NOTES AND CORRESPONDENCE

Shallow Water Flow Having a Lee Hydraulic Jump over
a Mountain Range in a Channel of Variable Width

By Kazuo Saito

*Meteorological Research Institute, 1-1 Nagamine, Tsukuba, Ibaraki 305, Japan**(Manuscript received 3 September 1991, in revised form 8 April 1992)*

Abstract

Unsteady and quasi-steady state solutions of shallow water flow having a lee hydraulic jump over a mountain range in a channel of variable width are calculated by expanding Houghton and Kasahara's (1968) theoretical model.

In an unsteady flow régime in which a lee jump moves downstream, both the decrease of the channel width and the increase of the mountain height contribute to the increase in the moving speed of the lee jump. This result confirms Arakawa's (1969) suggestion which indicated that a steady state flow is deformed by the channel width in the same way as by the mountain height. On the other hand, in the quasi-steady flow régime in which a lee jump stays in the lee of the mountain, the jump develops at the more leeward side when the channel width decreases, while it tends to develop at the more windward side when the mountain height increases. Namely, Arakawa's (1969) suggestion does not hold for the location of the stationary jump. This response of the lee jump in a quasi-steady régime to the magnitude of the channel width is analogous to the behavior of an internal hydraulic jump in a non-linear flow over a mountain range with a col.

The velocity of the fluid just before the hydraulic jump increased with the decrease of the channel width. This result corresponds to the fact that strong downslope winds tend to occur in the lee of a col of a mountain range.

1. Introduction

Hydraulic jump is a strong upward motion of a flow which often develops in the lee of an obstacle. In hydraulics, this phenomenon arises only from non-linear equations and is known as a water jump which is accompanied by a discontinuity of the flow velocity. In the meteorological field, similarities between the flow having a hydraulic jump and a downslope wind have been inferred for some time (Long, 1953; Akiyama, 1956). This inference has been supported by numerical experiments (Durran, 1986; Pitts and Lyons, 1990; Saito and Ikawa, 1991) and aircraft observations (Lilly and Zipser, 1972; Smith, 1987; Pitts and Lyons, 1989) in recent years.

Theoretical studies of the hydraulic jump have been made mainly for the two-dimensional hydrostatic flow of a single or two-layer fluid. Long (1954) theoretically studied the behavior of shallow fluid over a mountain and compared it with laboratory

experiments. He showed that there is a definite limit to the mountain height for the existence of the steady-state solution and that the behavior of the shallow fluid can be classified by the Froude number of the approaching flow and non-dimensional mountain height into three régimes: a sub-critical flow, an unsteady flow having hydraulic jumps, and a super-critical flow. Houghton and Kasahara (1968) calculated the theoretical solutions for the shallow water flow having a lee hydraulic jump by using the constant jump conditions. They compared their theoretical solutions with the numerical model solutions obtained from one-dimensional shallow water equations and they were able to show good agreement between them. Baines and Davies (1980) pointed out that there exists a hysteresis region in which the flow is either partially blocked or super-critical depending on the initial condition.

Arakawa (1969) considered a steady-state flow in a channel of variable width and showed that decrease in the channel width deforms the flow as does the increase of the mountain height, and that there is a

Fig. 1. Flow régime of a hydrostatic flow over a mountain. M_c : Non-dimensional mountain height; F_0 : Froude number.

definite limit to the channel width for the existence of the steady-state solution. He applied Houghton and Kasahara's theoretical model to the flow in a channel and showed that the flow in a channel could have a hydraulic jump as does the flow over a mountain. Gill (1977) calculated a solution of a flow having a stationary lee hydraulic jump over a mountain in a channel of variable width.

The results of Arakawa (1969) and Gill (1977) suggest that the horizontal convergence or divergence due to the variation of the channel width may affect the behavior of the hydraulic jump. However, Arakawa's study was mainly for a steady-state flow and he did not calculate the solution of a flow having a lee hydraulic jump for the case in which both the mountain height and the channel width vary simultaneously. Gill's solution omitted the upstream deceleration of the velocity of the fluid due to blocking by the obstacle since it assumed a steady state. Neither Arakawa (1969) nor Gill (1969) calculated the unsteady solution in which a lee jump moves downstream.

