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CRH SSD
APRIL 1993

CENTRAL REGION TECHNICAL ATTACHMENT 93-11

AN OROGRAPHICALLY INDUCED HEAVY SNOW EVENT IN THE BIG HORN MOUNTAINS

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1. Introduction

The forecasting of heavy snow has long been a challenge for the mountainous western states such as Wyoming. Heavy snow events often develop without being directly associated with a synoptic-scale lifting mechanism. On Tuesday, November 3, 1992, such an event occurred in the northern Big Horn Mountains of north central Wyoming.

The Big Horn Mountains are a mountain range located in north central Wyoming and extreme southern Montana with elevations ranging from 4000 ft to over 13000 ft MSL. The Cloud Peak Wilderness Area contains the highest elevations and is regarded as the dividing line between the northern and southern Big Horns.

A heavy snow event developed across the northern Big Horns late on the 2nd of November and continued through Tuesday the 3rd of November. Snow amounts were so heavy across this area that Highway 14, the lone road through the northern Big Horns, was closed for more than 24 hours as numerous cars and trucks were trapped and then buried in the heavy snow.

Though heavy snow events are not uncommon for the Big Horn Mountains, this one set itself apart from the others because of two factors: 1) the amount of snow which fell, and 2) the fact that the snow was produced almost entirely by orographic lifting.

2. The Snow Event

Snow began falling on the afternoon of the 2nd across the area, but much of this snow was convective in nature due to the steep lapse rates (700-500 mb) observed Monday afternoon. Temperature differences between 700 mb and 500 mb across the northern Rockies/Plains were -17°C to -18°C at 5:00 pm MST Tuesday which, by experience, we have found to be a good instability indicator for this area. Sheridan, Wyoming reported snow showers throughout much of the afternoon. Several inches fell in the Big Horn Mountains with these showers. Snow became heavier shortly after midnight on the 3rd as favorable upslope conditions deepened. At 7:00 am, Arrowhead Lodge reported 24 inches and Burgess Junction reported 22 inches of new snow as heavy snow continued. The report of 22 inches from Burgess Junction was the fifth greatest 24-hour snowfall total in the last ten years. Arrowhead Lodge received another 12 inches of snow from 7:00 am to 9:18 am. This was an increase of almost six inches per hour! At 3:30 pm, Arrowhead Lodge and Bear Lodge reported a storm total of 40 inches (Figure 1). Upslope forcing weakened as pressure gradients relaxed and heavy snow diminished by 5:00 pm.

While the northern Big Horns were being buried in 3 to 4 ft of snow, the southern Big Horns were experiencing relatively nice weather in, what can be described as, a "snow shadow". Snow shadows are simply a minimum in snow caused by being on the downwind side of a mountain. Meadowlark Lodge, only 30 miles south of Bear Lodge, reported 1.5 inches of new snow and Powder River Pass received only two inches.

3. Synoptic Situation

During the first few days of November, the central United States was under the effects of a large upper level trough. At 5:00 pm on the 3rd, a 533 dm low pressure center was located over southern Minnesota at 500 mb. An associated surface low was occluding over the upper Mississippi Valley. Another surface low was forming over eastern New Mexico as a 150 kt 300 mb jet and a series of shortwave troughs moved across the central and southern Rockies. At 5:00 am, November 3, the low pressure system remained stationary over Minnesota as the jet maximum moved down the backside of the trough. This enabled sufficient moisture to wrap around the low and move into the northern Rockies/Plains as very strong north winds developed. These strong winds were very deep and extended from the surface through 500 mb. For example, surface winds were northwest at 20 to 30 kts across northern Wyoming (Figure 2). Estimated 850 mb winds were 35 kts from the north with 700 mb and 500 mb winds from the north to northeast at 40 kts.

Thermodynamics, for the same time period, indicated favorable conditions for heavy snow. Very cold air was observed in the upper levels while relatively warm air held in place at the surface to produce an unstable atmosphere. Again, the temperature difference between 700 mb and 500 mb was -17°C upstream at Glasgow, Montana. Plenty of moisture was also available as dew point depressions were less than 3°C at 850 mb, 700 mb, and 500 mb. Average relative humidities throughout the same layer were over 90 percent with precipitable water values of more than 0.30 inches, which was around 100 percent of normal. Abundant moisture and an unstable atmosphere helped set the stage for this significant snow event.

