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Department of Geography, University of Canterbury, New Zealand

Dynamic and Thermal Effects on Surface Airflow Associated with Southerly Changes over the South Island, New Zealand

A. P. Sturman

With 8 Figures

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Summary

The Southerly Change Experiment (SOUCHEX) was conducted to examine the influence of the New Zealand Southern Alps on the structure and evolution of cold fronts, locally called southerly changes, as they travel up the east coast. The extensive data obtained by the augmented surface weather station network is used to examine in detail the mesoscale wind field associated with the events observed during the experiment. A comparison of the wind fields observed during the different events illustrates the influence of local dynamic and thermal factors. In particular, lee trough-induced northeasterlies and thermally developed diurnal wind systems are seen to interact with the wind field created by the passage of the front over the Southern Alps.

It is apparent that the wind field associated with southerly changes responds to a variety of factors as the cold fronts propagate northwards. For example, there is a tendency for the flow to turn onshore producing a southeast wind during daytime over the Canterbury Plains south of Banks Peninsula probably due to diabatic heating of the mountains and plains. This onshore flow is in direct opposition to pre-frontal foehn northwesterly flow which often continues in the mountain regions and aloft after the front has moved up the coast. The interaction of these air masses over Canterbury creates difficulties for local forecasting. Also, the nocturnal passage of a southerly change is often difficult to detect in surface anemograph traces because of the decoupling of the boundary layer air from that above, producing low level drainage flow over the Canterbury Plains. The overall effect is to create a complex mesoscale wind field resulting from interaction of cold fronts with regional orographic and thermal influences.

1. Introduction

The effect of the Southern Alps of New Zealand on the nature of cold front passage over the east coast was the focus of the SOUCHEX (The Southerly Change Experiment) field programme which was conducted in 1988 (Steiner et al., 1987). Two recent papers have concentrated on synoptic characteristics (Smith et al., 1991) and the mesoscale wind field (Sturman et al., 1990) respectively. The present paper uses the extensive data obtained by the augmented surface weather station network, to examine in more detail the mesoscale wind field associated with the events observed during the experiment. The emphasis of this paper is on the variability in the surface wind field observed during different southerly change events, due to interaction with dynamic and thermal effects of the earth's surface.

As indicated by McKendry et al. (1986), there are several interacting influences on low level airflow in the Caterbury region. These include the dynamic orographic effect of the Southern Alps which often leads to local perturbations in the pressure field, particularly the generation of a lee trough to the east of the mountains. The northeasterly wind observed in this area is largely a result of this localised pressure disturbance. There is also the thermal effect created by both the temperature difference between land and sea and the heating and cooling of hill slopes. This leads to the development of local and regional influences on airflow, particularly land and sea breezes. It is evident that as cold fronts move up the east coast of the South Island the lower level wind field will be affected to some degree by these thermal and dynamic effects.

Fig. 1. Location of surface observation stations used in this study. The letters indicate sites mentioned in the text: **A** – Alexandra, **C** – Culverden, **Ch** – Christchurch, **D** – Dunedin, **K** – Kaikoura, **T** – Timaru and **W** – Winchmore

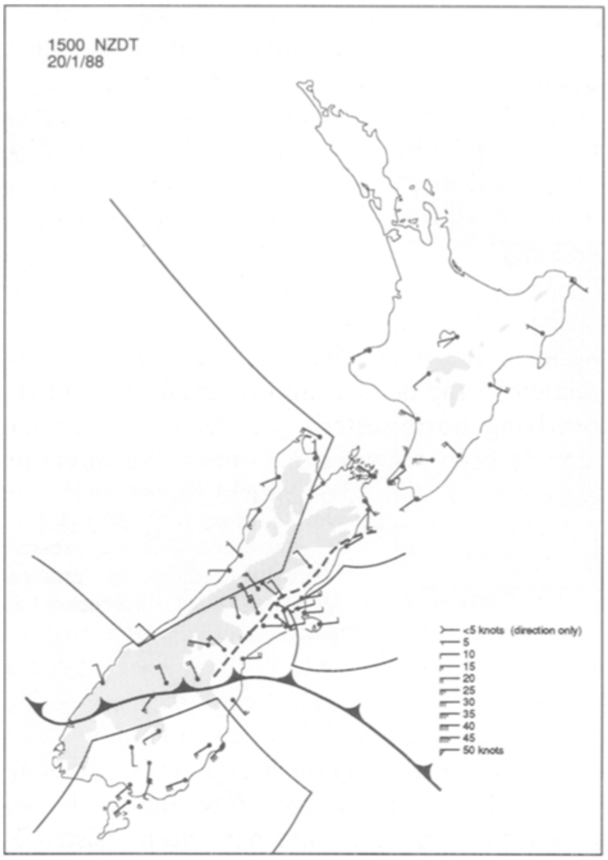
The four principal events observed during the field experiment are described in reasonable detail in Smith et al. (1991), while Sturman et al. (1990) examined the movement of the four cold fronts along the coast using isochrones and the mesoscale wind field associated with the first of these southerly changes. This paper examines in rather more detail the variation in the surface wind field experienced during the subsequent three events, and attempts to explain the differences observed. It should be noted that only summer time southerly changes were studied.

