Investigations of Strong Valley Winds in Alaska Using Satellite Infrared Imagery

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ABSTRACT

During the Alaskan cold season, the extreme low temperatures that prevail in the interior valleys are significantly modified by valley wind episodes. The infrared sensor on the NOAA polar orbiting satellite clearly detects this warming and delineates the exact area covered by valley winds. Satellite IR images were used in conjunction with surface and upper air maps, radiosonde data, and pilot reports to analyze two valley wind episodes during early 1975. Clear weather allowed excellent satellite viewing and strong temperature contrasts, because of strong radiational cooling in non-windy valley locations. In both cases a high-amplitude 500 mb ridge was moving into the interior from the west with a strong surface high centered east of the windy area. The strength of the surface wind correlated well with the strength of the surface pressure gradient parallel to the valleys. The wind originated in the narrow sections of the valleys and consistently gusted to 45 kt in the Tanana Valley. The ability of the satellite to view these areas of warming and associated turbulence will alert forecasters to valley wind episodes where there are no conventional surface observations or pilot reports.

1. Introduction

The occurrence of valley winds is well known and in the literature we find many theoretical computations and experimental observations to relate the speed of these valley winds to pressure gradient force and valley slope (for example, by Rao, 1970; Davidson and Rao, 1958; Defant, 1949). In addition to these reports, Mitchell (1956) and an unpublished report by M/Sgt. Lawrence Ray at Fort Greely, Alaska, discuss the occurrence of strong surface winds at Big Delta, Alaska, and indicate typical surface and 500 mb synoptic situations that are associated with these winds. The interesting features in these reports are that Big Delta usually experiences its first gusty surface winds when its surface pressure is 2 mb lower than that at Northway, Alaska, and that the temperature at Big Delta may rise by as much as 60°F when these winds occur, which is from late fall to late spring.

In Alaska, the increase in temperature of the valley surface during wind episodes always occurs during the cold season. The surface temperature inversions that occur under clear sky conditions are broken by these winds, the warmer air aloft is brought to the surface by mixing, and the valley surface temperature rises nearly to that of the surrounding mountain top temperatures. Therefore, satellite observation of the warming of valleys can be a primary indicator of the existence of valley winds.

The infrared (IR) channel of the very high resolution radiometer (VHRR) aboard the NOAA-4 polar orbiting satellite can detect temperature differences as small as 0.5°C at a spatial resolution of 1 km. Hence, IR imagery can be used to delineate valleys subjected to winds by virtue of the observed rise in temperature. We have observed the occurrence of bands of relatively high temperature along certain river valleys from the NOAA-4 IR imagery. We have chosen two periods during the winter of 1974–75 to investigate the meteorological conditions that initiate valley winds in interior Alaska. Because the meteorological situation causing the valley winds is very much the same in both cases as well as in other incidents, we propose that certain conditions are necessary for initiating valley winds.

2. Area of investigation

For convenience and for ease of obtaining surface and other meteorological data, we have restricted our analysis to an area within about 320 km of Fairbanks, Alaska. The topography of this area consists of three mountain ranges: a) Brooks Range to the north of Fairbanks, b) Alaska Range to the south, and c) White Mountains to the northeast. Of the many river valleys in this area, those that are wide enough to show the warming from the satellite pictures, yet narrow enough to initiate valley winds, are the Tanana River Valley from Northway to Big Delta, the Yukon River Valley northeast of Tanana, the Susitna River Valley north of Talkeetna, and the northern Copper River Valley (see Fig. 1).

