TERRAIN BLOCKING OF LARGE SCALE FLOWS

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Introduction

When a stable wind stream approaches an obstacle there is a slowing down of the lower layers, and if the combination of obstacle height, vertical stability, and wind speed is right there is a layer near the ground which is "blocked" entirely from crossing the obstruction. This type of phenomenon may occur with obstructions over a range of scales.

A number of investigations have been conducted into this effect, using theoretical, numerical modelling, physical modelling, and/or observational approaches. Some studies have described aspects of the associated flow patterns, and some have attempted to determine the pre-requisite physical conditions. A number of authors have focussed in particular on the Froude Number of the flow ($F= U/(NH)$, U being the speed of the wind approaching the obstacle, N the Brunt-Vaisala frequency, and H the obstacle height), giving critical values for this quantity above which blocking will not occur (1,2,3,4, 5). However, there has been little agreement about this critical Froude No., the values given ranging from $1/\pi$ (1) to 2.3 (2).

In this paper we will be concerned with blocking produced by large mountain ranges, which has associated effects in the blocked layer not observed on smaller scales. As part of the blocking mechanism a low level mesoscale pressure ridge is formed on the windward side of the mountains, and this results in a distortion of the horizontal air flow (6). If the mesoscale ridge lasts for more than a few hours, a corresponding mesoscale flow may be set up, resulting in a low level wind maximum in the layers below mountain top, parallel to the range. Measurements made in the Antarctic (7) and in California (8) suggest that this wind maximum may extend over 100 Km windward from the mountain range, and when there is a totally blocked layer this may also reach over 100 Km upwind. At times there is a flow away from the mountains in the lowest layers.

To the east and south of Albury-Wodonga there is an arc of mountains, at distances varying from about 120 to 80 Km, which is of similar height to the mountains considered in the above mentioned work in the Antarctic and California. During an investigation of the air dispersion meteorology of the area (9) a number of upper air measurements were made under conditions with a north-westerly upper wind and apparent blocking in the low layers. In this paper these measurements and some concurrent measurements of surface winds by a network of anemographs will be considered, together with some of their implications.

The Observations

All except one of the upper air wind and temperature profile measurements available for this study were made early in the morning, close to sunrise. Fig. 1 shows the results in a typical case. Three layers may be distinguished,

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corresponding to three of the layers found by Manins and Sawford (5) in their study of a flow blocked as it crossed a small valley (100 m deep). In the lowest layer there was a southeasterly flow with a strong inversion, showing the characteristics of a drainage wind. The surface winds over the whole Albury-Wodonga area on such mornings in fact showed the typical drainage wind flow pattern. Above the surface drainage flow was a layer of northeasterly to northerly winds. This layer would correspond to the near-stagnant blocked layer of Manins and Sawford, but due to the larger scale and longer duration of the blocking a mountain parallel wind had developed as in the cases discussed by Schwertweger (7) and Parish (8). Above this again there was the large scale flow. Manins and Sawford distinguished a layer of "sweeping wind" between the blocked layer and the ambient flow. This was a wind descending into the valley they were considering, below the level of the flanking hills. At Albury-Wodonga it did not prove possible to distinguish such a sweeping wind, partly perhaps because the flow was ascending a range rather than crossing a valley, but also because on the scale involved the corresponding vertical changes in the wind (if any) would have been hard to distinguish from vertical changes in the ambient flow.

The direction shears at the transition from the drainage wind layer to the blocked layer (A-A in Fig. 1), which usually occurred near the top of the surface inversion, and from the blocked layer to the ambient wind (B-B), were often quite sharp, as noted by Manins and Sawford in their case.

Profile measurements like that shown in Fig. 1 were made on 20 mornings. The thickness of the lowest drainage layer varied between 200 and 500 m, but was commonly close to 300 m. The thickness of the blocked layer was more variable, its top ranging from 500 m to 1700 m. Details are given in Table 1.

During the day following a morning with blocked flow the surface wind would sometimes develop to a general southeasterly to easterly flow over the whole Albury-Wodonga area; sometimes there would be general light and variable winds once the drainage flow ceased; sometimes there would develop a light easterly to northeasterly flow over part or all of the area; and sometimes there would develop a stronger northeasterly to northerly or northwesterly surface flow. The last of these developments corresponded to break down of the blocking pattern. The others would indicate different patterns of flow within the blocked layer. It is not proposed to consider this matter further here, except to note that there were a few occasions (not including any of the days with upper air observations) when blocking appeared to break down over part of the study area but not all of it.

Froude Numbers

To calculate Froude numbers from the available upper air measurements it was necessary to decide on: the effective height of the obstructing mountains; a method for estimating the speed of the ambient wind approaching the mountains; a method for estimating the effective vertical gradient of potential temperature; which air layers should be considered. It was taken that the arc of high mountains to the east and south were the cause of blocking, these being at an appropriate distance and of an appropriate height to produce such an effect, according to the observations of Schwertweger and of Parish. The effective height of these mountains was taken as 2000 m above sea level, or 1850 m above ground level at Albury-Wodonga. It was found that in most cases the winds between say 1500 and 2000 m were fairly steady with height, so their speed was taken as that of the incident wind. Finding the effective vertical gradient of potential temperature was a more difficult problem, as this gradient frequently varied considerably within the height ranges considered, and these variations might be presumed to have an important effect on the air motion over obstacles. As a first trial it was decided to use an average value, taken from the observed profile, from the bottom of the layer being considered to the height of the obstruction i.e. to 1850 m. Froude numbers were calculated for three types of layer. In the early morning profile each day the drainage wind layer would have a temperature structure so modified by nocturnal cooling as to bear no relation to the original blocking mechanism. Hence it was decided to calculate a Froude number omitting this layer, that is, the number was calculated for the layer from the top of the drainage flow up to the mountain top. This layer should give a Froude number corresponding to blocking. Secondly, a Froude number was calculated for the layer above the top of the blocked layer i.e. for the layer from the top of the blocked layer up to mountain top. This layer should give a Froude number corresponding to absence of blocking. Thirdly a Froude number was calculated for the whole layer from ground level to mountain top for the time of daily maximum temperature, or, if there was break down of blocking during the day, for the time of this break down. For this last mentioned calculation it was necessary to assume that the upper winds had not changed from the early morning values , and that the temperature structure had not changed either except for an upward warming of the lowest layers from the ground. It might be expected that the third Froude number on a day of continuing blocking would correspond to blocking, and that on a day of blocking break down it would be close to the critical value.