Recently, Saito (1992) made a numerical experiment of a three-dimensional stratified flow over a mountain range with a col, and it showed that the internal hydraulic jump tends to stay in the lee of the mountain and move downstream rapidly in the lee of the col. This behavior of the hydraulic jump seems to be related to the horizontal divergence or

convergence of the flow due to the three-dimensional effect of the orography. In this study, the theoretical model proposed by Houghton and Kasahara (1968) is expanded to the flow over a mountain range in a channel of *variable* width and the solutions of the non-linear flow having a lee hydraulic jump are calculated.

2. Basic equations

Consider a flow of a fluid of uniform density over a mountain range in a channel of a rectangular cross-section, assuming the three assumptions known as the 'hydraulic assumptions' (Lawrence, 1990): 1) inviscid, 2) hydrostatic, and 3) uniformity of u in each cross-section. When the channel width is constant, it is known that the flow régime is characterized by the following two parameters: Froude number, $F_0 = u_0 / (gh_0)^{1/2}$, and the non-dimensional mountain height, $M_c = m_c / h_0$ (Fig. 1). In this figure, the regions ① and ③ express a steady-state flow and correspond to a sub-critical flow and super-critical flow, respectively. The maximum value of M_c , which allows the steady-state flow, is obtained from Bernoulli's law, mass-flux conservation equation and critical flow condition at the mountaintop, and it is determined by the following equation for the critical curve (Long, 1954):

$$M_c = 1 + \frac{1}{2}F_0^2 - \frac{3}{2}F_0^{\frac{2}{3}}. \quad (1)$$

Fig. 2. a) Side view for a flow having a stationary lee hydraulic jump.
b) Side view for a flow having a moving lee hydraulic jump.

Fig. 3. Plan view for a flow in a channel whose width varies only in the section of a mountain range.

The unsteady flow régime can be divided into two régimes: region ②-a, a quasi-steady flow in which the lee jump stays in the lee of the mountain (Fig. 2a); and region ②-b, an unsteady flow in which the lee jump moves downstream (Fig. 2b). Between region ②-b and ③, there exists a hysteresis region ④ in which the flow is either partially blocked without a lee jump or super-critical depending on the initial condition. The line which divides region ③ and region ④ can be obtained as the line where the moving speed of the upstream jump becomes zero, and it is expressed by the following equation (Baines and Davies, 1980; Baines, 1987);

$$M_c = \frac{(8F_0^2 + 1)^{\frac{3}{2}} + 1}{16F_0^2} - \frac{1}{4} - \frac{3}{2}F_0^{\frac{2}{3}}. \quad (2)$$

When the channel width varies, the critical flow is established at the section called the *pseudo-crest* or *control point* (Arakawa, 1969; Gill, 1977; Armi, 1986), which is defined as the point where the following condition holds:

$$\frac{1}{b} \frac{db}{dx} - \frac{1}{h} \frac{dh}{dx} = 0, \quad (3)$$

where m is the height of the mountain slope and b is the width of the channel. When the highest point of the mountain and the narrowest section of the channel coincide, the crest of the mountain range becomes the pseudo-crest, and the following critical flow condition holds:

$$\frac{u_c^2}{gh_c} = 1. \quad (4)$$

In this study, we consider a case in which the channel width varies only in the section of a mountain range, as illustrated in Fig. 3. Then, Bernoulli's law and the mass-flux conservation equation are valid for the flow shown in Figs. 2a, 2b:

$$\frac{u_i^2}{2g} + h_i = \frac{u_c^2}{2g} + h_c + m_c, \quad (5)$$

$$h_i u_i b_0 = h_c u_c b_c, \quad (6)$$

where b_c is the channel width at the narrowest section and b_0 is the channel width at the inflow section. By replacing h_i and u_i in Eqs. (5) and (6) with h_0 and u_0 , and eliminating h_c and u_c in Eq. (4), the following critical curve equation for a flow over a mountain range in a channel of variable width can be obtained (Arakawa, 1969):

$$M_c = 1 + \frac{1}{2}F_0^2 - \frac{3}{2} \left(\frac{F_0}{B_c} \right)^{\frac{2}{3}}. \quad (1')$$

Here, $B_c = b_c/b_0$ is the ratio of the channel width at the narrowest section to that at the inflow section. The right-hand side of Eq. (1') realizes its minimum value, $1 - B_c^{-1}$, when $F_0 = B_c^{-\frac{1}{2}}$.

