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LEE CYCLOGENESIS IN NEW ZEALAND — A PREDICTION SCHEME

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ABSTRACT

A scheme for the prediction of lee cyclogenesis over the South Island of New Zealand is presented.

The phenomenon of lee cyclogenesis becomes important when deep depressions impact on the Southern Alps. Under certain upper level conditions, deepening, (or accelerated deepening), occurs as the low redevelops to the east of the South Island, and there is a northward deflection of the track. A period of very strong winds can occasionally be produced.

It was found that the occurrence of a 500 hPa jet at right angles to the Alps was a sufficient condition for the phenomenon to occur. An examination of a number of cases when lee cyclogenesis was occurring produced a relationship between the mean sea level pressures at various points before and after the traverse.

INTRODUCTION

On the evening of 20th January, 1988, a short period of severe southwest gales caused considerable damage on Banks Peninsula and the Kaikoura coast. The winds were associated with a deep depression, which had undergone an unexpected northward deflection and accelerated deepening as it crossed the South Island (Pascoe et al., 1990). On 17th January, 1990, Canterbury was again struck unexpectedly by a short period of severe gales, this time from the northwest. A truck was blown off a bridge near Kaiapoi, and the driver was seriously injured. The severe gales were again caused by the northward deflection and accelerated deepening of a depression as it crossed the South Island.

It was apparent that lee cyclogenesis had occurred on these two occasions. The term 'lee cyclogenesis' covers a range of events, from the formation, in the lee of the mountains, of a new depression on a front, far removed from the front's parent depression, to a depression that has moved across the mountains, becoming deeper on the lee side than it was on the windward side. This paper is concerned with the latter type of phenomenon, and, in particular, those *deep* depressions which, in crossing the mountains, experience a northward track displacement along with a lowering of central pressure. This development causes much more intense pressure gradients to develop in places where they would not have been anticipated from pure extrapolation of the previous track of the depression. The aim of this paper is to predict the track and deepening of these depressions, so that the high winds which result from the strong pressure gradients can be forecast.

The NWP models currently in use in New Zealand have an insufficiently fine grid to effectively simulate the phenomenon of lee cyclogenesis. Thus an empirical approach to the problem, as described herein, is necessary.

REVIEW OF LITERATURE

Bjerknes and Holmboe (1944) found that when an upper baroclinic wave with a divergence field moves eastwards while a low-level trough exists over a mountain range, the strong descending motion on the lee slopes induces some horizontal convergence in the lee slopes of the air column, but usually not enough to prevent a fall of pressure at the lee surface. If the divergence field moving in over the lee side, and the orographic downward motion combine, there will be a strong pressure fall.

In some parts of the world, lee cyclogenesis exerts a major influence on the climate. In Asia, there is the Tibetan massif, roughly oval-shaped, with its main axis lying east to west. In some numerical simulations, Murakami and Nakamura (1983) found a sudden increase in gradient as a low crossed the area, thus duplicating the well-known 'cold surges' of that region. In Europe, there are the Alps, oriented east to west. Buzzi and Tibaldi (1976) studied a particular case of cyclogenesis on a front in the lee of the Alps, and found that it probably would have developed without their influence, but the Alps dictated the site of the development, and enhanced the rate of deepening.

In North America, the Rockies cause frequent lee cyclogenesis. This mountain range is oriented northwest-southeast, and is thus much more comparable to the Southern Alps of New Zealand, with pre-frontal flows being mostly at right angles to the range, and post-frontal flows often parallel to it. The Rockies are taller, wider, and longer than the Southern Alps, so that the effects of lee cyclogenesis are much enhanced. Newton (1956) found in a case study of lee cyclogenesis associated with the Rockies, that it occurred in an area where the region of strongest upward motion at 500 hPa (ie. directly beneath the jet stream) became super-imposed over the band of maximum descending motion at the surface. Achtor and Horn (1986) found that cyclogenesis in Colorado also occurred in conjunction with a jet, although in their study development usually occurred in the poleward exit region of the jet. Chung et al. (1976), in a climatological study, found that for the family of moderate to intense lee cyclones which had a lifetime of more than one day, there was always an associated cold trough or low, and a divergence field aloft. Chung and Reinelt (1973) examined 146 cases of lee cyclogenesis for possible association with the 500 hPa flow. They established the following criteria as describing conditions either favourable to, or observed at, the time of lee cyclogenesis associated with the Canadian Rocky Mountains:

(a) A diffluent 500 hPa contour pattern is present over any one or all of the three principal mountain systems.
(b) The flow pattern is normal to, or nearly normal to the ridge of any one or all of the three principal ranges.
(c) A jet stream or a core of relatively strong winds is crossing the mountains.
(d) The distance from the Continental Divide to the nearest upstream trough is large. i.e. 500 km or more.