It was found that all of the early morning blocked layers except two had Froude numbers less than or equal to 0.5, these having F values of 0.62 and 0.52. All of the morning layers above the blocking had Froude numbers greater than 0.5 except three, which had F values of 0.41, 0.44, and 0.48. There were nine days on which break down of blocking occurred, and in all cases the Froude number for the time of break down was between 0.47 and 0.55. On all the other days (except one when there was a frontal passage) the Froude number at the time of maximum temperature was less than 0.5. The results, then, point fairly strongly to a critical Froude number close to 0.5, a value found by Baines (3) using an hydraulic modelling technique, but by no other investigators.

The heights found for the top of the blocked layer showed a weak relationship to F (Fig.2). Katabayashi (2) also found a relationship, and Baines, examining a flow approaching a ridge with a gap, found a relationship between F and the level below which the flow was sluggish (blocked?). Since the arc of mountains near Albury-Wodonga has a significant gap near Omeo, Baines' relationship is shown in Fig. 2 for comparison.

Conclusion

Much work is needed to elucidate the behaviour of the air in regions where the flow is blocked by an obstruction, and in particular to resolve the conflict between different determinations of the Froude number which characterises the transition from a flow regime without blocking to one with blocking.

Acknowledgements

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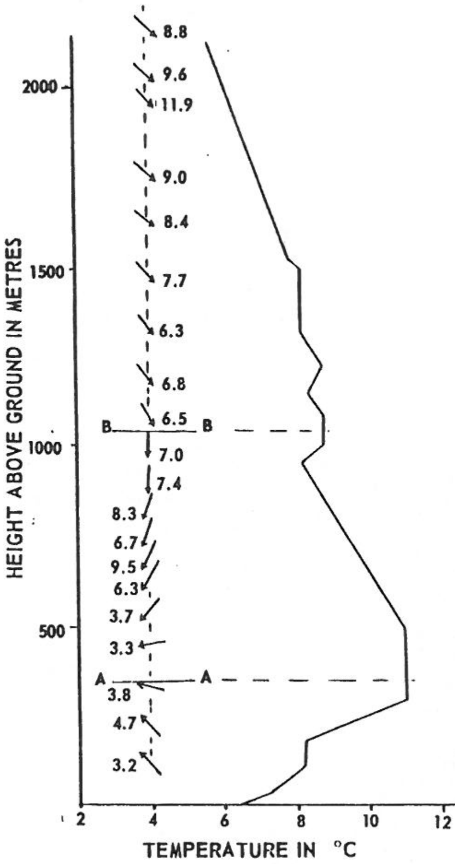

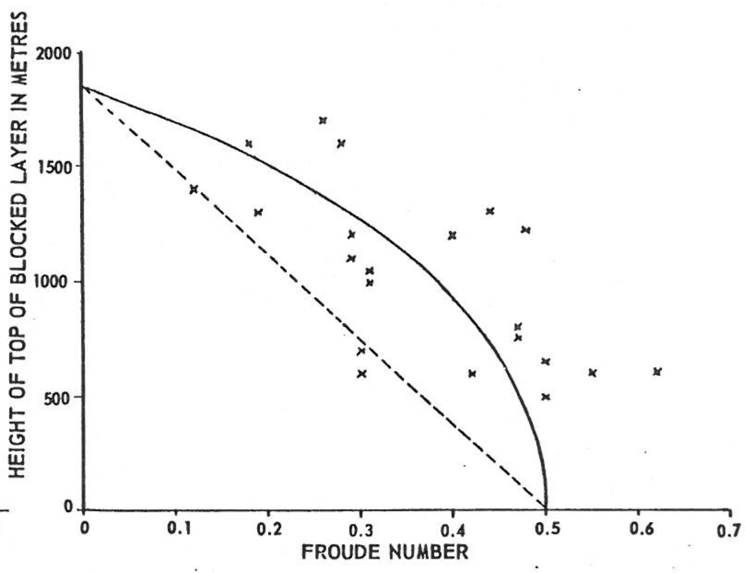

<u>Figure 1</u>. Profile of temperature and wind at sunrise on 16-9-79 at Albury-Wodonga. The wind speeds are given in m/s. Each wind is an average for the layer down to the next reading.

<u>Figure 2</u>. Height of the top of the morning blocked layer at Albury-Wodonga as a function of the Froude number for the layer extending from the top of the drainage layer (A-A in Fig.1) up to mountain top (1850 m). The dashed line gives a relationship found by Baines (3) between the Froude no. and the height of the top of the almost stagnant layer when a wind stream approaches a barrier with a narrow gap.

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