For the upstream jump, J_L , the following constant jump conditions are valid:

$$h_0 u_0 - h_i u_i = c_L (h_0 - h_i), \quad (7)$$

$$c_L = u_0 - \sqrt{\frac{h_i}{h_0} g \frac{h_0 + h_i}{2}}. \quad (8)$$

We can calculate five unknown variables c_L , u_i , h_i , h_c , c_R from Eqs. (4)–(8). When $c_L=0$, the following equation for the line which divides region ③ and region ④ is obtained by using a constant jump condition for the stationary jump:

$$M_c = \frac{(8F_0^2 + 1)^{\frac{3}{2}} + 1}{16F_0^2} - \frac{1}{4} - \frac{3}{2} \left(\frac{F_0}{B_c} \right)^{\frac{2}{3}} \quad (2')$$

Eq. (1') and Eq. (2') cross at $M_c = 3/2(1 - B_c^{-\frac{2}{3}})$ when $F_0 = 1$.

For the flow shown in Fig. 2b, Bernoulli's law, the mass-flux conservation equation, constant jump conditions for J_R and the rarefaction wave condition (Houghton and Kasahara, 1968) are valid:

$$\frac{u_i^2}{2g} + h_i = \frac{u_b^2}{2g} + h_b, \quad (9)$$

$$h_i u_i b_0 = h_b u_b b_0, \quad (10)$$

$$h_b u_b - h_d u_d = c_R (h_b - h_d), \quad (11)$$

$$c_R = u_b = \sqrt{\frac{h_d}{h_b} g \frac{h_b + h_d}{2}}, \quad (12)$$

$$u_d - 2\sqrt{gh_d} = u_0 - 2\sqrt{gh_0}. \quad (13)$$

We can calculate the values of five unknowns, c_R , u_b , h_b , u_d , and h_d , by Eqs. (9)–(13).

For the flow shown in Fig. 2a, Eqs. (9)–(12) are replaced by

$$\frac{u_i^2}{2g} + h_i = \frac{u_-^2}{2g} + h_- + m_j, \quad (14)$$

$$\frac{u_d^2}{2g} + h_d = \frac{u_+^2}{2g} + h_+ + m_j, \quad (15)$$

$$h_i u_i b_0 = h_- u_- b_j = h_+ u_+ b_j = h_d u_d b_0, \quad (16, 17, 18)$$

$$u_- - \sqrt{\frac{h_+}{h_-} g \frac{h_- + H_+}{2}} = 0. \quad (19)$$

In Eq. (19), we have assumed that the jump region (Δx) is very limited so that dm/dx in the jump region is negligible compared to $(h_+ - h_-)/\Delta x$. In this case, there are eight unknown variables, u_- , h_- , u_+ , h_+ , u_d , h_d , m_j and b_j . If some relation between m_j and b_j is added to Eqs. (13)–(19), the values of these unknowns can be calculated as the solutions of the eight simultaneous equations.

3. Results

The solutions of the flow having a lee hydraulic jump were calculated for various values of B_c , M_c and F_0 . In this section, the results for the case in which the height of the mountain and the width of the channel are related by

$$b = b_0 + (b_c - b_0) \frac{m}{m_c}. \quad (20)$$

are shown. This relation is obtained from the profiles of the mountain and channel width, which are illustrated in Figs. 2 and 3,

$$\begin{cases} m = \frac{m_c}{2}(1 + \cos x) & (-\pi \leq x \leq \pi) \\ m = 0 & (x < -\pi, \pi < x) \end{cases}, \quad (21)$$

$$\begin{cases} b = b_0 + \frac{1}{2}(b_c - b_0)(1 + \cos x) & (-\pi \leq x \leq \pi) \\ b = b_0 & (x < -\pi, \pi < x) \end{cases}. \quad (22)$$

In fact, the solutions depend only on Eq. (20) independently of Eqs. (21) and (22). For the flow régime in which the lee jump moves downstream, the solutions depend only on the value of b_c/b_0 , independently of Eq. (20).