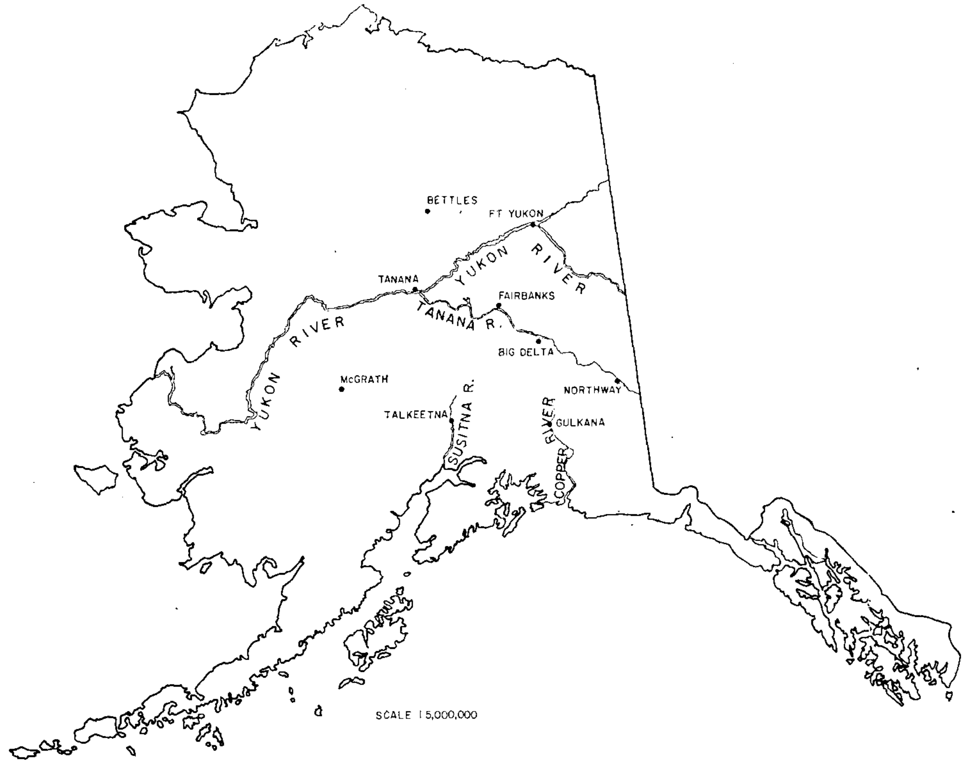


FIG. 1. Map of Alaska showing the river valleys considered in this study.

3. Observations

The warming of the valleys was observed using the infrared imagery of the NOAA-4 satellite. The characteristics of this satellite are shown in Table 1, and many other meteorological applications of the imagery from these and the other sister satellites are indicated by Rao and McClain (1974) and Streten (1974). The IR imagery from these satellites is an indicator of the radiative temperature of the emitting surface and, by convention, the gray tone of the NOAA satellite IR imagery is proportional to the radiative temperature, so the darker areas are warmer than the lighter areas. By using calibration in the spacecraft, the temperature can be directly read from the gray tone.

TABLE 1. NOAA-2, -3, and -4 satellites.

Orbit characteristics:	NOAA-2*	NOAA-3	NOAA-4
Altitude: Apogee	1453.98 km	1509.22 km	1457.73 km
Perigee	1448.10 km	1500.07 km	1443.88 km
Inclination (ascending)	101.771°	120.032°	101.732°
Period	115.00767 min	116.08574 min	114.89850 min
Equator crossing (descending)	0852 local time	0830 local time	0830 local time
Rate of precession of orbit plane	0.9874 deg/day	0.9894 deg/day	0.9887 deg/day
On board sensors:	Very High Resolution Radiometer (VHRR) Scanning Radiometer (SR) Vertical Temperature Profile Radiometer (VTPR) Solar Proton Monitor (SPM)		

VHRR characteristics (NOAA-3 and -4):	
Visible channel:	0.6–0.7 μm
Infrared channel:	10.5–12.5 μm
Brightness range (VIS):	65 to 10^4 foot-lamberts
Scene temperature range (IR):	180–315 K
Spatial resolution	0.9 km at nadir

* NOAA-2 is not being tracked presently.