On the other hand, little dynamic forcing was available as the polar jet carried most energy far south of the region. Cold air advection was taking place at lower levels across northern Wyoming and differential cyclonic vorticity advection (DCVA) appeared to be relatively weak. As a result, surface low pressure development occurred in the southern Rockies. Snow amounts for northern Wyoming were substantially less as one left the mountains. This illustrated that although moisture and instability were present, the synoptic-scale lifting mechanism needed to produce heavy snow was absent.

4. Computations

Typically in the mid-latitudes, outside of jet streaks or cumulus convection, synoptic scale vertical motions are on the order of;

$$|\omega| \approx 1\mu b\ s^{-1} \approx 10^{-2} m\ s^{-1} = \mathbf{1cm\ s^{-1}}$$

Common orographic effects such as, "upslope" or "downslope", are comparable to those of synoptic scale. To prove this one can use:

$$\omega \approx -\rho g W$$

Let W=0 at the surface because air cannot penetrate or escape from the ground.

$$\text{Therefore, } \omega \approx 0$$

On the other hand, when the surface slopes, $\omega \neq 0$ and the vertical component (Z) is a function of: zonal (X), meridional (Y), and time (t).

$$Z = Z(X,Y,t)$$

Then vertical motion at the surface is:

$$W_o = (DZ/Dt)_o = [(dZ/dx)\bullet(DX/Dt) + (dZ/dY)\bullet(DY/Dt) + dZ/dt]_o$$

$$W_o = (\mathbf{V}_h \bullet \nabla_h Z)_o + (dZ/dt)_o$$

Allowing $(dZ/dt)_o$ to go to zero because there is negligible change in the surface with time, we have:

$$W_o = (V_h \cdot \nabla_h Z)_o$$

For a typical horizontal wind speed of 10m s^{-1} and for surface elevation gradients such as those found on the high plains

$$W = |(\mathbf{V} \cdot \nabla_h Z)_o| \approx (10m\ s^{-1})(1km/1000km) \approx 10^{-2} m\ s^{-1}$$

$$W \approx \mathbf{1cm\ s^{-1}}\ \text{(upslope/downslope)}$$

Therefore, typical "upslope" or "downslope" conditions are accompanied by vertical motions comparable to those induced by dynamic effects.

$$\text{DYNAMICS} \approx \text{UPSLOPE} \approx 1cm\ s^{-1}$$

As one can see, on the average, dynamic and upslope forcing are comparable when dealing with typical high plains surface elevation gradients. But in the vicinity of mountains very large surface gradients are encountered causing $|(\nabla_h Z)_o|$ to be so large that orographic effects may completely overshadow any dynamic forcing. Aforementioned, upslope flow (W>0) cools the air parcels resulting in clouds and precipitation. The reverse is also true on the leeward side where fair skies and dry conditions often prevail.

The actual wind direction on the 3rd of November was not "ideal" (perpendicular to the ridge axis) for an upslope event in the northern Big Horns. But the magnitude of the wind vector was large enough to support a significant north-south component (**V**) which is an upslope vector.

The following assumptions were made:

NORTHERN BIG HORNS

$$\mathbf{V} = \mathbf{V}_h \approx 35kt \approx 18m\ s^{-1}$$

$$\Delta y \approx 15mi \approx 24.14km$$

$$\Delta z \approx 4000ft \approx 1.22km$$

Note: Δy and Δz were subjectively figured using appropriate distances and heights as to coincide with reported snow totals (Figure 3).

$$W = \mathbf{V}_h \bullet \nabla Z_o$$

$$W = (1.22\text{km}/24.14\text{km})(18\text{m s}^{-1}) = 0.91\text{m s}^{-1}$$

UPSLOPE $W \approx 0.91\text{m s}^{-1}$

SOUTHERN BIG HORNS

South of the Cloud Peak Wilderness Area snow reports were drastically less because of the following:

$$\mathbf{V} = \mathbf{V}_h = 35\text{kt} \approx 18\text{m s}^{-1}$$

$$\Delta y \approx 13\text{mi} \approx 20.92\text{km}$$

$$\Delta z \approx -3000\text{ft} \approx -0.91\text{km}$$

Note: Again numbers were appropriately chosen (Cloud Peak Wilderness Area to Meadowlark Lodge) (Figure 3).