Figures 4a–4c show the moving speed of J_R or the height of the mountain slope at which J_R stays as a function of F_0 and M_c . Following Houghton and Kasahara (1968), each value is normalized by the phase speed of the gravity wave or h_0 as $C_R = c_R/(gh_0)^{1/2}$ or $M_j = m_j/h_0$. In each figure, the heavy broken line shows the line of $C_R=0$, which divides the flow régimes into an unsteady region and a quasi-steady region. In the region above this curve J_R moves downstream as shown in Fig. 2b. While, in the region below this curve J_R stays on the lee slope of the mountain, as shown in Fig. 2a.

When the channel width is constant ($B_c=1.0$), the result (Fig. 4b) coincides with Houghton and Kasahara's one (there Fig. 9). In the unsteady region in which J_R moves downstream, C_R increases with the increase of M_c , while in the quasi-steady region in which J_R stays, M_j is not affected significantly by the change of M_c , and increases with the increase of M_c when M_c is greater than about 0.6. These relations are shown in Figs. 5a and 6a for the cases of $F_0=1.0$ and 0.3, respectively.

When the channel width decreases ($B_c=0.8$), the critical curve shifts to the upper-left as shown in Fig. 4a, and the flow becomes unsteady, even for a lower mountain height. In an unsteady region, C_R increases compared to Fig. 4b, while in a quasi-steady region, M_j decreases compared to Fig. 4b. When the channel width increases (Fig. 4c, $B_c=1.2$), a reverse tendency appears. The critical curve shifts to the lower-right and the steady region extends. In an unsteady region C_R decreases compared to Fig. 4b, while, in a quasi-steady region the jump develops on the more windward side.

Figure 5b shows the value of C_R as well as the velocity of the fluid just before and behind the hydraulic jump ($U_b = u_b/u_0$ and $U_d = u_d/u_0$) against B_c for the case of $(F_0, M_c) = (1.0, 0.5)$, which is shown by the ★ in Figs. 4a–4c. The change of the

Fig. 4. Contour lines of C_R (solid lines) and M_j (broken lines) as a function of F_0 and M_c , respectively. Heavy broken line shows the line of $C_R=0$. ★ and ☆ indicate the locations for the cases of $(F_0, M_c) = (1.0, 0.5)$ and $(F_0, M_c) = (0.3, 0.5)$, respectively. a) For the case of $B_c=0.8$; b) For the case of $B_c=1.0$; c) For the case of $B_c=1.2$

Fig. 5. a) The M_c -dependence of C_R and the normalized fluid speed just before and behind the moving lee jump ($U_b = u_b/u_0$, $U_d = u_d/u_0$). For the case of $(F_0, B_c) = (1.0, 1.0)$. b) The B_c -dependence of C_R , U_b and U_d . For the case of $(F_0, M_c) = (1.0, 0.5)$.

values of C_R , U_b and U_d in this figure is similar to that against M_c in Fig. 5a. Namely, in the unsteady region the decrease of B_c and the increase of M_c each contributes in the same way to C_R , U_b and U_d . This result confirms Arakawa's (1969) suggestion that the decrease of the channel width deforms a steady flow in the same way as does the increase of the mountain height.

Figure 6b shows the value of M_j and the velocity of the fluid just before and behind the hydraulic jump ($U_- = u_-/u_0$ and $U_+ = u_+/u_0$) against B_c for the case of $(F_0, M_c) = (0.3, 0.5)$, which is shown by the ☆ in Figs. 4a–4c. The change of the values of U_- and U_+ in this figure is similar to that in Fig. 6a. However, in Fig. 6b M_j decreases monotonically with the decrease of B_c , and this tendency is dissimilar to that in Fig. 6a. Namely, in the region in which the jump stays on the lee slope of the mountain, Arakawa's (1969) suggestion does not hold regarding the location of the stationary jump. U_- increases with the decrease of B_c and reaches about 4 when $B_c=0.6$; however, U_+ does not vary signifi-

Fig. 6. a) The M_c -dependence of M_j and the normalized fluid speed just before and behind the stationary lee jump ($U_- = u_-/u_0$, $U_+ = u_+/u_0$). For the case of $(F_0, B_c) = (0.3, 1.0)$. b) The B_c -dependence of M_j , U_- and U_+ . For the case of $(F_0, M_c) = (0.3, 0.5)$.

cantly with the change of B_c .

