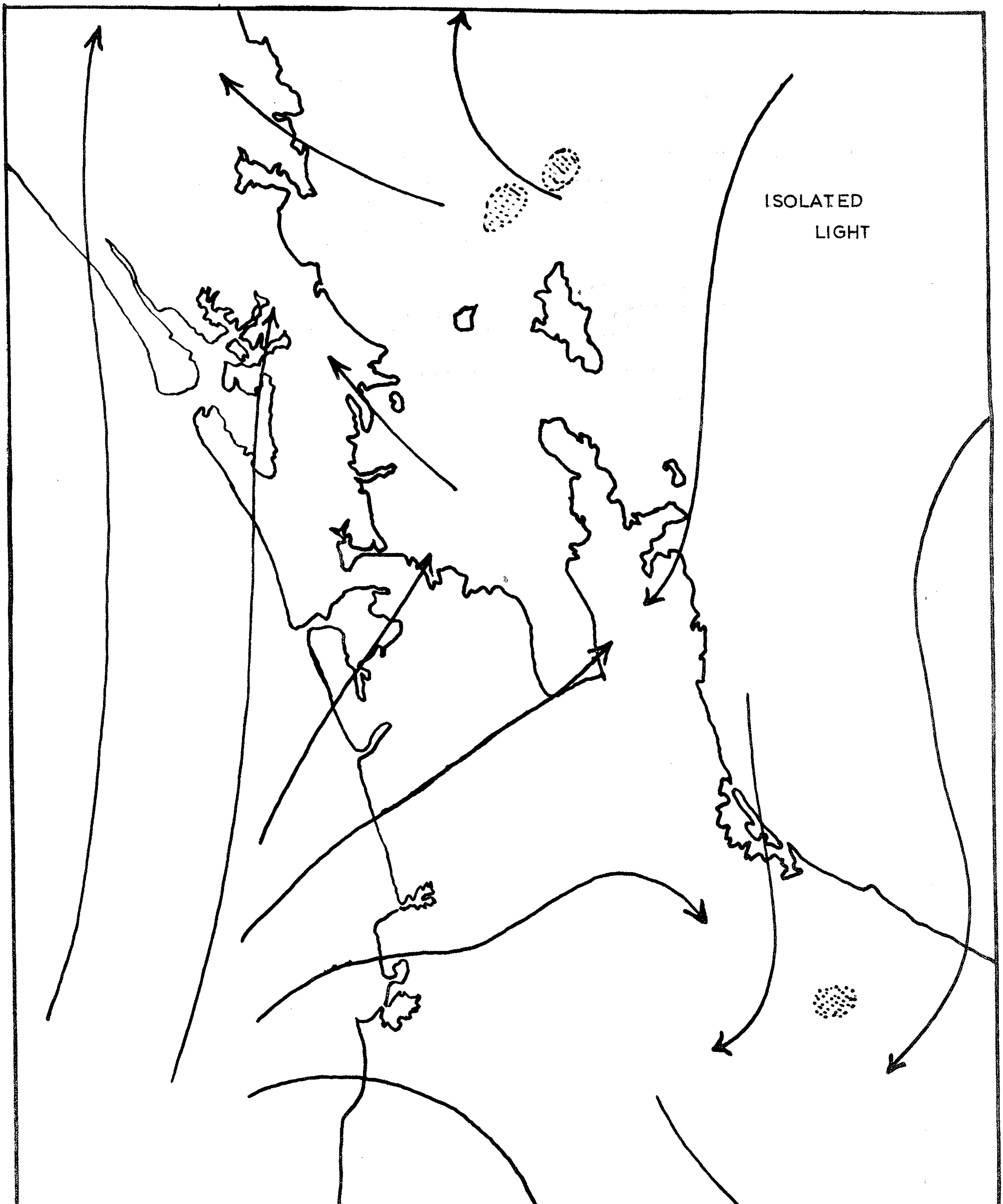

Fig. 10 Pattern of surface wind flow and radar-observed precipitation at 1430 N.Z.S.T. 9 January 1970.

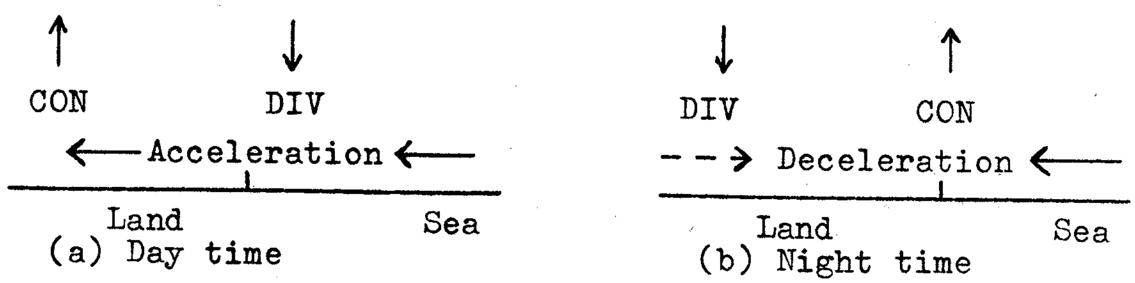

Fig. 11 Schematic coastal air-circulation pattern. Land breeze, usually weak, shown dotted.
CON = Horizontal velocity convergence
DIV = Horizontal velocity divergence
Resulting vertical components of motion indicated.