Flow behaviour in a trough blowout. Tangimoana, New Zealand

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Wind Flow and Topographic Steering within a Trough Blowout

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ABSTRACT

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This paper examines the behaviour of wind flow within a trough blowout on the Manawatu coastline, lower west coast, North Island, New Zealand. The trough blowout is 40 metres long, 20 metres wide and 7-8 metres deep. Virtually any wind flow approaching the blowout from a seaward, alongshore or slightly offshore direction in an arc of at least 200 degrees to the entrance orientation will be directed into the blowout. This happens for a number of reasons including (i) the relatively deep trough topography is an area of intense localised low pressure and winds are "sucked" into the blowout; (ii) topographic steering by the blowout erosional walls; (iii) local flow separation over the blowout wall crests and within the blowout during alongshore and offshore winds, and (iv) re-direction/deflection of low to moderate obliquity approach flows to seawards and over the foredune. This research indicates that winds from a wide range of approach directions will influence blowout flow, sand transport, erosion and deposition patterns, and evolution. It cannot be assumed that only "onshore" winds will transport sediment up a blowout. The implications for routine determination of sand transport by remote sensing in blowouts are significant.

ADDITIONAL INDEX WORDS: *Sand dunes, New Zealand.*

INTRODUCTION

Many blowouts can be classified as either a saucer or trough blowout (HESP and HYDE, 1996). These two blowout types are present on the Manawatu coast of the lower North Island of New Zealand. Trough blowouts are most common and regularly dissect a highly erosional foredune.

A trough blowout typically has an elongate, relatively deep, narrow shape. The deflation basin and floor is relatively deeper than in a saucer blowout, and the lateral erosional walls are longer and steeper. The depositional lobe of most trough blowouts is also larger and longer than saucer blowouts, and has a steep landward (or slip) face (CARTER *et al.*, 1990; HESP and HYDE, 1996).

In the last few years three major studies (GARES and NORDSTROM, 1995; HESP and HYDE, 1996; FRASER *et al.*, 1998) have been published regarding flow dynamics within coastal blowouts. HESP and HYDE (1996) conducted one of the first quantitative studies on flow dynamics within a trough blowout, examining wind flow under varying wind approach and speed/velocity conditions. A generalised flow model was produced for a direct normal approach wind. A pronounced jet formed up the blowout as flow accelerated, and corkscrew motion was common. These authors suggested that topographic steering of windflow within a trough blowout was very common and was enhanced as winds approached the blowout more obliquely.

FRASER *et al.* (1998) examined wind flow patterns under different wind directions in a blowout on the south shore of Lake Michigan. They found that wind flow in the blowout during north-east winds was relatively parallel with the blowout axis. Flow separated as it entered the blowout and a helical flow formed. A zone of stagnation developed up the depositional lobe and the boundary layer redeveloped at the depositional lobe crest. Wind flow during an oblique approach wind from the north-west entered the blowout over the western wall and flow separation occurred. A helical flow cell developed on the deflation floor and flow compression occurred as the wind traveled up and over the eastern wall.

HESP and HYDE (1996) found that a wind approaching a trough blowout obliquely to the central axis of the blowout was markedly steered within the blowout chiefly by the blowout walls. However, they only examined or viewed two situations where the flow approaching the blowout was somewhat oblique. The limited number of studies conducted means that it is unknown if the flow patterns described above, and, in particular, the nature of topographic steering of flow and its implications for blowout evolution are typical for trough blowouts.

Thus, flow behaviour has been examined in a trough blowout under as wide a range of wind approach directions as possible. The blowout examined was located near Tangimoana on the south-west coast of New Zealand's North Island, approximately 40 kilometres west of Palmerston North (Figure 1). This coast is a high energy windy environment with the prevailing wind approaching from the north-west. The surfzone-beach is a low to moderate energy dissipative, three bar, meso-tidal system and accreting around 0.5 metres per year.

Figure 1. The trough blowout viewed from the entrance (with driftwood exposed by deflation) up the deflation basin to the upwind slope of the depositional lobe.