$$W = \mathbf{V}_h \bullet \nabla Z_o$$

$$W = (-0.91\text{km}/20.92\text{km})(18\text{m s}^{-1}) \approx -0.78\text{m s}^{-1}$$

DOWNSLOPE $W \approx -0.78\text{m s}^{-1}$

Forecast synoptic lift for the same time was only 3 μbs^{-1} or 3×10^{-2} m s^{-1} at 700 mb. Therefore, in this case, synoptic lift due to dynamics was two orders of magnitude smaller than mechanical lift!

5. Conclusions

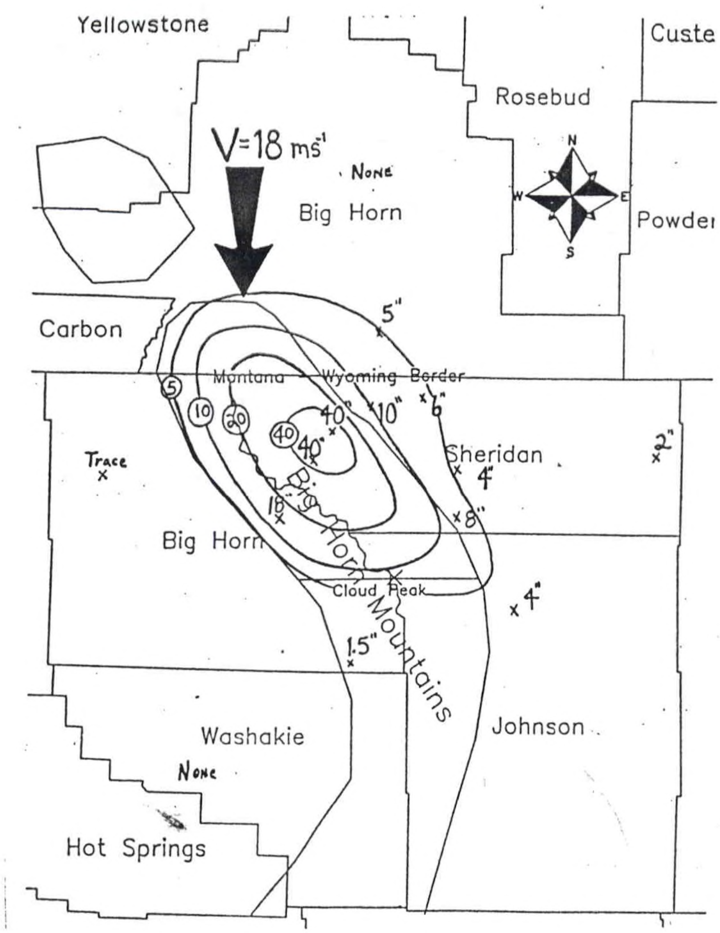
The great variety of topography has, and always will, play a vital role in forecasting weather for the mountainous states. Significant upslope snow events often develop when synoptic-scale lifting would have produced only light amounts. We have used this case to illustrate a synoptic pattern which would result in heavy snow for the northern Big Horn Mountains. Whenever a strong north or northeast component develops through a deep layer across northern Wyoming, sufficient moisture exists (typically early or late in the season), and the temperature is below freezing, heavy snow is likely to occur in the northern Big Horns.

5. Acknowledgements

We would like to extend special thanks to Robert Johns, NSSFC, for the time and effort he donated in his extensive review of this paper. His comments and suggestions were invaluable. We also extend thanks to Edward Jessup, formerly of OSF, Norman, OK, for his time reviewing the paper, and to Jim Harrison, WSFO Cheyenne, WY, for supplying data.

