Topographic wind steering through constructed foredune notches

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1. Background

• Foredune at St Kilda play an important role to protect urban amenities from coastal hazards

• The foredune was completely eroded in 1978, to the base of the dyke (John Wilson Drive), but accreted vertically after marram grass was planted in March 1980

• Prevailing wind is W-WSW (alongshore – highly oblique onshore)

• **Multiple foredune notches** have been constructed at the foredune since April 2016 to **steer the wind** through the notch, increase sand transport to the back dune to create more resilient morphology

• These management technique has been applied in The Netherlands, UK, France [1],[2],[3]
2. Knowledge gap and research questions

• The understandings of flow though the notch is largely based on coastal trough blowout studies [4],[5],[6]
• The recent studies on notched foredune focus on morphodynamic evolution [7],[8]
• There is no attempt to investigate the topographic wind steering through the foredune notch
• This study aims to
  ➢ Examine the sensitivity of incident wind approach angles to wind flow though the notch
  ➢ Examine flow deflection over notched vs. intact foredune

Different incident wind direction and their approach angels)
3. Method (1)

3.1. Field experiment

- Field work was undertaken on 21\textsuperscript{st} – 22\textsuperscript{nd} Nov 2020 with 2D ultrasonic anemometers (1Hz)
- Incident wind was recorded by anemometer C at 6.5 m from foredune crest
- Secondary wind was recorded by grid of 12 anemometers across notch C

Incident wind direction shifted from highly onshore oblique to notch axis parallel
3. Method (2)

3.2. Anemometry data analysis

- Anemometry data were averaged at 3 run lengths: 1 min; 1.5 min and 2 min
- The relationship between incident wind direction and normalised wind speed at A3 were examined for 3 runs
- The results show that both 3 run length provide similar relationship
- Run length 1 min is selected
3. Method (3)

3.3. Computational fluid dynamics (CFD) validation

- The sensitivity of domain setup (shape and size) and mesh size were examined
- Modeled wind data is validated with field observation at the same incident wind direction

\[
\Delta WD = WD_{\text{modeled wind data}} - WD_{\text{field data}}
\]

\[
\Delta NWS = -\frac{WS_{\text{modeled wind data}}}{IWS_{\text{modeled wind data}}} \cdot \frac{WS_{\text{field data}}}{IWS_{\text{field data}}}
\]

\[
RMS_{WD}^{12} = \sqrt{\frac{1}{12} \sum_{i=1}^{12} \Delta WD_i^2}
\]

\[
RMS_{WD}^{11} = \sqrt{\frac{1}{11} \sum_{i=1}^{11} \Delta WD_i^2}
\]

\[
RMS_{NWS}^{12} = \sqrt{\frac{1}{12} \sum_{i=1}^{12} \Delta NWS_i^2}
\]

\[
RMS_{NWS}^{11} = \sqrt{\frac{1}{11} \sum_{i=1}^{11} \Delta NWS_i^2}
\]

- Note: RMS\(^{11}\) means 11 secondary wind anemometers (without B4) to reduce the effects of vegetation
3. Method (4)

3.3. Computational fluid dynamics (CFD) validation
4. Results

4.1. Sensitivity of approach angles to secondary wind speed

- Wind speed inside the notch decreases when approach angles are from axis parallel to highly oblique onshore.

Regression model between approach angle and average wind speed at notch surface (A1 - 0.2 m): $y = -0.01225x + 0.9451$, $R^2 = 0.9634$.

Approach angles from axis parallel -> highly oblique onshore.
4. Results

4.2. Sensitivity of approach angles to average wind direction (blue); SD of wind direction (red)

- Wind direction inside the notch is still relatively notch axis parallel, but more reversal and turbulent (A1 – A3) when approach angles are from axis parallel to highly oblique onshore particularly from 40°
4. Results

4.3. Sensitivity of approach angles, wind speed, and direction from upper beach to the notch

Wind speed at 0.2 m from the bed (m/s)
4. Results

4.4. Flow deflection over notched and intact foredune

Deflection angle at 2.5 m from the bed

Deflection angle at 0.46 m from the bed

Notch C long axis elevation

- Inlet wind direction = 192 degrees (notched foredune)
- Inlet wind direction = 226 degrees (notched foredune)
- Inlet wind direction = 255 degrees (notched foredune)
- Inlet wind direction = 192 degrees (intact foredune)
- Inlet wind direction = 226 degrees (intact foredune)
- Inlet wind direction = 255 degrees (intact foredune)
5. Conclusions and future work

5.1. Conclusions

- Wind speed (normalised) inside the notch is strongly correlated with incident wind approach angle
- Wind direction inside the notch is steered toward notch axis parallel when approach angle $< 25^\circ$, and turbulence increases significantly when approach angle $> 40^\circ$
- Flow deflection begins from the upper beach and increases when approaching the notch
- Flow deflection over notched foredune is up to $20^\circ$ greater than intact foredune

5.2. Future work

- Examine the detailed flow structure through the notch and its implications for sand sedimentation processes
References