The meteorological stations from which wind information was used are indicated in Fig. 1, although data were not always available for all stations for each event.

2. The Surface Wind Fields

The first southerly change was noteable for the occurrence of two distinct onsets of southerly airflow. These were separated by a disturbance in both the wind and pressure fields at the surface as discussed in Sturman et al. (1990) and Smith et al. (1991). During this event the surface wind field on the Canterbury Plains ahead of the front was dominated by a warm, foehn northwesterly flow. This was replaced by a south to southeast wind, which backed to become northeasterly before returning to a southeasterly with the second change. The pressure rose during the period between the wind changes, and seemed to be related to the descent and intensification of the overlying northwesterly jet. As this event has already been discussed in some detail in earlier papers it will not be examined further here, but readers are referred to Sturman et al. (1990) and Smith et al. (1991) for details.

The second event of 20 and 21 January 1988 was also quite complex, as the northwesterly foehn wind did not develop at the surface ahead of the front on the Canterbury Plains (Fig. 2a). Instead, the coastal plains were dominated by a 1 km layer of easterly onshore flow (Smith et al., 1991). This layer was probably due to the sea breeze effect, but may also have been assisted by orographic perturbation of the local pressure field as described by McKendry et al. (1986). This conclusion is reinforced by examining pressure differences along the east coast. Figure 3 shows that a gradient existed from Kaikoura towards Timaru (i.e. towards the southwest) from 0300 to 1500 NZDT. Analysis by McKendry et al. (1986) indicates that the magnitude of the gradient measured here is quite sufficient to be associated with development of a northeasterly flow along the coast. The reversal of gradient between the pair of sites occurs with the passage of the cold front, as expected around 1600 NZDT. It is interesting to note that the gradient is particularly strong between 1200 and 1500 NZDT, the time of maximum solar heating immediately preceeding the front. Analysis of the temperature records show that several inland sites experienced temperatures up to 20 °C (Winchmore) while sea surface temperatures were of the order of 13 to 14 °C during the experimental period, providing a sufficient sea breeze mechanism. Both the northwesterly and easterly air currents disappeared at the surface from the Canterbury Plains with the onset of the southerly change (Fig. 2b). By midnight the southerly flow had weakened, but can be seen penetrating into the mountain valleys. A light



a

c

b

Fig. 2. The surface wind field associated with event 2, (a) 1500 NZDT 20 January, (b) 0000 NZDT 21 January and (c) 0300 NZDT 21 January 1988. (NZDT = New Zealand Daylight-saving Time)

westerly flow had also started to develop on the plains inland from Banks Peninsula. This cold air drainage became more widespread on the coastal plains during the night, as southerly flow associated with the front pushed onto the North Island (Fig. 2c). This event shows that the surface wind field during the passage of the cold front is significantly modified by the diurnal heating and cooling cycle as well as pre-frontal deformation of the pressure field.

Events 3 and 5 were similar to each other in some respects, particularly in the change from northwest to southerly airflow with passage of the front (Figs. 4 and 5). However, event 3 on 26 and 27 January was only weakly reflected in the surface wind field, probably partly due to the fact that it occurred overnight when there was no diabatic heating. The reduced temperature change with passage of the front is illustrated by the minor drop soon after 0000 NZDT in Fig. 6.