In New Zealand, the only literature on the subject is a brief case study by Hutchings (1943), which describes the development of a lee cyclone on a front as it crossed the South Island. The discussion was limited to developments at sea level. Hutchings notes that this phenomenon is 'often observed'.

FORMULATION OF SOME FORECASTING RULES

The primary concern of this study is to predict the deflection and intensification of cyclones of moderate or strong intensity as they cross the South Island. Summarising and simplifying the overseas literature suggests that the following rules should provide some useful guidance:

1. Deflection and intensification should occur only if there is a 500 hPa jet crossing the South Island, normal, or nearly normal to the line of the Alps, *and* the 500 hPa trough is 500km or more to the west.
2. The new centre of the surface depression should form *beneath* the 500 hPa jet.

In an attempt to verify these rules, 48 cases of depressions crossing the main divide were studied, using 50 knots at 500 hPa and 125 knots at 250 hPa as threshold values for a jet. There were 13 cases where the criteria in (1) were satisfied. On all 13 occasions, the depression redeveloped in the lee of the main divide beneath the jet (as suggested by (2)), accompanied by some intensification. In two of the 13 cases, the depression lay beneath the jet prior to its passage across the main divide, and in these cases there was no deflection. There were several other cases where intensification occurred, but it may be possible to ascribe these intensifications to effects other than lee cyclogenesis. There were no other cases (outside the 13) where significant deflection occurred. The following was also noted with regard to these 13 cases:

(a) They took six to nine hours to cross the South Island.

(b) The central pressure on the eastern side was usually close to 4 hPa lower than it was on the western side.
(c) The pressure in the 'target area' (i.e. the point on the east coast towards which the cyclone had been moving before deflection) would fall, then rise, as the cyclone crossed the South Island. The pressure after the traverse had been completed was usually close to 1 hPa lower than its pressure immediately before the traverse.

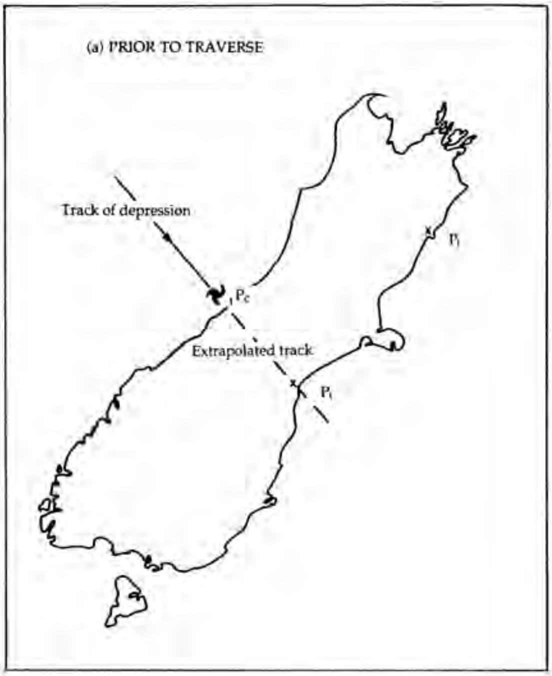
THE PREDICTION SCHEME, AND VERIFICATIONS

The scheme depends on correctly predicting the position of the 500 hPa jet throughout the period of lee cyclogenesis. The 250 hPa isotach field can be of use here, since there are numerous aircraft reports available for this level.

