

# The Characteristics and Soaring Potential of Long Lee Waves in Southern Alberta

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## Summary

Stable, southwesterly airflow over the mountains of southwestern Alberta frequently produces a gravity wave phenomenon with a typical length of 50–100 km. Recent observations by aircraft and satellite indicate that the wave (1) is usually best defined in the first cycle downwind of the mountains, (2) shows great lateral extent (over 1000 km in some cases), (3) shows a slow downwind movement, (4) may persist for several hours, (5) may persist over 200 km downwind of the mountains. The present paper illustrates the wave characteristics and examines the soaring potential.

## 1. Introduction

It has generally been accepted that mountain lee waves with length scales up to a few tens of kilometres are the only atmospheric wave phenomena capable of consistently producing upward motions adequate for soaring. Gravity-inertia waves with scales of hundreds of kilometres are too weak as are the even longer Rossby waves. In the past several years, however, meteorologists have become aware of another mountain-induced wave structure that is intermediate in scale between the common lee wave and the gravity-inertia wave and which can produce sufficient lift for gliders. For convenience, we will refer to these phenomena as "long lee waves" or "LLWs". LLWs have been investigated recently both in the field and theoretically (e.g., Lilly and Zipser, 1972; Lilly, 1972; Lester and Fingerhut, 1974; Klemp and Lilly, 1975). Most evidence suggests that the LLW is forced by the mountains and has a length compatible with the overall width of the mountain barrier (versus the width of an individual mountain range). To some extent, the LLW resembles a hydraulic jump and may occasionally cause severe turbulence for aircraft in flight and extreme downslope surface winds (Holmboe and Klieforth, 1957; Kuettner, 1959; Houghten and Kasahara, 1968; Lilly and Zipser, 1972; Klemp and Lilly, 1975; Brinkmann, 1975).

**Table 1. Total Days on Which Chinook Arch Cloud Was Observed from Calgary**

<b>1974</b>		<b>1975</b>		<b>1975</b>	
Nov.	4	Apr.	3	Nov.	7
Dec.	10	May	6	Dec.	15
		Jun.	4		
<b>1975</b>		Jul.	4	<b>1976</b>	
Jan.	11	Aug.	M	Jan.	15
Feb.	4	Sep.	7	Feb.	13
Mar.	7	Oct.	8	Mar.	14

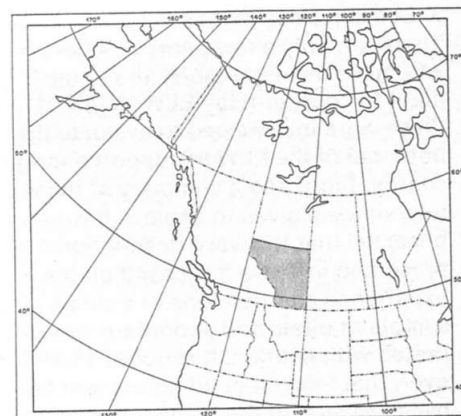
Total days per month when one or more chinook arch clouds were observed from Calgary. A bias towards lower numbers early in the period may be due to less frequent observations at that time (Lester, 1976d).

One characteristic of the LLW that facilitates its study is the presence of an extensive lenticular cloud in its crest. Evidently the occurrence of this cloud is less common in Colorado than in areas which have a moisture source within a few hundred kilometres upstream (e.g., in New Zealand, Reid, 1975, and Alberta, Canada, Lester, 1976a). In southern Alberta, a recent observational program included the acquisition of long wave cloud\* data from visual observations, time lapse photography, satellite imagery and also a few flights by instrumented aircraft. Analyses of these data have revealed that the LLW occurs frequently over a wide area of Alberta (Lester, 1976 a, b). The purpose of this paper is to present the results of those analyses, describing the LLW, its environment and its potential for supporting long soaring flights.

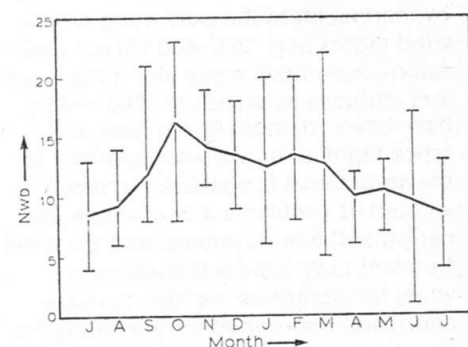
## 2. The Long Wave and its Environment

The area of interest is shown in Figure 1. The southwestern part of Alberta has a very high incidence of lee waves as documented recently by Lester (1976e) and shown in Figure 2, which was derived from wave cloud observations made at Pincher Creek, Alberta. In that area, lee wave clouds are observed on an average of 141 days per year. The long wave cloud associated with the LLW occurs about 75% as often and has provided useful infor-

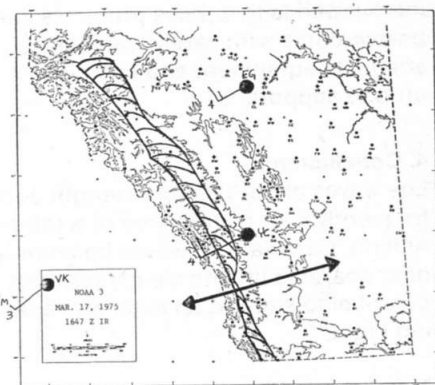
\* known locally as the "chinook arch cloud".