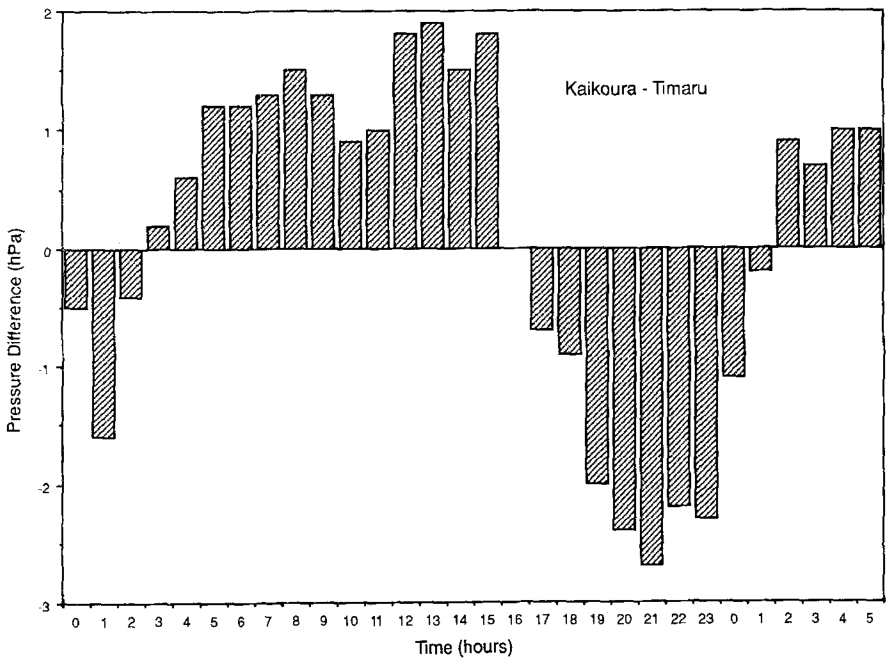
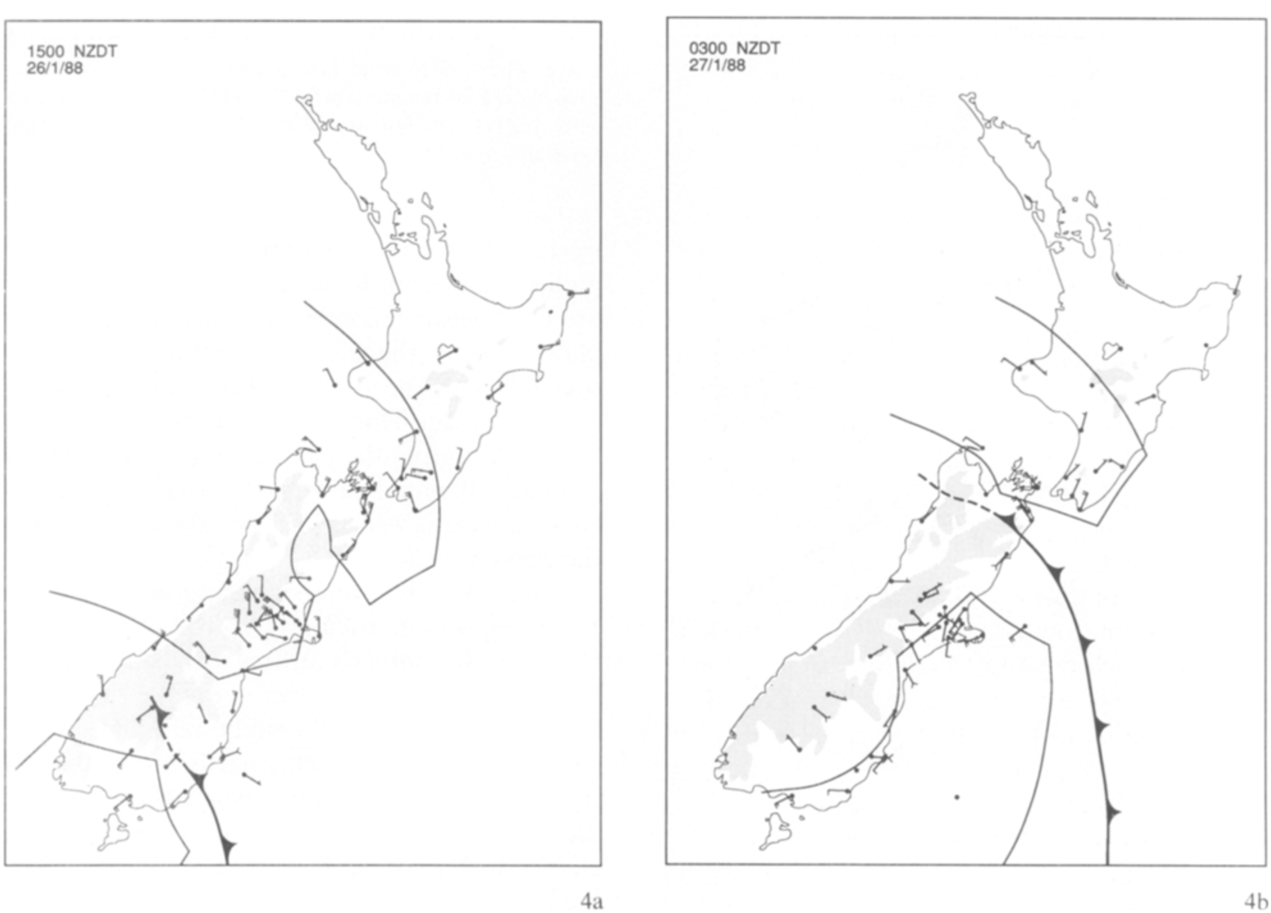


