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Flow within a Trough Blowout at Cape Cod

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ABSTRACT

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The Province Lands dunefield at Cape Cod is characterised by large parabolic dunes on which have developed very significant numbers of active saucer and bowl blowouts. Blowouts occur across the entire dune landscape but many are initiated on the high lee margins of large erosional ridges and bowl blowouts within the larger parabolic dune landscape. Evolution of these blowouts is characterised by multiple stages. The first few evolutionary stages are described. In addition, the aerodynamics and flow structure within a trough blowout and former saucer blowout developed within a high ridge crest is elucidated from 2D sonic anemometer data, smoke bombs and videography. The flow is characterised by decreasing then increasing flow up the blowout centreline, and marked, highly turbulent opposed flow separation immediately inside and around the marginal entrance walls of the blowout.

ADDITIONAL INDEX WORDS: *Cape Cod, blowout stages, saucer blowout, trough blowout flow dynamics.*

INTRODUCTION

The Cape Cod National Seashore is managed by the U.S. National Parks Service and encompasses 176 km² of beach, foredunes, parabolic dunes and other landscapes on Cape Cod, Massachusetts, USA. A casual assessment of coasts of the world via Google Earth indicates the Cape has one of the highest, if not the highest densities of saucer and bowl blowouts in the world (Hesp unpub. surveys; Abhar *et al.*, 2015). Significant numbers are active, and have principally formed on the upper windward slopes and crests of the large parabolic dunes which extend across the Cape. The parabolic dunes have migrated to the W-NW at rates varying from ≤ 2 m/yr in wetter months, and 4 – 7 m/yr during drier months (Forman *et al.*, 2008). The dominant pioneer species colonising the dunes is American beach grass (*Ammophila breviligulata*) (Smith *et al.*, 2008).

Cape Cod has a mean annual precipitation of 106.5 cm with rainfall spread relatively evenly throughout the year (NOAA, 2002). The precipitation in winter generally falls as snow (Forman *et al.*, 2008), and in some years there is very significant snow fall (e.g. the winter of 2015 when snow depths were up to 1.9m). The wind regime is predominantly bi-directional with dominant modes from the northwest and southwest (Abhar *et al.*,

2015). Winds are predominantly from the south during summer and autumn, north and south during spring, and predominantly west and northwest in winter (Abhar *et al.*, 2015; Forman *et al.*, 2008).

In the following we briefly describe blowout types and initial stages at Cape Cod, and then examine the flow dynamics of one of these types, namely, a notched, former saucer blowout.

METHODS

A topographic survey of a trough blowout was carried out using a clinometer (accurate to ± 1 degree) and tape measure. A series of transect lines along and across the blowout were established and surveyed at 50cm intervals or at breaks of slope. A digital elevation model was created from this data.

Six 2D RM Young sonic anemometers were placed at 0.25m above the bed, and orientated to the slope within the blowout primarily up the axis and at two lateral positions. A 40 minute record was obtained, with the anemometers recording at 1hz. The wind direction was oblique to the central axis of the blowout, approaching from the WNW. Smoke bombs were utilised to visualise the highly 3D flow.

A companion paper compares this field data with CFD modelling (see Smyth and Hesp, 2016, this Special Issue).

RESULTS

Blowouts at Cape Cod

The Province Lands dunefield at Cape Cod is characterised by large parabolic dunes on which have developed very significant

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numbers of active saucer and bowl blowouts at very high densities. Blowouts occur all across the dune landscape (Abhar *et al.*, 2015) but many are currently initiated on the high lee margins of either laterally continuous erosional ridges or large bowl blowouts within the extensive parabolic dune landscape.

Evolution of these blowouts is characterised by multiple stages. In the first stage (I) small, bare, elongate, ovoid to circular bare sand patches develop (Figure 1). It is as yet unclear why these unvegetated patches develop but one possibility is that the patches are initiated in areas where dieback of *Ammophila* vegetation occurs. Significant dieback/death of *Ammophila* is occurring across much of the New England dunefields (Seliskar and Huettel, 1993), so it is possible that creation of the patches is related to this. Their initiation may also be related to a higher frequency of storm winds at certain periods. They do not appear to be animal (*e.g.* rabbits) related. The patches commonly occur on the lee slopes of eroding ridgelines, and on or near the crests of the parabolic dunes.



Figure 1. A Stage I sand patch approximately 4m long at Cape Cod.