Methodology

Three methods to determine flow directions within the blowout have been used; one, compass measurements of sand ripple orientations, and two, compass measurements of small wind vanes placed at various locations near the bed throughout the blowout during sand transport events. Visual and video observations of small, coloured smoke bombs were made to record three dimensional flow behaviour in the blowout. Offshore, onshore and alongshore winds were monitored and four typical examples of these flow conditions are outlined below.

THE BLOWOUT

The blowout selected for this study is characteristic of those found in this region (Figure 1). It is a relatively small trough blowout; 40 metres long, 20 metres wide and 7-8 metres deep (maximum). The northern erosional wall is characterised by an avalanche slope in summer and little vegetation. In winter this northern wall steepens to an angle of 60 to 70 degrees as it is virtually permanently in shade and moisture levels are relatively high. The southern erosional wall has a higher vegetation cover, receives solar radiation year-round, and has both depositional and erosional slope segments with some minor avalanche slopes. The depositional lobe is orientated NW-SE, is approximately 30 metres long and is relatively well vegetated on the crest and downwind slope. There is a small erosional lobe formed within a clump of native Pingao *(Desmoschoenus spiralis)* which extends from the base of the seaward northern wall some distance across the blowout entrance (Figure 1).

FLOW BEHAVIOUR WITHIN THE BLOWOUT

Topographic steering and re-direction of wind flow is considerable within the blowout, and varies markedly under different wind conditions.

Almost normal approach flow up the blowout (WSW wind)

Figure 2 displays the pattern of flow within the blowout during a relatively direct, normal approach wind from a west-south-west direction. In this, and all subsequent figures, the large arrow indicates the regional approach wind and the small arrows the flow directions within the blowout. Ripples immediately seaward of the blowout entrance are orientated towards the southeast compared to the prevailing (large arrow) south-west wind (smaller arrows). As flow enters the blowout, the surface flow is steered more towards the northeast on the steep northern wall, being directed along and around the erosional walls and up the axis of the deflation basin. Overall the flow upwind of the foredune and blowout is deflected to the southeast by the foredune, and there is some minor steering of flow within the blowout.

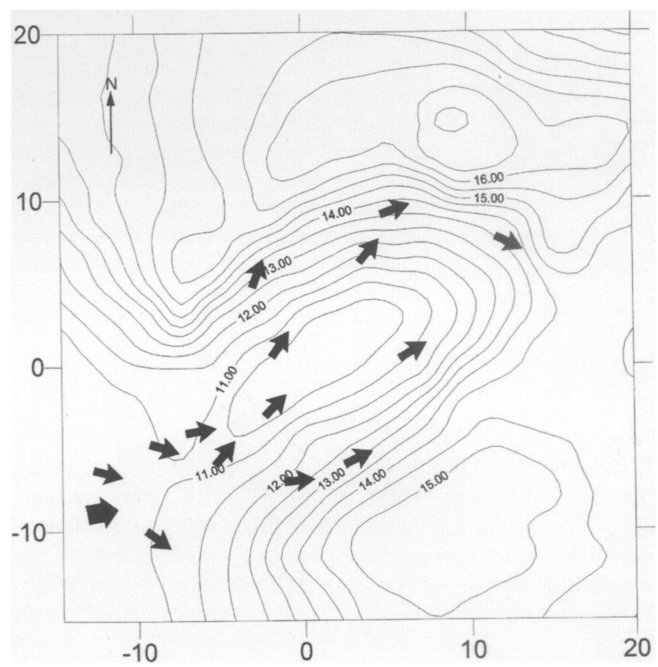

Figure 2. Pattern of surface windflow within the blowout (represented as a contour map – in metres) during a nearly normal up-axis approach wind from the south-west. The approach wind is indicated by the large seaward arrow, the flow directions within the blowout by the small arrows.