Pressures in the target area, (defined above) and the 'lee cyclone' area (the position on the east coast beneath the 500 hPa jet, where the depression is expected to lie immediately after traverse) are calculated as follows:

For pressure in target area:

$$P_{t+6} = P_t - 1 \text{ (hPa)}$$



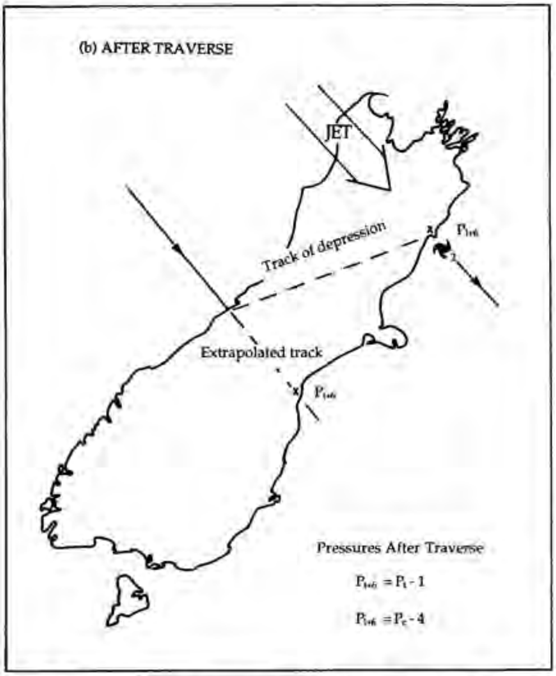


Fig. 1. Schematic diagrams of effects produced by lee cyclogenesis, showing pressures at crucial points (a) before and (b) after traverse of depression across Alps. The vortex symbol denotes positions of surface depression. Double arrow shows position of 500 hPa jet. Single arrow denotes direction of movement of depression.
P_t = Pressure in target area before traverse.
P_{t+6} = Pressure in target area after traverse.
P_l = Pressure in lee cyclone area before traverse.
P_{l+6} = Pressure in lee cyclone area after traverse.
P_c = Central pressure of depression before traverse.

where P_{t+6} is the target area pressure immediately after traverse i.e. 6 hours after the time t, and P_t is the target area pressure immediately before traverse.

For pressure in lee cyclone area:

$$P_{l+6} = P_c - 4 \text{ (hPa)}$$

where P_{l+6} is the pressure in the lee cyclone area immediately after traverse and P_c is the *central pressure* of the *depression* immediately before traverse.

The traverse is shown schematically in Fig. 1.

The pressures P_{t+6} and P_{l+6} become the most important points in an H+6 forecast chart.

Forecast pressures at some other places e.g. Hokitika, Wellington, are obtained by the usual principles. For example, if the pressure at Hokitika is falling at a certain rate as the depression approaches, then it should rise at the same rate as it moves away, *unless* the

southerly gradient in the rear of the depression is stronger/weaker than the northerly gradient ahead of it, in which case it will rise more/less quickly. At Wellington, the pattern is usually complicated by an associated front. The pressure at Wellington will usually fall rapidly ahead of the front. After the front passes, the pressure will usually continue falling, but at a slower rate, and will not begin to rise until the process of lee cyclogenesis has been completed.