The two periods chosen for our investigation were from 31 January to 4 February 1975, and 7–10 March 1975. These periods were mostly cloud-free over the area under study and the synoptic situation changed sufficiently through each period to allow us to follow the development of valley winds in this area. Surface meteorological observations are available hourly at some stations so that surface isobars could be drawn to the nearest hour of the satellite pass. In addition, a few pilot reports (PIREPS) relating to wind conditions were also available in or near these valleys. The 850 mb and 500 mb weather maps prepared by the Weather Service Forecast Office (WSFO) at Fairbanks and their radiosonde data at 0000 GMT and 1200 GMT were also used to determine the upper air conditions during the valley wind episodes.

The NOAA-4 satellite passes over interior Alaska at about 0500 GMT and 2000 GMT every day. The imagery from these two passes covers the entire area of interest and is available to us in digital and photographic form in near real-time from the Gilmore Creek Tracking Facility. The radiative temperature of the ground was determined by measuring the gray tone of a negative transparency using a microdensitometer.

4. Analysis and discussion

Our analysis was primarily a comparison of the meteorological situation as presented by the satellite

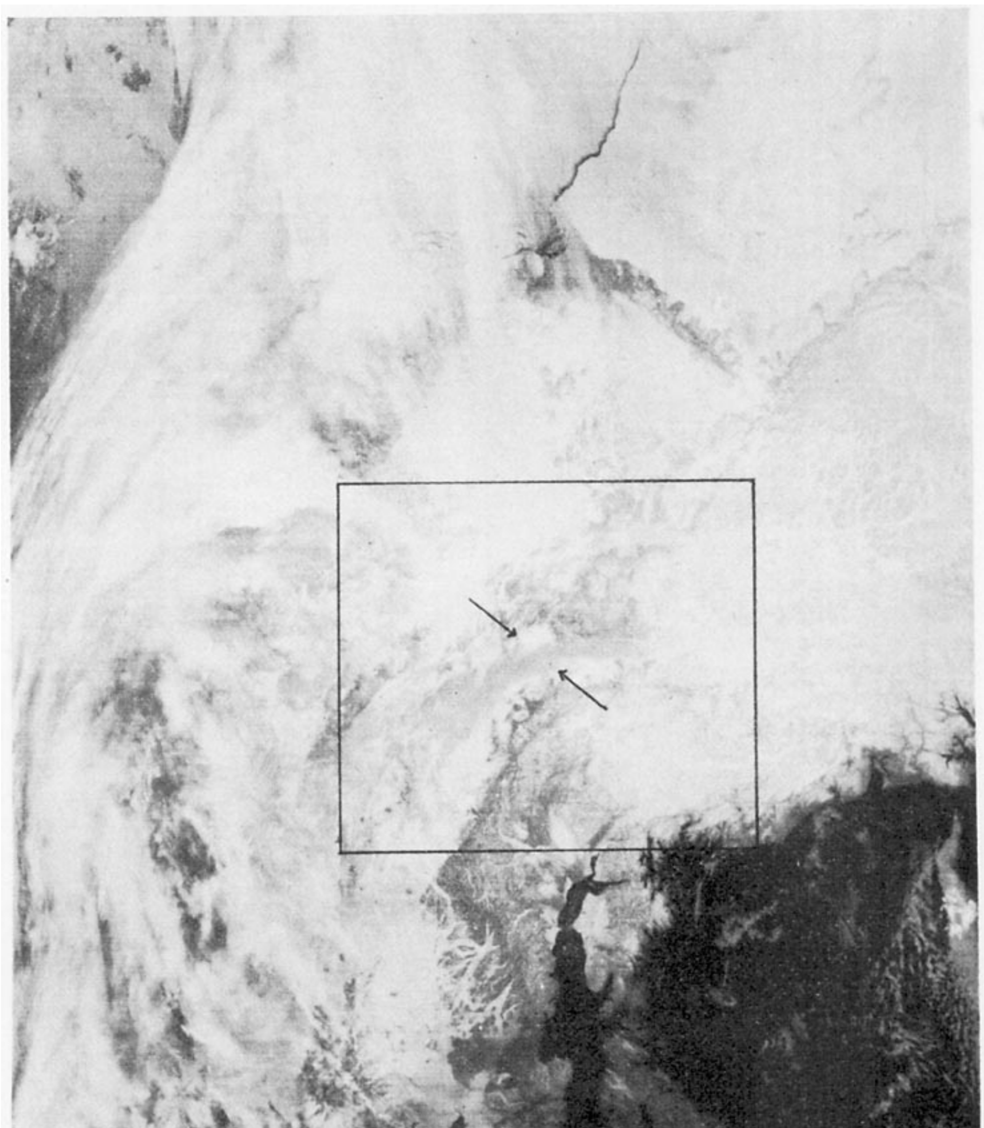


FIG. 2. *Continued* p. 1132

(b)

FIG. 2. (a) NOAA-4 very high resolution infrared imagery for 2 February 1975 showing the dark band (indicated by the arrows) caused by warming of the Tanana Valley by winds. (b) Enlargement of the boxed area of Fig. 2a with the temperature contours in °F. (This area includes the area under investigation.)

surface, 850 mb, 500 mb pressure maps, and the Fairbanks Rawindsonde Observation (RAOB). These levels were chosen because we believe any local dynamic effects may be detected from the surface maps, and 500 mb pressure maps indicate the influence of general large-scale weather patterns on valley wind phenomena. The 850 mb data are chosen because it is believed that synoptic situations at this level have important implications on the weather of interior Alaska (Willis and Grice, 1975). The Fairbanks RAOB is useful to show the vertical structure of the wind and temperature.