Stage II is characterised by the aeolian erosion of the patches into shallow saucer blowouts, typically ovoid to elliptical in morphology with marked erosional rims and relatively poorly defined depositional lobes (Figure 2). Note that the wind regime here is strongly bi-directional (but with multi-directional elements also), so at this stage some saucer blowouts may have partial depositional lobes or low convex mounds formed all around the blowout. If formed during the dominant winter winds period, there may be one predominant depositional lobe. The subsequent evolution of the blowout very much depends on its position relative to an eroding ridgeline or larger blowout.



Figure 2. A Stage II saucer blowout at Cape Cod.

It is possible that the small saucer blowout develops into a bowl blowout (Stage III) (Figure 3). These have deeper deflation

basins and somewhat more pronounced depositional lobes, although depending on their topographic position in the landscape and exposure to winds from different directions, they may have at least two obvious depositional lobes.

Stage III bowl blowouts may very rapidly develop into larger, deep bowls (Stage IV; Figure 4; see *e.g.* Figure 17 in Hesp and Walker, 2013). Alternatively, the saucer blowout may be captured by the adjacent eroding ridge line or larger blowout. In this case, the saucer blowout develops a notch, or narrow, steep walled slot

created by aeolian erosion of a portion of the adjoining ridge. Subsequently, the notch rapidly enlarges into the blowout and converts it to a trough blowout (Figure 5). The authors have been conducting flow experiments in several of these blowout types or stages. In the following, we briefly examine the flow within a notched trough blowout (former saucer blowout).



Figure 3. A small bowl blowout at Cape Cod. Note that the blowout will soon be notched as the windward scarp ridgeline (arrowed) retreats and breaks through into the small unvegetated section of the blowout.



Figure 4. A Stage IV large bowl blowout at Cape Cod. Note the steep ridgeline and unvegetated erosional slope to the right. The blowout will eventually be canabised by the erosional slope.

Flow within a Trough Blowout (Former Saucer Blowout)

The blowout was situated within a NW facing eroding ridgeline (Figures 5 and 6). Observations from Google Earth historical imagery indicates the blowout was originally formed leeward of the ridge crest and is present as a saucer by May, 2010. The northern windward ridge was sinuous to crenulate with several narrow and arcuate notches within the ridgeline at this time. In the following 2 years, ridgeline erosion continued and expanded to the south, and the notch was almost joined to the saucer blowout. By mid-2014, the two landscape units had joined, and the bowl was united with the notch, and converted into a trough.



Figure 5. A trough blowout at Cape Cod. The blowout was formed as a discrete saucer blowout and evolved into a trough blowout as the adjacent erosional ridge was notched. The flow experiment was conducted in this blowout. The arrows indicate the position of the sonics. The most distant sonic anemometer (no. 4) is on the depositional lobe.

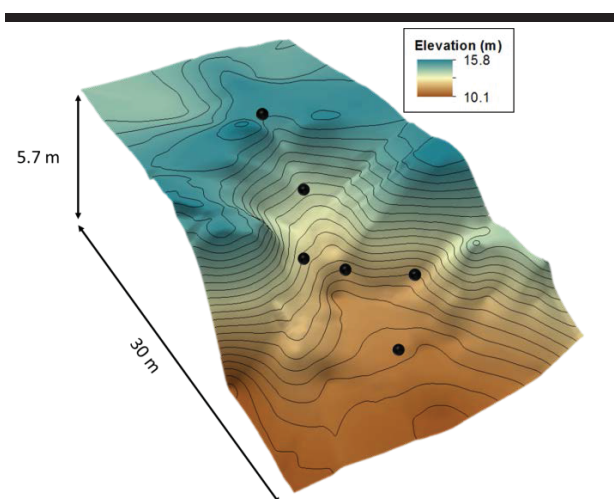


Figure 6. DEM of the Stage IV² trough blowout at Cape Cod. Black dots indicate sonic anemometer positions.

The internal morphology of the trough blowout is crenulate, displays marked vertical slopes held by dense vegetation on the left northeastern margin and less dense vegetation on the northwestern margin (Figures 5 and 6), and a low, convex depositional lobe downwind. Snow and ice were significant in the more shaded portions, and marked, vertical ice cornices were present on the upper slope margins (Figure 5).

DISCUSSION

Figure 7 illustrates mean wind velocity and direction vectors up the blowout for the oblique incident wind. The

incident wind was topographically steered within the blowout to flow more directly up the blowout axis in similarity to other studies in trough blowouts, (cf. Hesp and Hyde, 1996; Hesp and Pringle, 2001; Gares and Pease, 2015; Smyth *et al.*, 2014). Smoke bombs clearly showed that flow separation occurred on the left and right lateral cliffed margins. At sonic 5 (figure 7) a defined flow separation roller vortex was formed at the base of the arcuate scarp and flowed up and over the adjacent wall. At sonic 6 (eastern left side) a pronounced helical corkscrew vortex formed near the base and flowed up the blowout, escaping out and over the scarp wall to the east. Flow is highest on the crest of the depositional lobe (sonic 4, Figure 7).