***Example 1* 19 Jan 88 (Fig. 2)**

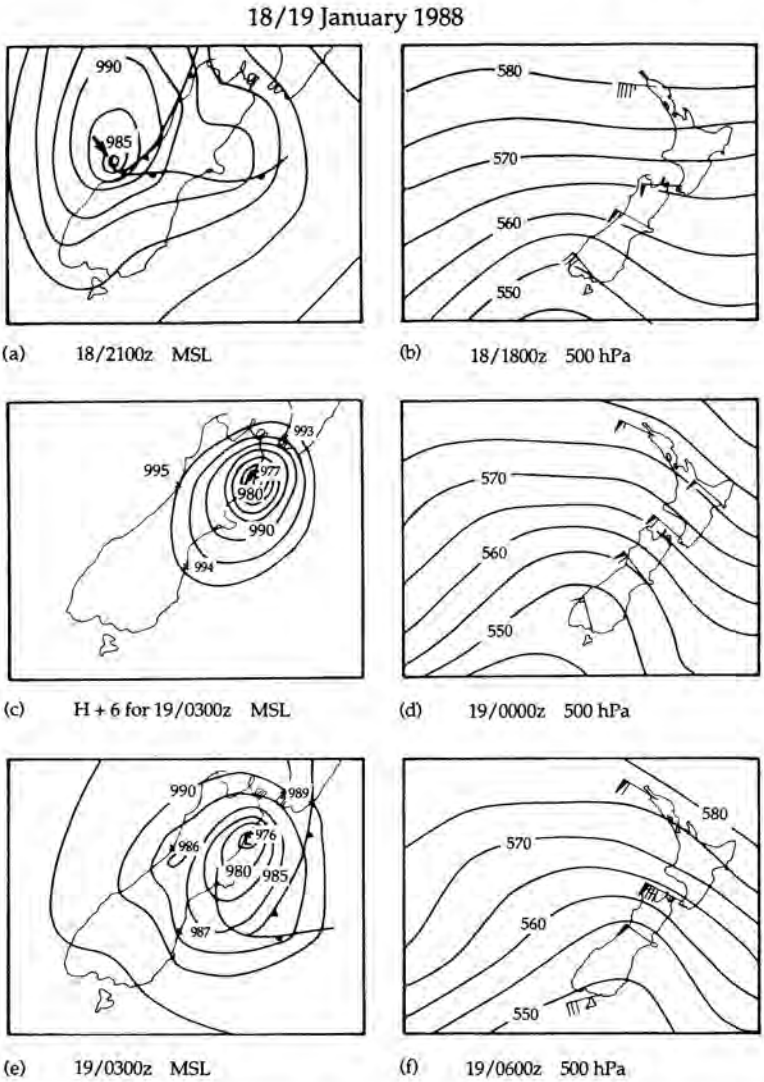


Fig. 2. For 18/19th January 1988.
(a) Mean sea level analysis for 18/2100 GMT. The arrow denotes direction of movement prior to traverse.
(b) 500 hPa analysis for 18/1800 GMT.
(c) 6 hr mean sea level forecast chart for 19/0300 GMT, produced using Prediction Scheme.
(d) 500 hPa analysis for 19/0000 GMT.
(e) Mean sea level analysis for 19/0300 GMT.
(f) 500 hPa analysis for 19/0600 GMT.

Jet over Kaikoura.

At 182100z: Low off West Coast with central pressure 981 hPa.
Pressure at target area (Timaru) — 995 hPa.
Pressure at lee cyclone area (Kaikoura) — 994 hPa.
Pressure at Hokitika — 989 hPa.
Pressure at Wellington — 1000 hPa.

Forecast for 190300z:
Target area (Timaru): 995 - 1 = 994 hPa.
Lee cyclone area (Kaikoura): 981 - 4 = 977 hPa.
Hokitika: 995 hPa.
Wellington: 993 hPa.

Note that the scheme predicts a pressure difference of 8 hPa between Kaikoura and Christchurch at 190300z, indicating the development of a strong south or southwest gradient. In actual fact, the pressure difference was 5 hPa at this time, but at 0600z, it had risen to 11 hpa.

