Multipliers for orographic lee effects

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Introduction

Winds in mountainous areas of New Zealand are often high. Typically the peaks are normally windy when weather systems are moving over the area and very high speeds have been recorded at some instrumented sites. However, the valley floors between the ranges are also sometimes windy to the point that damage occurs to some structures. These events are very significant because costs of potential damage are high. There is little doubt that gravity waves generated by the mountains are a primary cause of the high winds. Loadings codes since 1992 have had some provision for structures in places where such winds are likely. This paper aims to provide further information on the lee effects and to show how lee effects should be combined with hillshape multipliers.

Case study

On 3 October 1981 the maximum gust reached 71 knots at Queenstown Airport (Figure 1). This is not a high speed in absolute terms but the record in Figure 1 shows that power cuts were occurring suggesting that higher winds were probably occurring in the vicinity and damaging the power supply. The wind direction was northwest – a rare direction at the site and one in which high hills are within about 1 km of the site. For winds to reach this strength, a large downward speed is needed so that a wave effect is almost certain.

On this same day, wave clouds were apparent in satellite pictures and two other wind-measuring stations in the South Island had wind speeds to the tops of their measuring scales. Power cuts and damage were widespread.

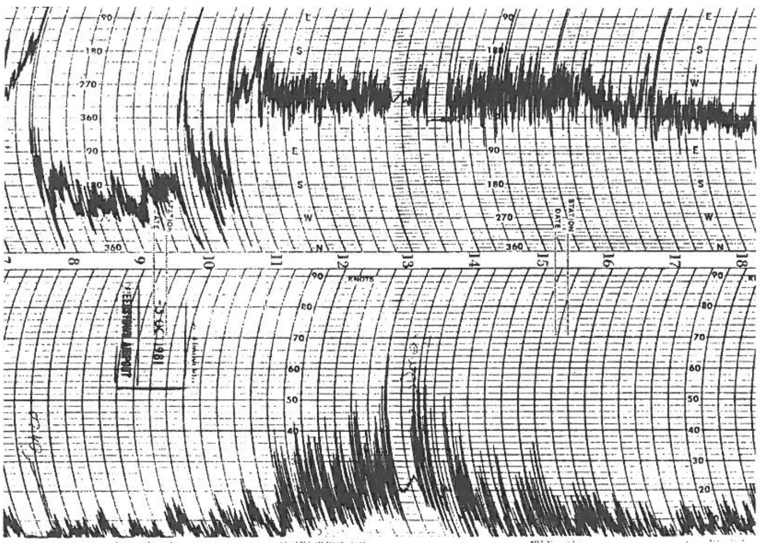


Figure 1. Anemogram of the highest wind at Queenstown Airport on 3 October 1981. The direction trace is at the top and the speed at the bottom.

Lee zones

Lee zones that are designated in New Zealand and Australian loadings codes are based on wind recordings, damage reports and satellite pictures. The latter are useful for showing places where wide gaps between wave bands are common and strong downward air motions are present. The shapes of the mountain ranges are also important and places where there is a lee-side escarpment are known to be favourable sites for strong lee winds.

Queenstown is not in a designated lee zone. The main reason for this is that measured winds speeds are within the ranges found at other stations. Further, there is a known proportionality between tropospheric wind speed and lee wavelength. For places that are confined by mountains on both sides, like Queenstown, it is reasonable to suppose that maximum wind speeds due to waves will also be limited and there is less possibility of an extreme event than in open terrain.

Modelling of winds in lee zones

Realistic models of wind flow over mountains are comparatively recent and much of the science that has been applied to the practical problems has been based on linear models that only apply to perturbation-scale effects i.e. very small hills. It has been generally assumed that wind flows over large hills or mountains are a limiting case of the perturbation theory. Recent research has shown that flows over large hills and mountains generate wind patterns that are quite unlike the perturbation flows and must be considered using a completely separate range of models. For New Zealand, this is a useful development because linear wind models have been unable to explain many of the wind phenomena that are observed.

A non-linear model BLASIUS (Boundary Layer Above Stationary, Inhomogeneous, Uneven Surfaces) with stability typical of lee wind storms (i.e. quite large) has been run for two topographic cases. The topographic cases used have been for simplified mountain systems so that they rise to a uniform 1200 m above a base level. Many of the ranges of the Southern Alps have a valley floor to mountain top height difference of about this magnitude. Two mountain range widths have been used: one that is 20 km across and another that is 5 km across. The two cases are shown in Figure 2. Wide mountain ranges are characteristic of situations with strong lee wind effects. Comparisons with neutral flow cases have also been made. The linear model WAsP has also been used for comparison.