When there are strong valley winds during the winter months, the IR imagery from the NOAA satellites shows a dark band (relatively warm surface) as illustrated in Fig. 2a. Unlike most clouds, this band will appear to have a very smooth texture and will be coincidental with the valley. In Fig. 2b the satellite temperature contours are drawn for the boxed area of Fig. 2a, which is essentially the area under investigation. These temperature contours suggest that in the Tanana Valley the dark bands, i.e., the area warmed by the winds, may be represented by the −23°C (−10°F) contour line for the first period (31 January–4 February) and by the −6.5°C (20°F) contour line for the second. This demarcation temperature, of course, is rather arbitrary and very dependent on the period under study; but for the investigation mentioned here, these two values represent the approximate equilibrium temperature to which the valley floors were warmed by continuous mixing. We may also mention here that the white areas in Fig. 2 may be as cold as −46°C (−50°F), while some south slopes of ridges are near −17.5°C (0°F).

The boundaries of the warmed area were then transferred into a base map to produce maps shown in Fig. 3a, b, c. From hourly surface charts and twice daily satellite observations we found that the winds originate in the narrowest part of the river valley. The winds spread along to the wide flats after they have developed substantially. The repeated initiation of the winds in these similar locations indicates the importance of the inter-play between the local topography and meteorology in the generation of valley winds.

In order to infer these local conditions, we have also plotted on these maps the surface weather observations within an hour of the satellite pass and the mean sea