Figures 7a–7c show the side views for the profiles of a quasi-steady state flow for the cases of $(F_0, M_c) = (0.3, 0.5)$. The mountain shape and the width of the channel are given by Eqs. (21) and (22). Solutions for other profiles are obtained easily by suitable stretching of the x -axis. As shown in these figures, when the channel width decreases, the upstream jump and rarefaction wave, as well as the lee jump, become clear. On the other hand, they become obscure with the increase of the channel width.

4. Summary and concluding remarks

Unsteady and quasi-steady state solutions of shallow water flow having a lee hydraulic jump are calculated by expanding Houghton and Kasahara's (1968) theoretical model to the flow over a mountain range in a channel of variable width. The equation of the conservation of mass-flux through a rectangle cross-section is used on the basis of the hydraulic assumptions. When the channel width decreases, flow

Fig. 7. Side view of a profile of the quasi-steady state flow calculated by theoretical solutions for the case of $(F_0, M_c) = (0.3, 0.5)$. The depth of the fluid is normalized by h_0 . The locations of the upstream jump and the rarefaction wave are not meaningful since they each move upstream or downstream respectively. a) For the case of $B_c = 0.8$; b) For the case of $B_c = 1.0$; c) For the case of $B_c = 1.2$.

over the mountain range increases its unsteadiness and the occurrence of a lee hydraulic jump becomes more probable. In an unsteady region in which a lee jump moves downstream, the moving speed of the lee jump is increased both by the decrease of the channel width and by the increase of the mountain height. This tendency appears to confirm Arakawa's (1969) results for the steady state flow which indicated that the flow is deformed by a channel in the same way as by a mountain. On the other hand, in a quasi-steady region in which a lee jump stays in the lee of the mountain, the jump develops on the more leeward side when the channel width decreases, while it tends to develop on the more windward side when the mountain height increases. Namely, Arakawa's (1969) suggestion does not hold for the location of the stationary jump.

The velocity of the fluid just before the hydraulic

jump increased with the decrease of the channel width. This result corresponds to the fact that strong downslope winds tend to occur in the lee of a col of a mountain range.

The response of the lee jump in a quasi-steady régime to the magnitude of the channel width shown in Section 3 is analogous to the behavior of an internal hydraulic jump in a non-linear flow over a mountain range with a col shown by Saito (1992). The result that the location of the lee jump moves windward when the channel width increases is consistent with the fact that the internal hydraulic jump in a stratified atmosphere tends to stay in the lee of the mountain when the wind flows around the mountain (Smolarkiewicz and Rotunno, 1989; Crook *et al.*, 1990). However, in the atmospheric flow which flows around a three-dimensional mountain, the outward deflection of the stream line by the mountain remains downstream. A flow in a channel whose width increases in the section of the mountain range and does not return to its original value may correspond to such a case. In such a case, the propagation speed as well as the location where the stationary jump develops may be affected more significantly by the variation of the channel width compared to the cases herein, in which we have assumed that the channel width varies only in the section where the mountain range exists and is constant in other sections. If the channel width decreases in the section of a mountain range and does not return to its original value, the occurrence of the quasi-steady state in which the jump stays may become difficult. There are many uncertainties concerning the relationship between the behavior of the hydraulic jump in shallow water fluid and that of the internal hydraulic jump in a stratified atmosphere. More studies should be conducted in order to understand further the analogy between the two.

In this study, the hydraulic assumptions are used, thus the channel width is assumed to vary so gradually that the u -component of the velocity of fluid in each section is effectively uniform. When the channel width varies abruptly, this assumption is not appropriate since the potential vorticity is not exactly conserved in such a case, and the abrupt changes in orography cause violation of the hydrostatic assumption. Numerical experiments using appropriate start-up procedures and careful treatment of the lateral boundary condition at the side walls of the channel may be able to verify the adequacy of these assumptions for the cases dealt with in this study.