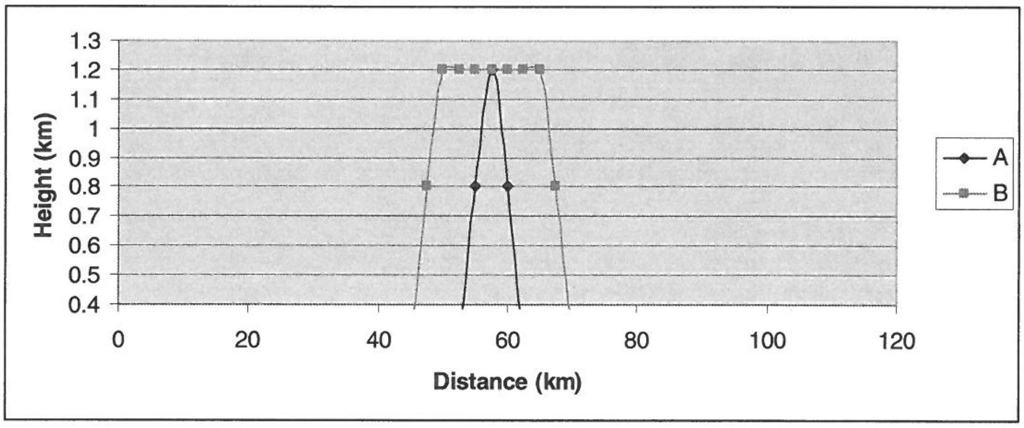
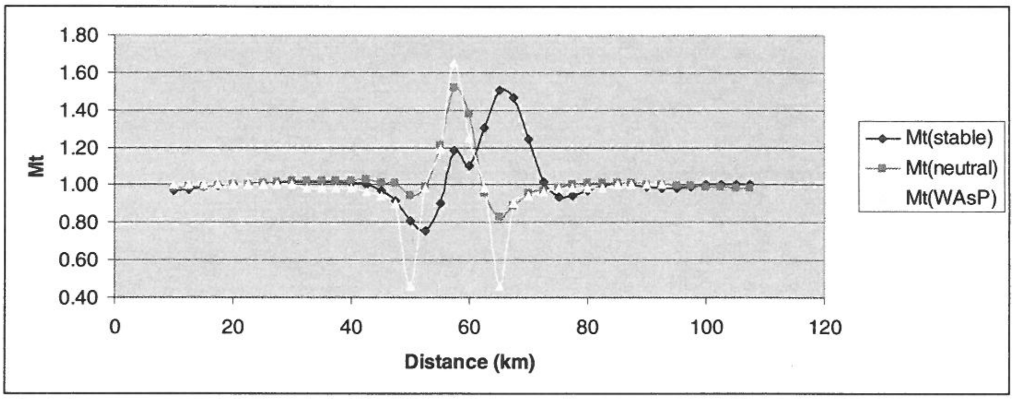


Figure 2: Ridge profiles used for the model runs.

The model domain is 120 km x 120 km and the mountain ranges are about 100 km long. An upstream free-air wind flow of 35 m/s (as was observed in a 2004 wind storm) is directed across the mountain range and disturbances over the mountains are allowed to develop. The model typically approaches a realistic flow field after about 500 seconds and the multipliers on the winds are extracted after run times of 900 seconds. The flow fields develop further but often become unrealistic. The parameter that is extracted from the model is the topography multiplier M_t for mean winds at heights of 10 and 50 m above ground. It is obtained against a reference wind speed at a point 20 km into the modelling domain and about 25 – 30 km before the upwind slope of the range.



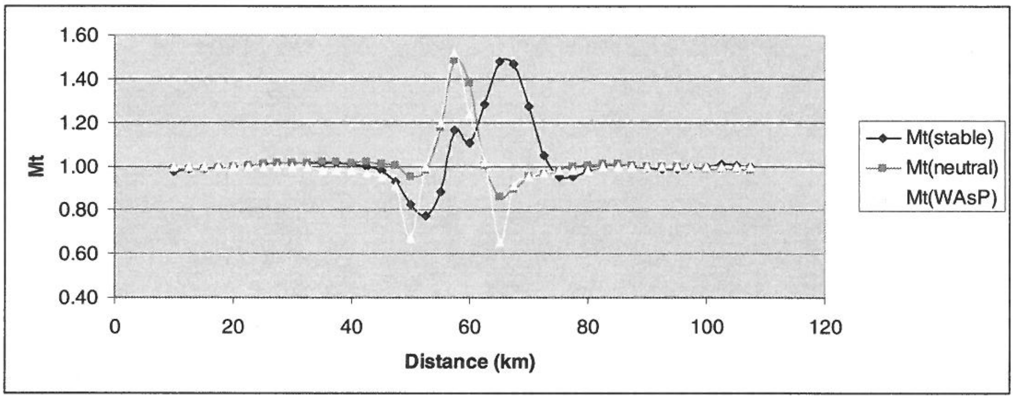
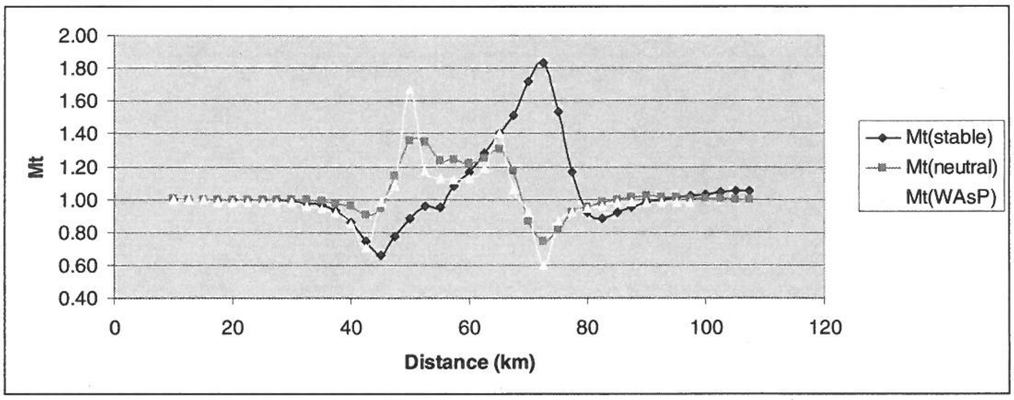