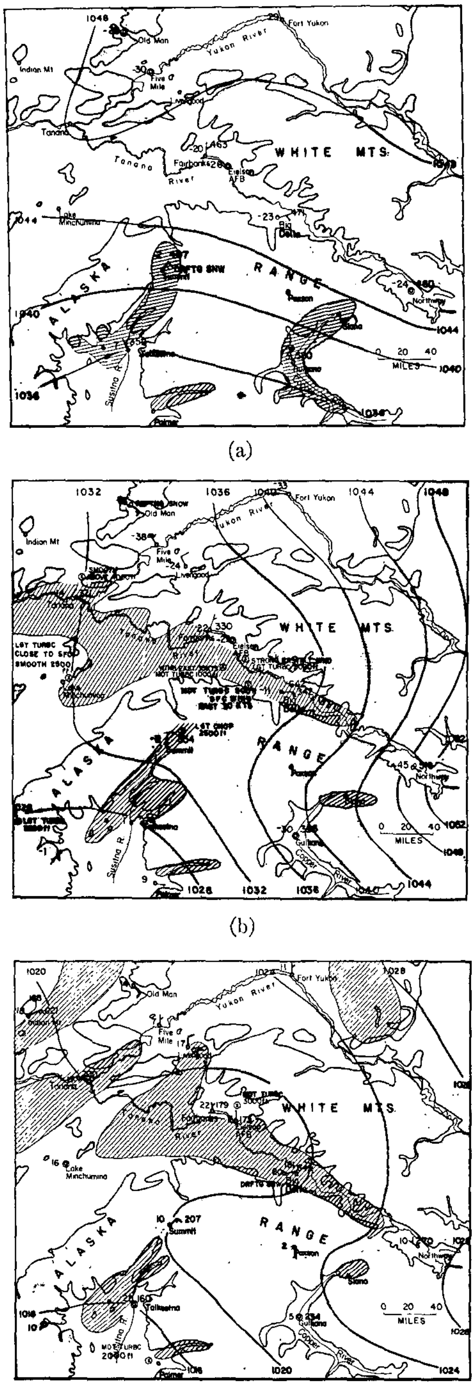


Fig. 3. Surface maps showing surface observations, isobars and hatched wind areas. The temperature is in °F. (a) 31 January 1975 at 0005 GMT. (b) 2000 GMT 2 February 1975. (c) 2100 GMT 8 March 1975. (All terrain above 600 m or 2000 ft is shaded to outline the valleys.)

level isobars at 4 mb intervals. Our analysis then consists of following the development and changes of the winds with these meteorological parameters and the upper air conditions.

In order to illustrate the important points of our inferences, we will now discuss the situations for the three days indicated in Fig. 3a, b, c.

a. 31 January 1975

This day corresponds to a typical situation where valley winds begin to develop in this area. A high-amplitude 500 mb ridge was located over western Alaska with a strong straight dry flow from the north over the entire area of interest. Ridging was also strong over western and central Alaska at all lower levels. The Fairbanks RAOB showed northerly winds increasing with height up to 500 mb. This situation allowed for clear skies, strong radiational cooling, and formation of a strong east-west surface pressure ridge in the wide interior flats. The result was a strong north-south pressure gradient over the Alaska Range to the south (Fig. 3a). We observed warming in the IR imagery and significant winds were reported south of the range in the Susitna and Copper River valleys (see Fig. 4). There was a sea level pressure difference of about 6 mb in these two valleys when the wind developed, blowing from higher pressures in the cold interior to lower pressures along the southern coast. A weak pressure gradient and little wind was observed in the interior.

b. 2 February 1975

In the days following 31 January, the 500 mb ridge developed eastward and northeastward into the interior region with anticyclonic flow aloft and a decrease in wind speeds (Fig. 5a). By 2 February the 850 mb ridge center had correspondingly moved eastward into the northern Yukon, setting up a strong flow at low levels from the southeast in the Fairbanks area, paralleling the Tanana Valley (Fig. 5b). The surface high pressure center on 2 February (Fig. 3b) had moved to central Yukon Territory, setting up a surface pressure gradient parallel to the Tanana Valley.