Fig. 3. Pressure differences between Kaikoura and Timaru for 20–21 January 1988 (see Fig. 1 for site locations). Positive pressure differences indicate a gradient operating from northeast to southwest



c

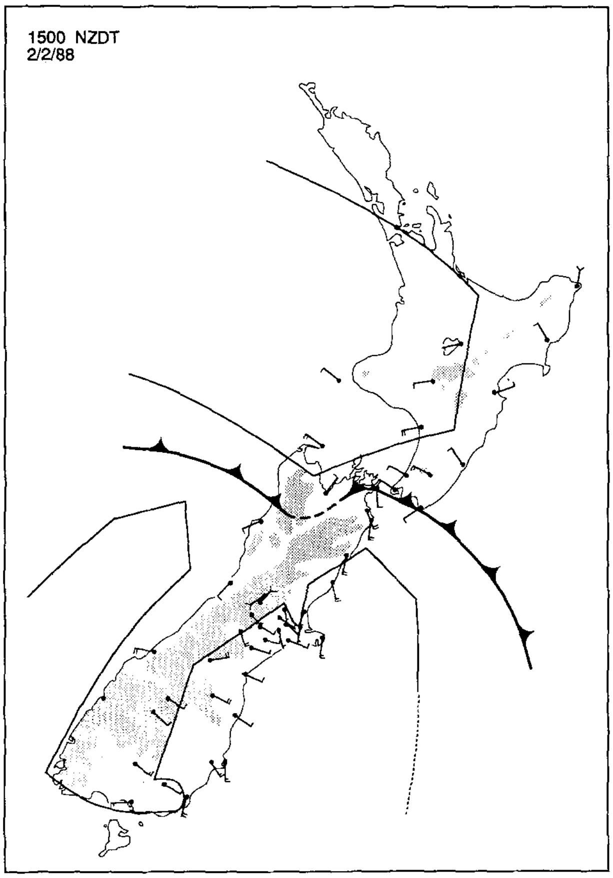
Fig. 4. The surface wind field associated with event 3, (a) 1500 NZDT 26 January, (b) 0300 NZDT 27 January, (c) 1200 NZDT 27 January 1988

The drop in temperature decreases in magnitude as the front moves northward, as it arrived at each site progressively later into the night. Thirty kilometers north of Banks Peninsula it is no longer apparent, while 70 km further still at Culverden there appears to be a slight jump in temperature perhaps due to downmixing of air by the front into a well established nocturnal boundary layer. By 1200 on 27 January southerly airflow was poorly organised at the surface, with some evidence of backing of the wind on the plains inland and southwest of Banks Peninsula (Fig. 4c). This onshore flow is likely to be in response to daytime development of a sea breeze component, as evidenced by warm temperatures at Winchmore (21 °C) and Culverden (26 °C). Similar light onshore flow was observed along the east coast of the North Island at this time (Fig. 4c).