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References

- Akiyama, To., 1956: On the occurrence of the local severe wind "Yamaji". Part 1. *J. Meteor. Res.*, **8**, 627–641 (in Japanese).
- Arakawa, S., 1969: Climatological and dynamical studies on the local strong winds, mainly in Hokkaido, Japan. *Geophys. Mag.*, **34**, 349–425.
- Armi, L., 1986: The hydraulics of two flowing layers with different densities. *J. Fluid Mech.*, **163**, 27–58.
- Baines, P.G. and P.A. Davies, 1980: Laboratory studies of topographic effects in rotating and/or stratified fluids. In *orographic effects in planetary flows. GARP publication*, **23**, WMO/ISCU 233–299.
- Baines, P.G., 1987: Upstream blocking and air flow over mountains. *Ann. Rev. Fluid Mech.*, **19**, 75–97.
- Crook, N.A., T.L. Clark and M.W. Moncrieff, 1990: The Denver cyclone. Part 1: Generation in low Froude number flow. *J. Atmos. Sci.*, **47**, 2725–2742.
- Durrán, D.R., 1986: Another look at down slope windstorms. Part 1: On the development of analogs to supercritical flow in an infinitely deep, continuously stratified fluid. *J. Atmos. Sci.*, **43**, 2527–2543.
- Gill, T., 1977: The hydraulics of rotating-channel flow. *J. Fluid. Mech.*, **80**, 641–671.
- Houghton, D.D. and A. Kasahara, 1968: Non-linear shallow fluid over an isolated ridge. *Commun. Pure Appl. Math.*, **21**, 1–23.
- Lawrence, G.A., 1990: On the hydraulics of Boussinesq and non-Boussinesq two-layers flows. *J. Fluid Mech.*, **215**, 457–480.
- Lilly, D.K. and E.J. Zipser, 1972: The front range windstorm of 11 January 1972—a meteorological narrative. *Weatherwise*, **25**, 56–63.
- Long, R.R., 1953: A laboratory model resembling the "Bishop-Wave" phenomenon. *Bull. Amer. Meteor. Soc.*, **34**, 205–211.
- Long, R.R., 1954: Some aspects of the flow of stratified fluids. 2. Experiments with a two-fluid system, *Tellus*, **6**, 97–115.
- Long, R.R., 1970: Blocking effects in flow over obstacles. *Tellus*, **22**, 471–480.
- Pitts, R.O. and T.J. Lyons, 1989: Airflow over a two-dimensional escarpment. 1: Observations. *Quart. J. Roy. Meteor. Soc.*, **115**, 965–981.
- Pitts, R.O. and T.J. Lyons, 1990: Airflow over a two-dimensional escarpment. 2: Hydraulic flow. *Quart. J. Roy. Meteor. Soc.*, **116**, 363–378.
- Saito, K. and M. Ikawa, 1991: A numerical study of the local downslope wind "Yamaji-kaze" in Japan. *J. Meteor. Soc. Japan*, **69**, 31–56.
- Saito, K., 1992: A numerical study of the local downslope wind "Yamaji-kaze" in Japan. Part 2: Non-linear aspect of the flow over a mountain range with a col. (manuscript in preparation)

Smith, R.B., 1987: Aerial observations of the Yugoslavian Bora. *J. Atmos. Sci.*, **44**, 269–297.
Smolarkiewicz, P.K. and R. Rotunno, 1989: Low Froude

number flow past three-dimensional obstacles. Part 1: Baroclinically generated lee vortices. *J. Atmos. Sci.*, **46**, 1154–1164.

浅水流に生ずるハイドロリックジャンプの流路幅の変化への応答

齊藤和雄

(気象研究所予報研究部)

運河の中の流れに直交する山脈を越える浅水流体についての Houghton and Kasahara (1968) の理論的モデルを拡張し、山脈域で流路幅が変化する場合のハイドロリックジャンプを伴う流れの解を求めた。

山脈の風下側に移動するジャンプを伴う非定常な流れのレジームでは、流路幅の減少と山脈の高さの増大はいずれもジャンプの移動速度を増大させる。この結果は、山を越す流れと谷間を吹き抜ける流れは同じ様に変形される事を示した Arakawa (1969) の定常流についての指摘を裏付ける。一方、山脈の後面にジャンプが停滞する準定常な流れのレジームでは、ジャンプは流路幅が減少する場合にはより風下側に発生し、流路幅の減少と山脈の高さの増大はジャンプの停滞位置に関してはむしろ反対の効果を持つ場合がある事が分かった。この領域における流路幅の変化に対するジャンプの位置の振舞は、鞍部を伴う山脈を越える大気に生ずる内部ハイドロリックジャンプの振舞と類似が見られる。

ジャンプの手前の流速は流路幅の減少とともに増大し、この結果は強いおろし風が鞍部を伴う山脈の鞍部風下側に発生する傾向がある事に対応している。