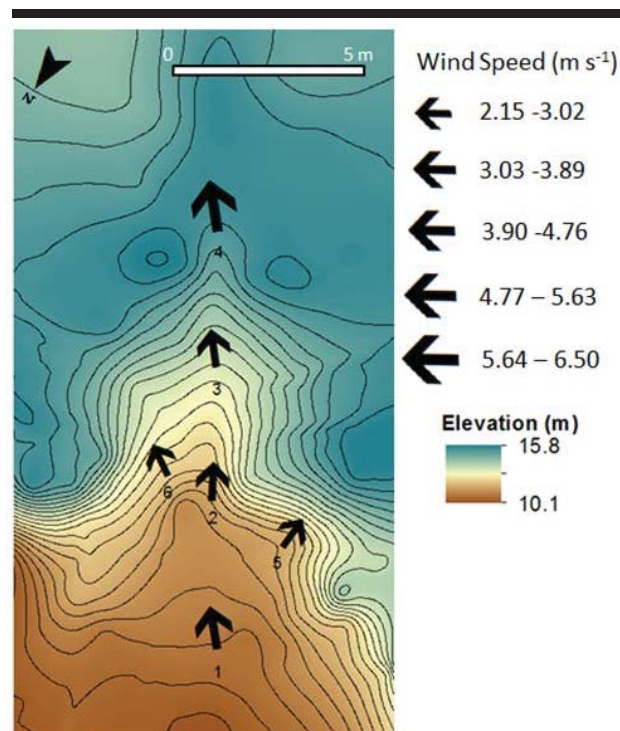


Figure 7. Mean wind velocity and direction vectors in the blowout. The oblique wind is steered up the blowout, radially spreads into the upwind lateral wall margins, and accelerates over the depositional lobe.

Figure 8 illustrates mean wind speed, coefficient of variation of the wind speed (CV), direction, and turbulent kinetic energy (TKE) up-axis and across the blowout.

The up-axis data show that, unlike most studies of blowouts where the flow generally increases up-axis or