The surface wind change associated with the early morning event of 2 February was slightly clearer than event 3 in spite of the absence of

5a

5b



c

Fig. 5. The surface wind field associated with event 5, (a) 0300 NZDT, (b) 0900 NZDT, (c) 1500 NZDT 2 February 1988

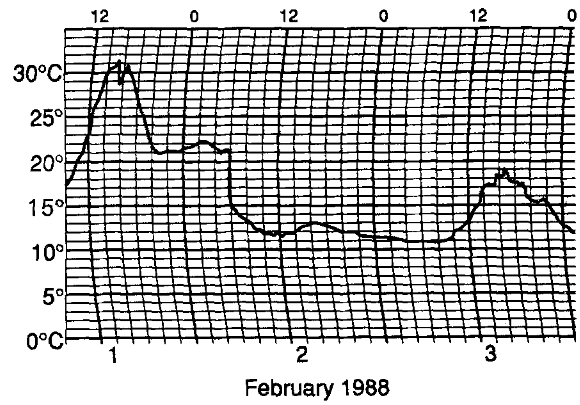


Fig. 7. Temperature record for Winchmore 1–3 February 1988 (see Fig. 1 for site location)

diabatic heating, but it lacked the intensity of the first event of 14 January (Fig. 5). However, subsequent daytime development of onshore airflow behind the cold front is more clearly evident (Figs. 5b and c). The southerly flow had a clear onshore component over much of the coastal region around and south of Banks Peninsula by 0900 NZDT (Fig. 5b). By 1500 NZDT, onshore flow existed along the whole length of the east coast of the South Island, and extended well inland into the mountain valleys. However, although a thermal mechanism is a possibility, the southeast flow at inland sites would also be

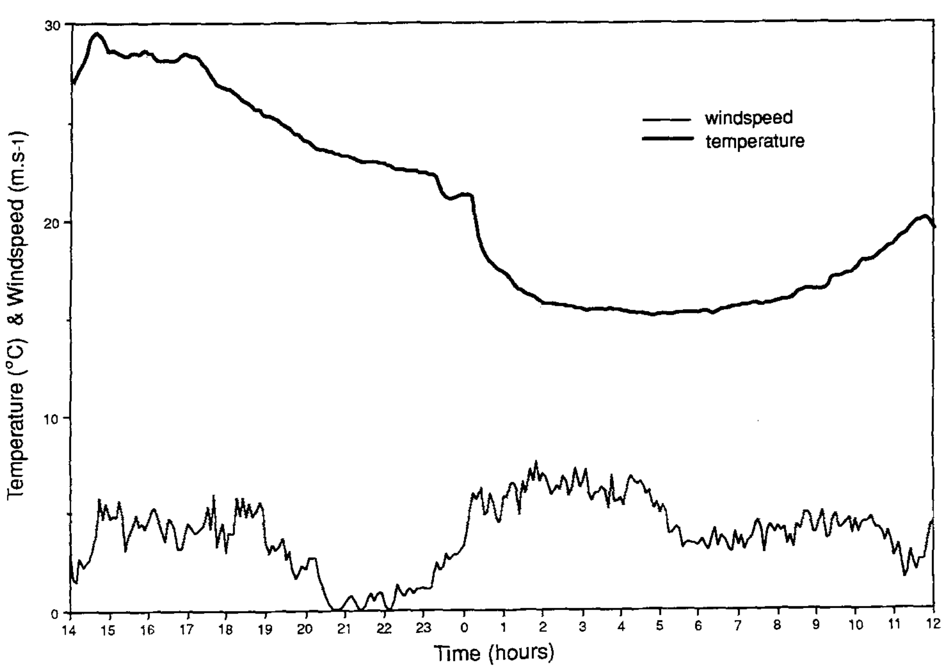


Fig. 6. Temperature and wind speed measurements at the University of Canterbury, Christchurch during 26 and 27 January 1988 (see Fig. 1 for site location)