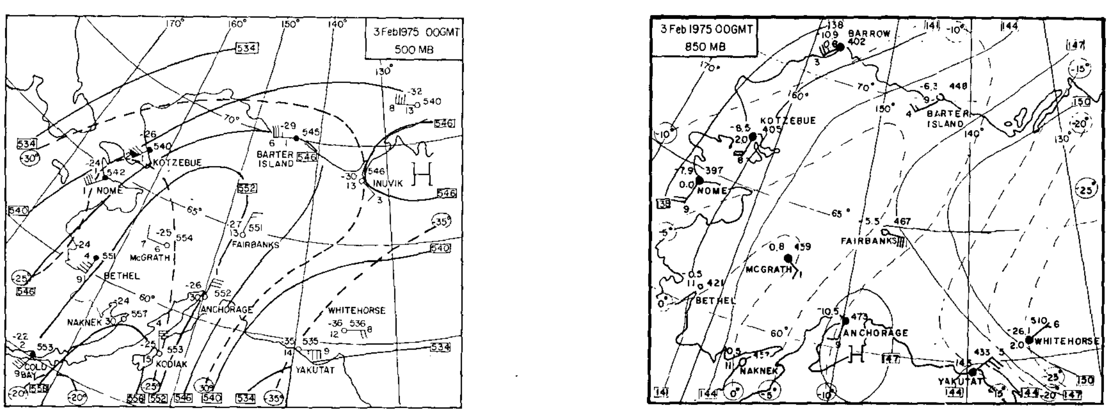
In the Tanana Valley between Northway (elev. 520 m) and Big Delta (elev. 335 m), a sea-level pressure difference down the valley of 17 mb was established. (Up to 3 mb of this difference results from reduction of the pressures to sea level.) The winds first became noticeable in this narrow part of the valley and then extended along the river all the way to the Yukon River beyond the town of Tanana as the pressure gradient increased along the river. Notice that, during this day, the whole Tanana-lower Yukon River Valley is virtually normal to the isobars while the narrow upper Yukon Valley southeast of Ft. Yukon is nearly parallel to them. Consequently, no significant warming is observed along this latter valley. Subsequent to this day, the gradient became parallel to this part of the Yukon River and valley winds were observed there on 3 February. Meanwhile the winds along the Susitna and Copper rivers ceased, the gradient now being perpen-

FIG. 4. Existence of winds in the Susitna and Copper River valleys on 21 January 1975 is indicated as dark bands in the IR imagery while Tanana Valley without wind remains cold and appears white. (A, B, and C denote Tanana, Susitna, and Copper River valleys).

dicular to these two valleys. During this period, the Tanana River Valley near Big Delta experienced 45 kt wind gusts with temperatures near −23°C (−10°F) while Northway, 100 miles up the valley, and not subjected to winds, had temperatures near −43°C (−45°F).

The Fairbanks RAOBS for this period show a wind speed maximum near 900 mb (about 1200 m) from the east-southeast at 35 kt (Fig. 6). However, Fairbanks is sheltered on the surface from the valley winds, so the balloon must rise to this level to reach the high wind zone. The strongest surface winds at Big Delta occurred when this wind maximum at Fairbanks reached greatest intensity.

Pilot reports showed turbulence in the windy valleys below 1500 m with smooth conditions above, again



(a) (b)

FIG. 5. Upper air pressure systems typical of these valley wind situations: (a) 500 mb, (b) 850 mb.

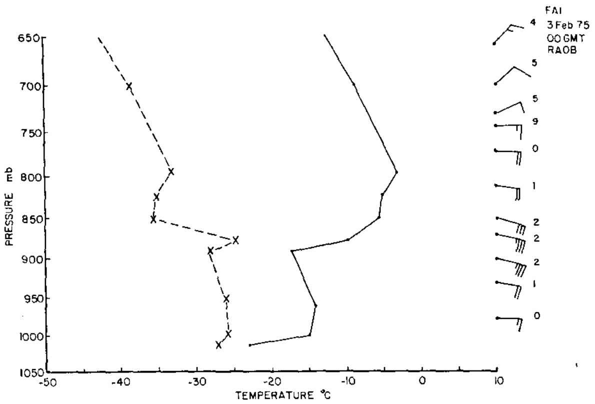


Fig. 6. Radiosonde observation for Fairbanks during a windy period.

demonstrating the low-level nature of this phenomenon.