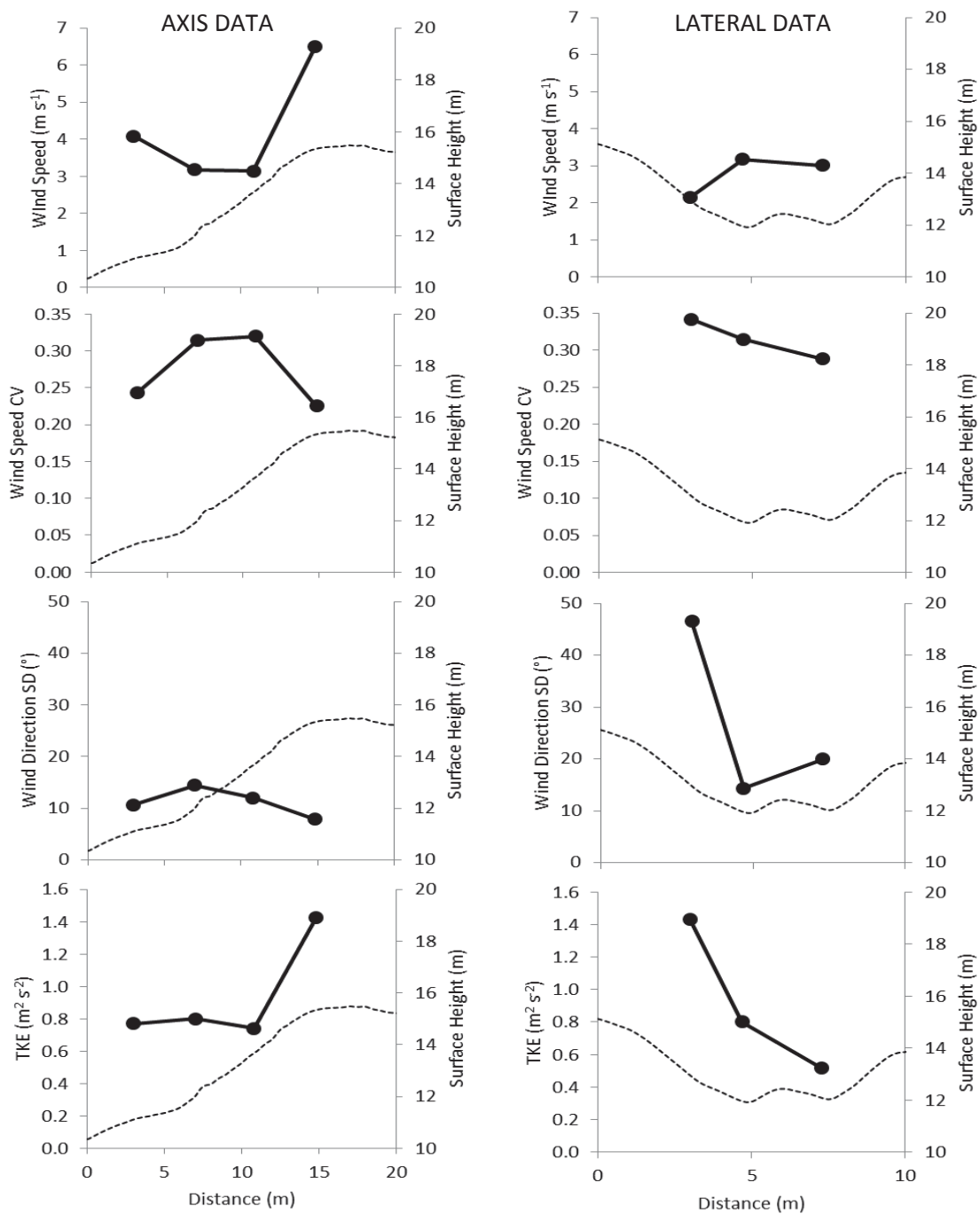


Figure 8. Mean wind speed, coefficient of variation (CV) of wind speed, standard deviation (SD) of the wind direction, and turbulent kinetic energy (TKE) for the up-axis (sonics 1 to 4) and across-blowout (lateral) (sonics 6-2-5, left to right) anemometers. The dashed lines indicate the surface topography. High turbulence in the margins of the entrance lead to reduced wind speeds in the entrance and mid regions of the narrow blowout.

downwind within the blowout due to flow compression and sometimes the formation of jets, the flow decelerates in the entrance (sonic 2) and mid-blowout (sonic 3) regions. The CV of wind speed shows that these two regions are more turbulent, and the smoke bombs clearly showed that the flow separation, and corkscrew (sonic 6) and roller (sonic 5) vortices created on the each side of the narrow entrance (i.e. adjacent to sonic 2 in the entrance) had a pronounced effect on the general flow in the narrow entrance region. The incident wind tends to collide with the eastern wall, creating the larger and more turbulent corkscrew vortex steering along and upwards in the blowout. This high eastern margin turbulence (sonic 6) is indicated by the SD of wind direction (which is, in essence, a proxy for turbulence), wind speed CV and high TKE.

Walker and Nickling (2003) found that, as flow progressed up a transverse dune slope, streamwise accelerations lead to a reduction in turbulence and an increase in flow stability (cf. Wiggs *et al.*, 1996). It is likely that a similar effect is occurring by sonic 4 as the flow recovers up-axis and approaches the crest of the depositional lobe. Since the TKE is also partly a product of wind speed, the TKE is also relatively high at the crest of the depositional lobe (sonic 4).

Smyth *et al.*, (2014) found that the turbulent kinetic energy (TKE) correlates best with sediment transport in a blowout, and our longer term studies at Cape Cod indicate that once a steep wall is produced within a saucer blowout, or the notching process begins, the rate of notch expansion, and of saucer to bowl blowout evolution is phenomenal (see Abhar *et al.*, 2015 their figure 7) indicating these areas of pronounced TKE are regions of marked transport and erosion. Naturally, so is the upper windward slope of the depositional lobe where marked speedup occurs and again the TKE is significant.

CONCLUSIONS

Blowout evolution at Cape Cod tends to follow a path from sand patch to saucer blowout. At this point the blowout may evolve into small to large bowl blowouts, or it may be notched and form a trough blowout. At any point the notched trough blowout or bowl may be captured or cannabalised by a larger erosional feature, particularly steep eroding ridgelines and scarps. This evolutionary sequence is quite different to those observed elsewhere to date (e.g. Gares and Nordstrom, 1995; Hesp, 2002).

Flow processes in a notched bowl blowout are also partly different than those observed elsewhere. Up-axis speedup is not as systematic at least when the incident flow is oblique, and highly turbulent vortices are formed at the entrance erosional walls and profoundly affect flow inside the entrance and further into the blowout.

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