17 January 1990

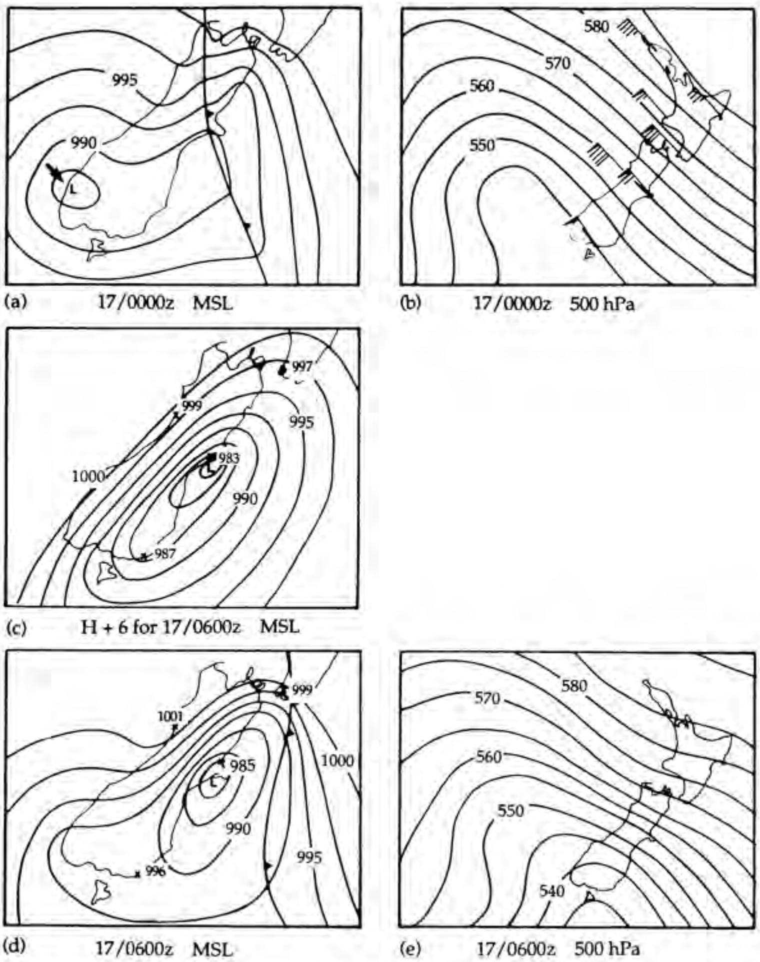


Fig. 3. For 17th January 1990.
(a) Mean sea level analysis for 17/0000 GMT. The arrow denotes direction of movement prior to traverse.
(b) 500 hPa analysis for 17/0000 GMT.
(c) 6 hr mean sea level forecast chart for 17/0600 GMT, produced using Prediction Scheme.
(d) Mean sea level analysis for 17/0600 GMT.
(e) 500 hPa analysis for 17/0600 GMT.

Example 2 17 Jan 90 (Fig. 3)

Jet over Ashburton.

At 170000z: Low off West Coast with central pressure 987 hPa.
Pressure at target area (Nugget Point) — 988 hPa.
Pressure at lee cyclone area (Ashburton) — 992 hPa.
Pressure at Hokitika — 996 hPa.
Pressure at Wellington — 1000 hPa.

Forecast for 170600z:
Target area (Nugget Point): 988 - 1 = 987 hPa.
Lee cyclone area (Ashburton): 987 - 4 = 983 hPa.
Hokitika: 999 hPa.
Wellington: 997 hPa.

Note that the scheme predicts 15 hPa between Christchurch and Hokitika, as against the observed 15.5 hPa. Thus, a very strong northwesterly is produced in Canterbury, in contrast to the very strong southerly of the previous sample.

For the 13 cases of lee cyclogenesis found, the following verifications were obtained:

Pressure change in target area (hPa)

Case Number	4	7	8	10	19	28	34	35	Jan 88	Jan 90	1A	44	45
Forecast	-5	-6	-1	-1	-1	+1	-1	-1	-1	-1	-1	-1	-7
Actual	-3	-8	+2	-1	+1	+4	0	-4	-9	+3	-2	-4	-6

Note 1. For cases 4, 7 and 45, the target area coincided with the lee cyclone area. In these cases, the forecast pressure was computed to be the average of those obtained by the two prediction methods.

Note 2. In case 28, the forecast values were adjusted because the method predicted a lower pressure in the target area than that predicted in the lee cyclone area.

Note 3. In Jan 88, the pressure in the target area rose 7 hPa in the 3 hours following the verification time.

Pressure change in lee cyclone area (hPa)

Case Number	4	7	8	10	19	28	34	35	Jan 88	Jan 90	1A	44	45
Forecast	-5	-6	-5	-6	-6	-5	-1	-10	-17	-9	-16	-16	-7
Actual	-3	-8	-7	-2	-6	-4	0	-8	-18	-9	-8	-12	-6

Note 4. In case 10, the jet was fairly weak.
Note 5. In case 1A, the lee cyclone area was Cape Palliser, in the North Island.
Note 6. Note the large changes well predicted in January 1988 and January 1990.

SUMMARY AND CONCLUSIONS

The results suggest that when a depression crosses the Southern Alps, in most cases, noticeable lee cyclogenesis will not occur. However, if there is a jet over the South Island, aligned normally, or nearly normally, to the Alps, then there will be a deepening (or accelerated deepening), and usually a northward deflection, of the depression as it crosses the island. The depression will redevelop on the east coast beneath the 500 hPa jet. If the depression is deep, then there may be some strong gradients produced for a short time, and it will be worthwhile to draw a forecast chart for the time 6 hours after landfall on the west coast. A useful prognosis can be obtained by using the forecast rules outlined previously in the text.

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