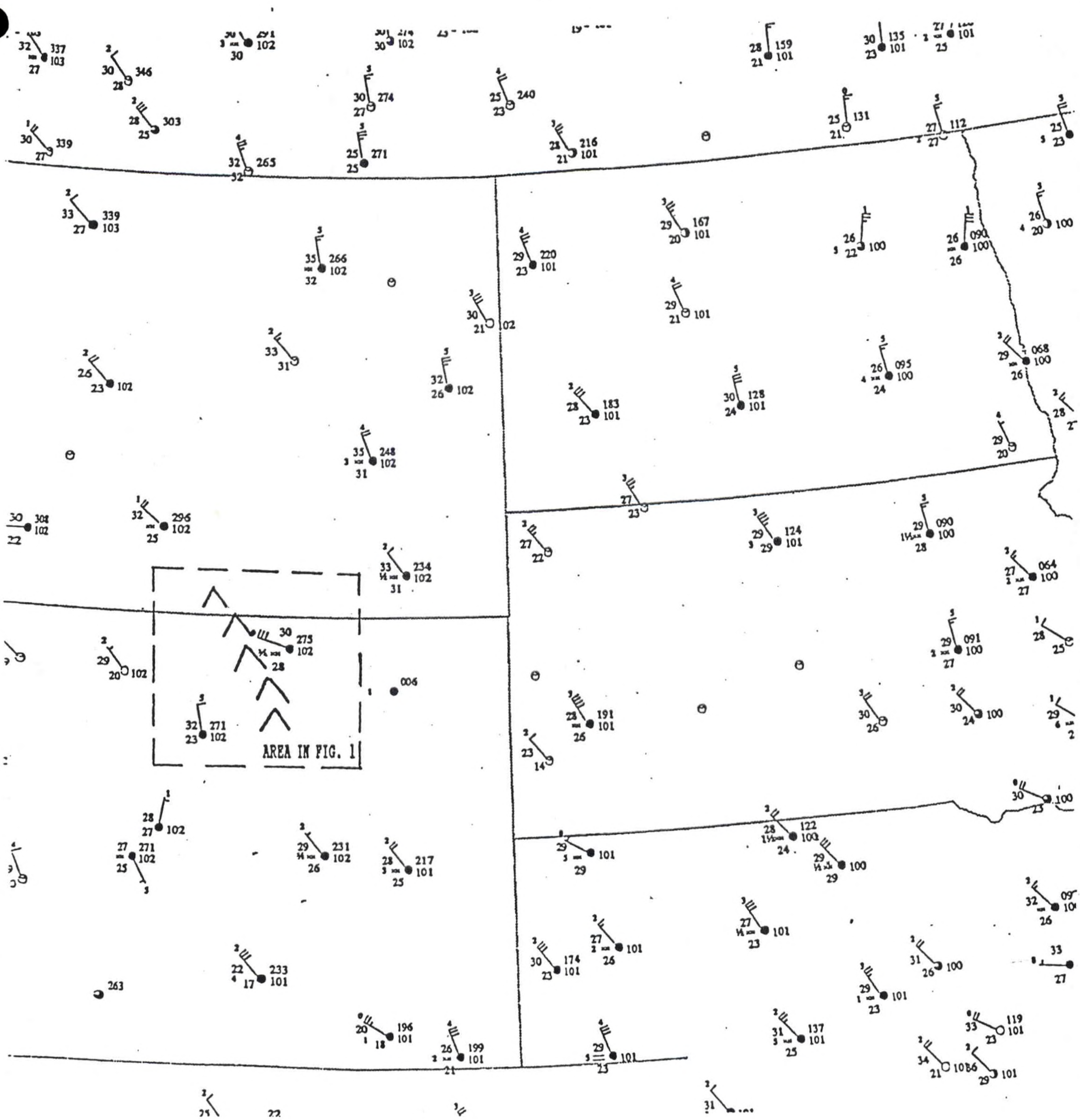
7. References

Bluestein, H., 1990: Synoptic Meteorology Notes. University of Oklahoma, Department of Meteorology.



Snow totals from the 3rd of November 1992.