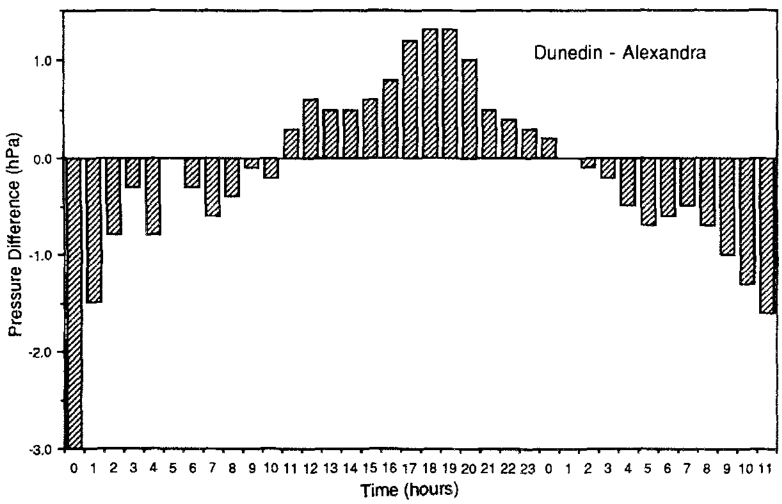


Fig. 8. Pressure differences between Dunedin and Alexandra for 2–3 February 1988 (see Fig. 1 for site locations). Positive values represent an onshore gradient

influenced by channelling within the mountain valleys. Examination of inland temperatures indicates that a sea breeze component was unlikely as the normal daytime temperature peak was almost entirely eliminated from the temperature traces at most sites and maximum temperatures remained around 13 °C (Fig. 7). An alternative explanation could be slope heating in the mountain region producing a sufficient horizontal thermal contrast for such a component to develop. However, there are insufficient data to test this hypothesis. Examination of pressure data revealed that a local onshore gradient developed several hours after the passage of the front (Fig. 8). The reasons for this can only be speculated, but appear to be dynamic in origin due to interaction of the postfrontal air mass with Southern Alps.

3. Discussion

The passage of cold fronts over a mountainous island, such as the South Island of New Zealand, does not produce a simple effect on observed surface airflow. Instead, it produces a complex range of surface wind fields due to the interaction of the synoptically developed air masses with the underlying surface. The main processes involved can be loosely divided into thermal and dynamic effects. The dynamic effects include surface friction and localised channelling of airflow, as well as the broader development of regional pressure field perturbations which may lead to airflow modification. The lee trough developed northeasterly wind is an example of the latter effect (Mckendry et al., 1987). The thermal effect is a function of the temperature difference between land and sea, as well as slope heating. Both of these factors are known to strongly influence surface airflow over the South Island (Sturman and Tyson, 1981; McKendry et al., 1986, 1987, 1988a, b). The results presented here support Ridley's (1990) analysis of earlier southerly changes which concluded that, although the synoptic environment provides the overall control of wind and pressure fields, such mesoscale effects are locally important. In particular, there is evidence that diabatic heating often augments the orographic trough ahead of the front, by providing localised pressure gradients to which the wind field responds. The post frontal air mass may also be similarly affected by such heating, as shown here, by causing the surface wind to back. The interaction of the orographic dynamic effects with those of diabatic heating controls the ultimate character of the surface wind field during a southerly change. The greatest effects are therefore observed during the middle of the day along the eastern side of the South Island, immediately to the lee of the Southern Alps. Nocturnal cooling also complicates the airflow pattern by allowing the surface skin of cold air to become decoupled from the overlying flow. This is clearly a very localised effect, dominated by topography.

As a cold front moves across the Southern Alps it produces a low level surge of cold air which propagates up the east coast. As seen here and in earlier papers (Sturman et al., 1990; Smith et al., 1991; Ridley 1990), this cold air interacts with the pre-existing northwesterly wind and its associated lee trough. The northwesterly often continues aloft and occasionally in the central parts of the mountains. It is also obvious from the results presented here that the northward moving cold air interacts with the ground surface to produce quite complex mesoscale wind fields. Time of day clearly has an important influence on local airflow during the passage of a cold front because of the role of diabatic heating and cooling, but so too does the role of the pre-frontal lee trough.

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Author's address: Dr. A. P. Sturman, Department of Geography, University of Canterbury, Christchurch 1, New Zealand.