Oblique approach flow up the blowout (W to WNW wind)

In figure 3 the wind is approaching the blowout entrance obliquely from a west to west-north-west direction. The wind flow and sand transport patterns are evident from the contrasting mixed titanomagnetite, quartz and pumice sands. As figure 3 and the arrows in figure 4 indicate, there is significant steering of flow before it reaches the blowout, flow compression, acceleration and marked steering as the wind approaches the blowout entrance.

It is common for low to moderate obliquity flow to be deflected or re-directed more normal to a foredune ridge as the oblique flow approaches the ridge (SVASEK and TERWINDT, 1974; RASMUSSEN, 1989). The flow just upwind (up to ~10 m seawards) of the foredune is therefore deflected and approaches parallel to the blowout axis.

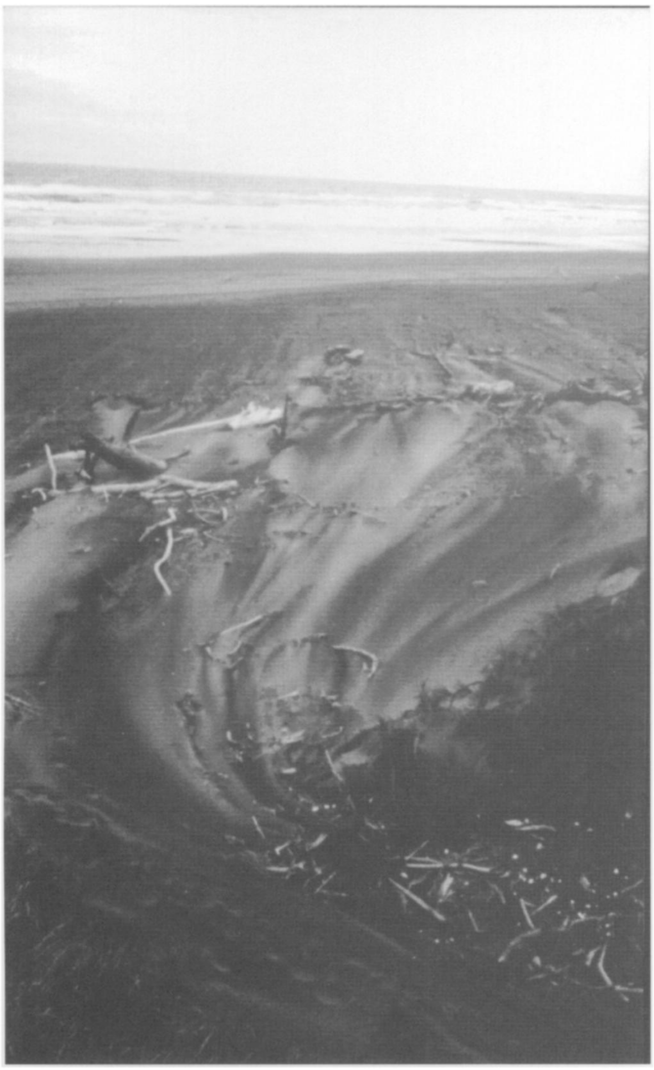

Figure 3. Re-direction of the regional wind flow as it approaches the blowout entrance (foreground) indicated by the sand transport flow lines.

Immediately seawards of the blowout, the small erosional Pingao mound, which extends out from the northern foredune wall, acts to block the near-surface flow and flow separation occurs. Under these conditions echo dunes are commonly formed in the immediate upwind region.

As flow enters the blowout it is immediately directed in a more northerly direction along the lower portion of the southern erosional wall and WNW up and over the upper portion of this wall. Re-direction of flow adjacent to the neck of the blowout is significant. Flow turns approximately 90 degrees against the wind approach direction and is directed up and over the northern erosional wall. This is in part aided by corkscrew flow separation which occurs in the lee of the Pingao mound. The wind flow up the central axis is also no longer orientated with the wind approach direction but steered up the blowout axis and spreads radially across the windward face of the blowout depositional lobe.