On the following day, 3 February, the northeast-southwest-oriented 500 mb ridge had moved to the eastern part of the state, allowing middle and high level moisture into the interior. The resultant cloud shield obscured the valleys from view by the end of the day. Surface reports of strong surface winds and a tight pressure gradient in the upper Tanana Valley continued, persisting until the upper air ridge moved east of Alaska altogether.

c. 8 March 1975

Figure 3c is chosen as a representative of the March episode. The situation was very similar to the previous episode. Once again, the high winds (up to 50 kt) in the Tanana Valley began when a 500 mb ridge was located over central Alaska. A northerly flow of dry air aloft and subsidence in the anticyclonic flow pattern created clear skies over the entire area, enabling good satellite viewing of the surface conditions. Light surface winds were observed before this clear weather regime became established. Also similar was the location of the 850 mb ridge in the northern Yukon through the entire period. The surface high center was in southeastern Yukon and a surface pressure gradient of 10 mb was observed between Big Delta and Northway in the upper Tanana Valley. During this 3-day period, a closed anticyclone developed at 500 mb and moved eastward across northern Alaska, setting up southeasterly winds at all levels in the interior. Vertical soundings at Big Delta were available during this period, showing a low level wind maximum in the lowest 600 m, then speeds increasing with height above 700 mb. The Fairbanks RAOB also showed a low level wind maximum about 900 mb (1200 m). The greater height of the wind maximum at Fairbanks may be due to the sheltering effect of nearby hills below 600 m. Pilot reports again indicated moderate turbulence associated with this low level jet. The relationship between the occurrence of valley winds and the orientation of the valley parallel to a strong surface pressure gradient is borne out clearly in this period. Again, from the appearance of dark bands in the IR imagery during this episode, it is evident that the valley winds originated in the narrow portions of the interior valleys of Alaska.

5. Conclusion

In this paper we have used the capability of the VHRR data in the IR sensor of the NOAA satellite to delineate ground temperature differences; to show that, in Alaska during winter, valleys with winds are warmer than calm valleys; and to locate the areas of strong valley winds with accompanying blowing snow and severe turbulence. The ability of the satellite to locate and delineate the exact area covered by such winds should be useful to alert forecasters to strong turbulence warnings in places where conventional observations are not available. Such warnings are extremely useful to aircraft pilots who tend to fly at low levels and follow river valleys. Our analyses confirm that the winds are driven primarily by synoptic-scale surface pressure gradients along narrow valleys. When the surface isobars run parallel to the valleys, the winds are light. Another observation is that the winds, once initiated in the narrow valleys, can extend along the wide flats to very large distances. The typical slope for the Tanana Valley between Fairbanks and Northway is approximately 1 to 1000. This slope is insufficient to cause any strong drainage effects. Thus the synoptic-scale surface pressure gradient seems to be the most important parameter to initiate and maintain strong valley winds.

The changes in the surface pressure patterns are, of course, related to the large scale weather systems moving across the state. We observed the presence of a large amplitude 500 mb ridge to the west of our area of interest at the beginning of both windy periods. This placed the interior valleys under the region of the flow pattern that typically produces subsidence, therefore clear skies and strong radiational cooling at the surface (Bowling *et al.*, 1968; Ohtake, 1970). In both cases, the 850 mb ridge was centered in the northern Yukon, producing strong flow parallel to the Tanana Valley. The surface high center was in the southern half of the Yukon Territory, creating a surface pressure gradient nearly parallel to the valleys. This appeared to be the ideal situation for production of strong valley winds and for good satellite detection of the area affected by these winds.

Once the upper air ridge had moved east of Alaska, satellite viewing was hampered by cloudiness. At this time, surface reports indicated a weakening in the pressure gradient and a major slackening of the resultant winds as the 850 mb and surface ridge centers corresponding moved eastward.

Most likely there are other situations that can lead to valley winds under cloudy conditions. However, it is only under clear skies in winter that the interior of Alaska experiences its most extreme low temperatures and strong surface inversions (Wendler and Jayaweera, 1972). Hence, the strong warming by the valley wind will be most intense under clear skies. Therefore, the IR sensor on the NOAA satellite can be used to detect these dangerous wind areas quite effectively under these conditions.

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