**Figure 1**  
Map of southwestern Canada and northwestern United States. Southern Alberta is shaded. The Continental Divide corresponds with the southwestern border of the shaded area. The major LLW activity occurs within 200 km northeast of the divide.



**Figure 2**  
Average number of days per month when wave clouds are observed. Dates are from Pincher Creek which is located in the extreme southwestern portion of the shaded area in Figure 1 (Lester, 1976e).



**Figure 3**  
Schematic of arch cloud drawn from infrared image from NOAA 3 Satellite, 1647 GMT, 17 March, 1975. The heavy line in the southern part of the province indicates the approximate path of the NAE/NRCC instrumented T-33 flown about two hours after the satellite image was recorded. 500 mb windspeeds are in metres per second. VK is Vernon, British Columbia, and EG and YC are Edmonton and Calgary, Alberta respectively. The map corresponds with the shaded area in Figure 1. Ground contours are shown for 2000, 3000, 4000, and 6000 feet ASL (-600, 900, 1200 and 1800 m ASL).

mation about the nature of the LLW (Lester, 1976b). The unique characteristics of the LLW are its great length, large lateral extent and high frequency. These properties are illustrated in Figures 3 and 4 and in Table 1. Table 2 gives an overall summary of the features of the LLW as determined from several sources.

### 3. Soaring Possibilities

There are only a few pilots in Alberta who have the experience and equipment to cope with the LLW. A few of these were interviewed to evaluate the potential of the LLW to support a long soaring flight and a summary of those interviews is given in Table 3. It is emphasized that the wave description presented in Table 3 is based on the experience and opinions of a small sample of pilots and should be interpreted with caution. It is noted, however, that there is good agreement between several of the items noted by the pilots and those deduced by independent study (Table 2).

Long downwind flights of 500 km or more have been made into Saskatchewan, but in these cases the wave lift near the mountains was supplemented by thermal lift to the east. Long crosswind flights (e.g., 350–400 km out and return) have been made along the wave and altitudes in excess of 9500 m ASL have been attained. A very long distance flight along the wave (parallel to the mountains) is possible but is not without its problems. For example, the period of the most intense and the most frequent LLW activity is wintertime when temperatures are low, days are short, and the rugged terrain below the prospective flight path is snow-covered. Also a long flight along the LLW from northern Montana through northwestern Alberta would include intersections with several major airways. However, the general consensus of the pilots interviewed is that these problems can be overcome with careful planning, adequate equipment and sufficient ground support.

### 4. Conclusions

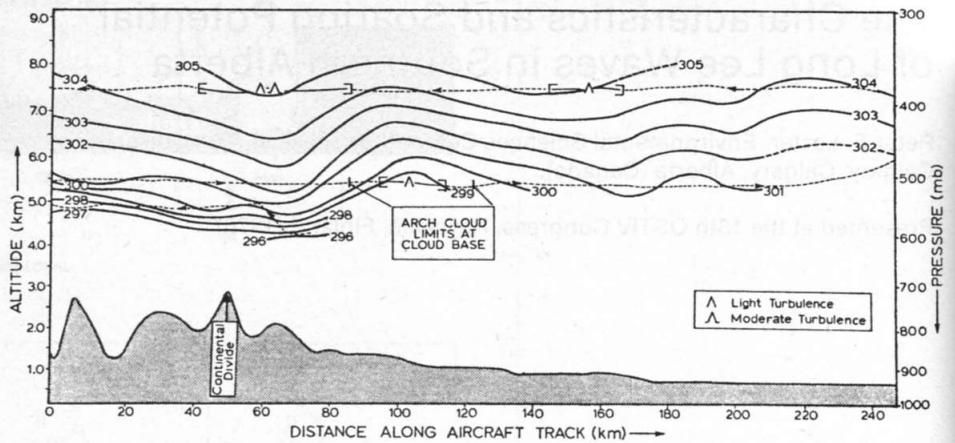
Lee waves of 50–100 km in length occur frequently over a large area of western Alberta, Canada. The waves commonly offer soarable lift and clearly have the potential to support an extensive soaring flight.