Highly Oblique NNW flow

Figure 5 indicates the flow within the blowout during alongshore NNW wind conditions. In this case the approach wind is slightly offshore. Yet the flow turns over 90 degrees into the blowout and flows up the blowout axis. While there is probably some topographic steering of the wind by the lower portion of the southern wall, it is suggested here that the large pressure differential existing in the blowout compared to the surrounding beach and foredune may be significant. The low pressure in the blowout would act to "suck" air into the blowout from the beach.

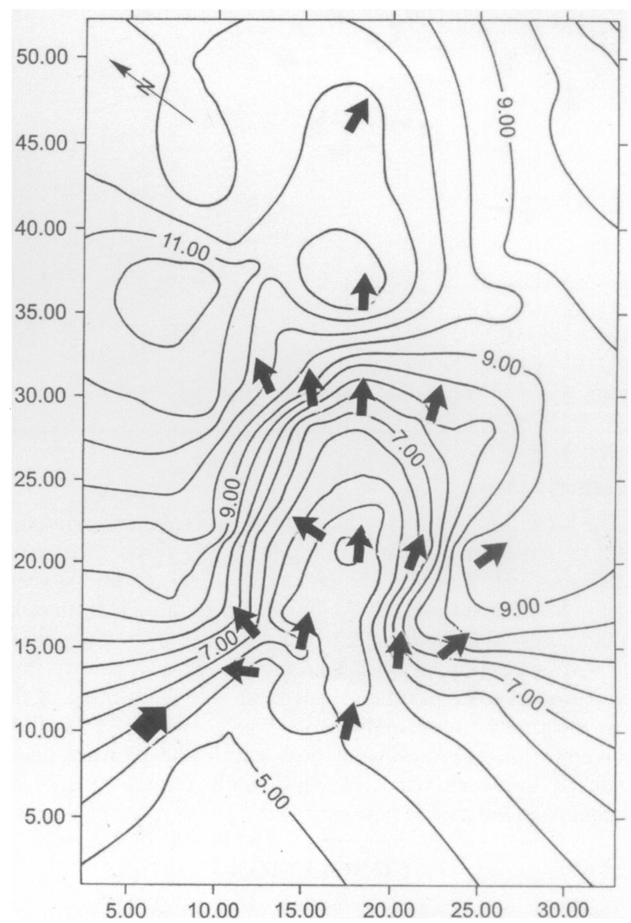

Figure 4: Pattern of surface windflow within the blowout during an approach wind from the west to west-north-west. Note that this contour map relates to an earlier survey period than the other contour maps.

The wind flow also moved up the central and upper portions of the northern wall, a local reversal in wind direction of up to 180^0. A large helicoidal roller vortice occurred at the top of the northern wall where the approach wind separated over the steep slope crest and met the re-directed southerly surface flow moving up the slope. This separated flow probably acts to increase the occurrence of northerly and north easterly surface flow up the northern blowout wall.

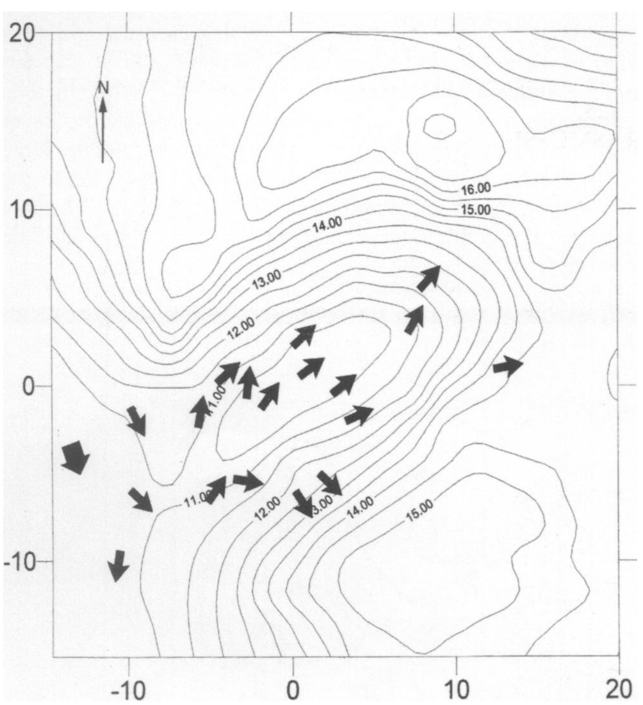

Figure 5: Pattern of surface windflow within the blowout during an approach wind from the NNW.