Figure 3: Multipliers of mean speeds for ridge shape A. (Upper) 10 m above ground. (Lower) 50 m above ground

The first case (Figure 3) considered is with the narrow range. The highest M_t values for the neutral flow are a little higher than for the values in the loadings code (NZS4203:1992 gives a value about 1.5) and the lee factor is a little less than the code value (1.6 within the 0-12 km zone to the lee of the high point of the mountain system). The high lee multiplier only occurs in stable flows and the high hillshape multiplier only occurs in neutral flows. The presumption in the loadings code that the hillshape and lee multipliers do not require combination at elevations below 500m appears correct. In fact, there need be no limitation on this approach to any altitude.

The second case (Figure 4) is very similar to the first but with a wide ridge. The WAsP values differ more from the values derived from the non-linear model than in the first case. The lee multipliers in this case are quite a lot more than the code values and may require special provisions in places where the effective mountain-range width is large.



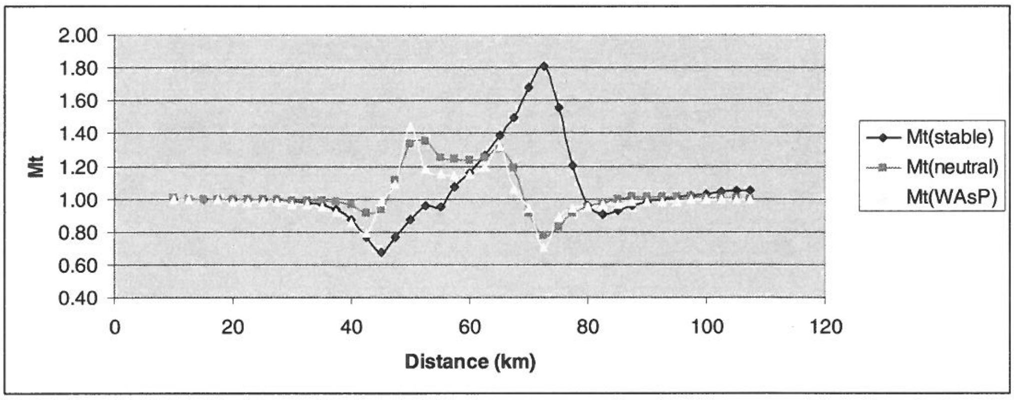


Figure 4: Multipliers of mean speeds for ridge shape B. (Upper) 10 m above ground. (Lower) 50 m above ground

Discussion

Real mountain ranges form complex agglomerations of peaks and valleys unlike the regular features used in the model runs. Nevertheless, airflows over complex systems of mountains seem to behave as if regular features are present because of the cloud patterns in satellite pictures. Commonly the flows seem to behave as if several ranges act as a single barrier. Conversely, a valley, possibly because of a particular orientation, may appear to the flow as an end point and the flow descends strongly. The way airflows can be seen to respond to mountains is regarded as justification for the use of simplified models. It seems likely that land surface complexities may reduce the amplitude of the response of airflows to mountain systems because of conflicting effects. This offers an explanation for the rare occurrence of large responses which may be seen as resulting from combinations of atmospheric structure, wind direction and terrain form that approximate the ideal cases.

Summary

In this modelling study, large lee multipliers are shown to develop in the lee of broad mountain ranges. The largest multipliers for sites on the mountain tops occur in neutral flows. It is reasonable to ignore the design case that combines the 2 multipliers because when hillshape multipliers are high there will be no lee effect and when the lee effect is high the flow over the whole hill is affected.