Figure 1



15Z Tue November 3rd 1992

Figure 2

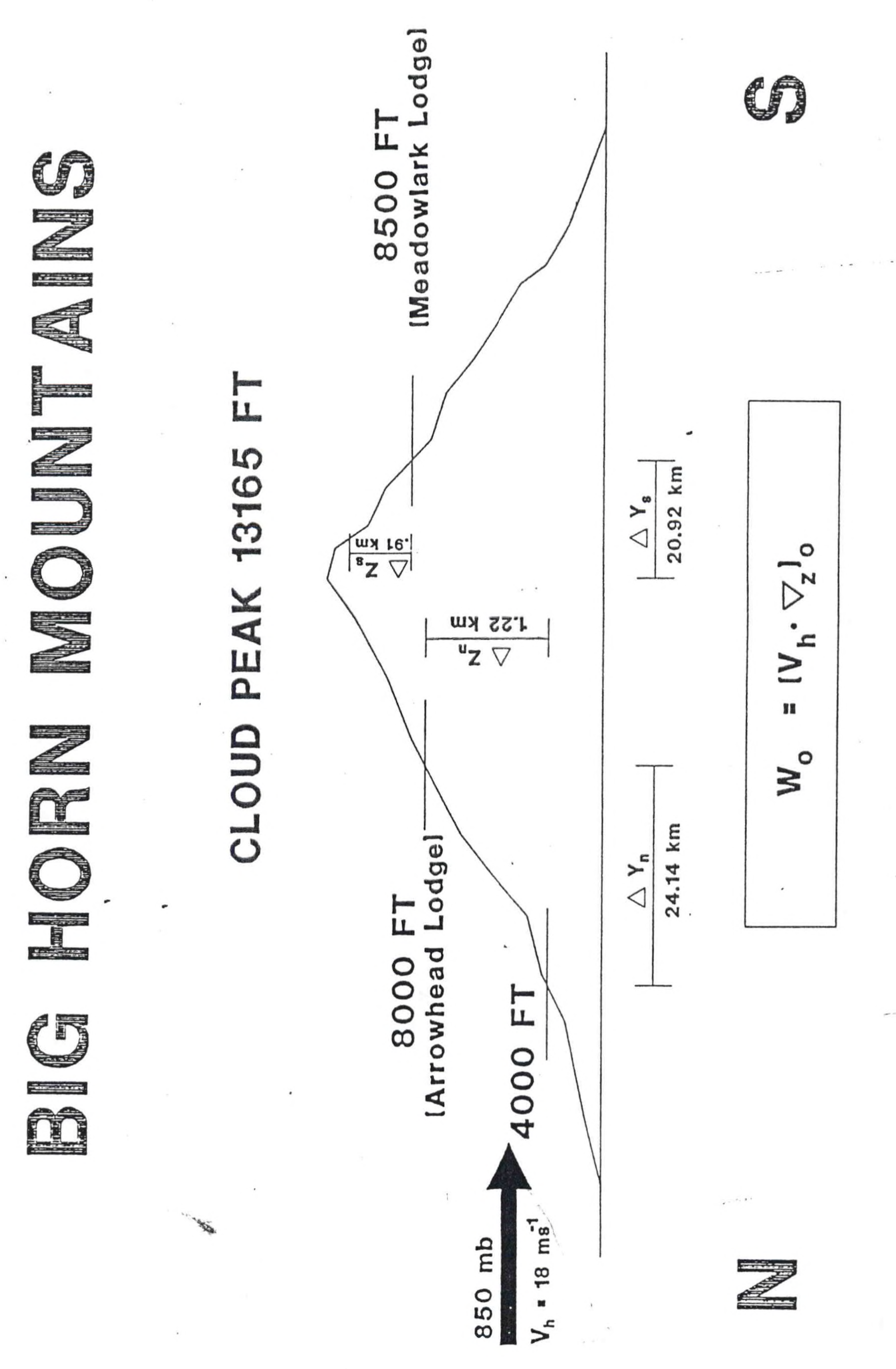

BIG HORN MOUNTAINS
CLOUD PEAK 13165 FT
8500 FT
(Meadowlark Lodge)
8000 FT
(Arrowhead Lodge)
4000 FT
ΔZ_s .91 km
ΔZ_n 1.22 km
ΔY_s 20.92 km
ΔY_n 24.14 km
850 mb
V_h = 18 ms^{-1}
$W_o = (V_h \cdot \nabla_z)_o$
N
S

FIGURE 3