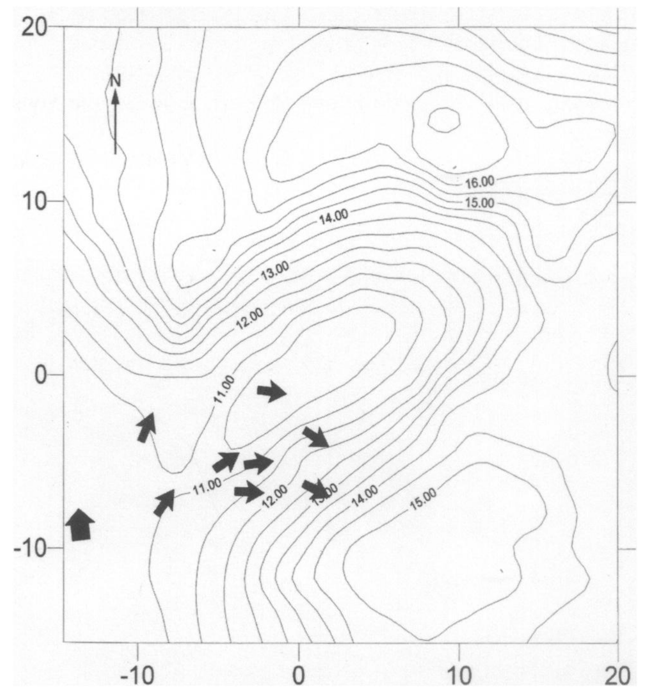

Figure 6: Flow directions in the blowout during a southerly wind approach.

Southerly Flow

The local flow within the blowout during southerly approach flow conditions is indicated in Figure 6. We suspect that three conditions act in concert to create the flow conditions seen: firstly, low pressure within the blowout acts to suck air into the trough; secondly, the flow is topographically steered around to the east and southeast by the northern wall, and, thirdly flow separation over the southern wall crest aids the turning of the flow towards the south and east.

Overall, local surface wind flow within the blowout under southerly approach winds is significantly turned 90^0 to 160^0 around from the approach wind.

CONCLUSION

This research indicates that virtually any wind flow approaching the blowout from a seaward, alongshore and slightly offshore direction in an arc of at least 200 degrees to the entrance orientation will be directed into the blowout. This presumably happens for a number of reasons including (i) that the relatively deep trough topography is an area of intense localised low pressure and winds are "sucked" into the blowout; (ii) topographic steering by the erosional walls; (iii) local flow separation over the blowout wall crests and within the blowout, and (iv) re-direction/deflection of low to moderate obliquity approach flows over the foredune.

While HESP and HYDE (1996) demonstrated that oblique approach winds were turned into and steered within a trough blowout, this study shows that even when the wind approaches from directly alongshore or even slightly offshore the flow is still directed into the blowout and very marked steering takes place (cf. Figures 5 and 6). Overall, it appears the more oblique the wind flow is to the blowout entrance the more enhanced is the steerage of flow within the blowout.

These observations have important implications for blowout development. We commonly assume that either prevailing or storm "onshore" winds are the dominant controlling winds in determining blowout orientation and evolution. This research indicates that winds from a wide range of approach directions will influence blowout flow, sand transport, erosion and deposition patterns, and evolution.

HESP and HYDE (1996) found that jet flows often occurred in trough blowouts and that estimates of sand transport in blowouts could therefore be significantly lower than values estimated utilising remotely sensed wind data (typically a nearby meteorological station). The observations of local flow in blowouts shown here indicate that remotely derived estimates of sand transport within and up many blowouts will be even more incorrect because typically such estimates place little or no value on alongshore and obliquely offshore winds.

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