### 5. Acknowledgements

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### 6. References

- Brinkmann, W. and Ashwell, I. Y., 1968: The structure and movement of the chinook in Alberta, *Atmos.*, 6, 1–10.
- Brinkmann, W., 1975: Strong downslope winds at Boulder, Colorado. *Mon. Wea. Rev.*, 102, 592–602.
- Holmboe, L. and Klieforth, H., 1957: Investigation of mountain lee waves and airflow over the Sierra Nevada. Final Report, Contract AF 19(604)–728, Dept. of Met., UCLA, 290 pp.
- Houghton, D. D., and Kasahara, A., 1968: Nonlinear shallow fluid flow over an isolated ridge. *Communications on Pure and Applied Mathematics*, 21, 1–23.



**Figure 4** Cross section analysis of potential temperature ( $^{\circ}\text{K}$ ) field constructed along track shown in Figure 3. Dashed lines show aircraft track. Average topographical cross section along the flight track is shown along the bottom of the diagram (Lester and McPherson, 1976).

**TABLE 2**  
CHARACTERISTICS OF LONG GRAVITY WAVES  
OBSERVED IN NORTHERN MONTANA AND SOUTHERN ALBERTA

Wave Property	Description	Remarks	Sources
Area of major occurrence	Continental Divide to 200 km east, 45N to 55N	May begin slightly west of Divide, south of 50N. Eastern boundary highly variable.	Lester (1976a,b)
Frequency of occurrence	Annual average: 8.25 days $\text{mo}^{-1}$ Annual range: 3–15 days $\text{mo}^{-1}$	Based on 16 months of wave cloud observations.	Lester (1976b)
Favored season (months)	October–March (December, January)	Based on 16 months of wave cloud observations.	Lester (1976b)
Wave length	50–100 km	Based on aircraft, tower and surface observations	Brinkmann and Ashwell (1968) Holmes and Hage (1971) Kellie (1972) Lester and MacPherson (1976)
Horizontal extent and variations	100 to more than 1000 km along the mountains (crosswind). Ordinarily only one wave cycle observed downstream of the mountains but multiple cycles have been documented on occasion.	Based on surface and satellite observations of associated clouds. Based on aircraft observations of the temperature field and visual observations of wave clouds.	Thomas (1963) Lester (1976a,b) Holmes and Hage (1971) Lester (1976b) Lester and MacPherson (1976)
Vertical extent and variations	Has been observed throughout the troposphere and lower stratosphere.	Based on several case studies and 16 months of wave cloud observations.	Brinkmann and Ashwell (1968) Holmes and Hage (1971) Kellie (1972) Lester (1976a,b) Lester and MacPherson (1976)
Wave amplitude	Insufficient information	May occur alone or coexist with ordinary, shorter lee waves at different levels or superimposed. If two different scales of waves exist at two separate levels, shorter waves will always be at the lower level.	Lester (1976a) Lester and MacPherson (1976)
Wave life cycle	Wave lasts a few to several hours, and often shows eastward movement at a few $\text{ms}^{-1}$ (i.e., generally less than mid-tropospheric windspeeds). Wave weakens noticeably as it moves eastward beyond Calgary, Alberta.	Based on satellite aircraft, visual and photographic observations of wave clouds. Stationarity is most common and apparent retrogression has been observed. Kellie (1972) finds faster speeds of movement.	Lester (1976a,b) Lester and MacPherson (1976)
Mean upstream synoptic conditions			
cross mountain wind component at 700 mb	11.7 $\text{ms}^{-1}$	average wind directions upstream of the Continental Divide are typically WSW when the wave (cloud) is present.	Lester (1976a)
at 500 mb	15.0 $\text{ms}^{-1}$		
temperature at 700 mb	-7.5C		
at 500 mb	-22C		
lapse rate 700 mb - 500 mb	5.8C $\text{km}^{-1}$		
cross mountain sea level pressure gradient	6 mb (320 km) $^{-1}$	lower pressure in the lee (Castlegar, B.C. to Calgary, Alberta).	

**Table 3. Soaring Characteristics of Long (50–100 km) Lee Waves**

Wave Property	Description	Remarks
"Soarability"	Very good	Presence of "chinook arch cloud" (Figure 2) usually indicates a soarable LLW.
Number of long wave cycles	One	Pilots other than those interviewed have reported secondary cycles.
Rates of climb	2–3 $\text{ms}^{-1}$	Values of 7–8 $\text{ms}^{-1}$ have been observed in lower levels.
Lift area	Wider than that found with ordinary, short lee waves	Reduces need for turns when flying along the wave. A lift area 9 km wide (along wind dimension) has been reported.
Relation to ordinary, short lee waves	LLW may exist with shorter waves at lower levels or superimposed.	Superposition will complicate the lift pattern of the LLW.
Flight level winds	Not exceptionally strong. Direction generally perpendicular to the ridge line.	Some variation, but excessive crabbing to maintain ground track during crosswind flights is not usually necessary. Very strong winds may occur at low levels.
Possibility of supporting a long soaring flight (e.g., world's record)	Excellent	But see text for problem discussion.

