Classical Sierra Wave Triggering Mechanism

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1. Introduction

During Easter vacation week April 2–10, 1977 a large contingent of sailplane pilots assembled at Minden's Douglas Country airport (elevation 1438 m) in western Nevada's Carson Valley approximately 20 km east of the southeast corner of Lake Tahoe – their objective: attempt soaring flights for altitude and distance in the Sierra wave. The purpose of this paper is to present a case study that will highlight a Sierra wave triggering mechanism; namely, wind impulses ebedded in the upper atmospheric jet stream. The paper is a synthesis of empirical evidence gathered over the last several years by forecasters at the National Weather Service Forecast Office, Reno, Nevada in support of their efforts to provide tailored forecasts for the growing soaring community. Early recognition and forecasting of this meteorological phenomenum have importance not only for sailplane soaring activities, but also, for forecasting strong ridgetop winds in support of other major forecast office programs such as fire-weather, air pollution, avalanche and general aviation.

This study will investigate the events leading up to the abrupt triggering of the Sierra wave on Good Friday, April 8, 1977 mainly through use of cloud patterns identified on weather satellite still pictures and a time-lapse film loop. See Figure 1.

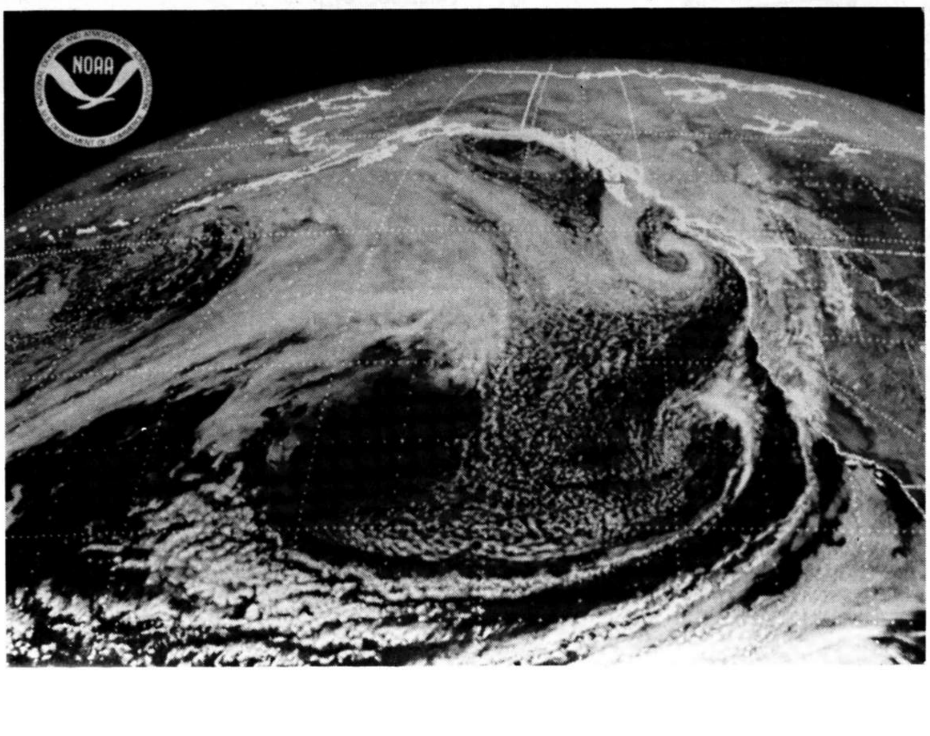
It is of interest to note that during this particular wave event 70 soaring pilots succeeded in making 5 km gains for diamond altitude flights. The longest flight of the day was 825 km, out and return, from Minden, Nevada south to Inyokern, California located at the southern end of the Sierra. Carl Herold piloted an ASW-12 for the flight which lasted 10 hours 30 minutes.

2. Theory

Recent investigations by specialists in weather satellite interpretation have provided some very useful information concerning the common characteristics of cloud patterns often associated with jet stream features. For example, this case study compares favorably with the 4th Phase of development for a "cold air vortex" as described by Weldon (1975). He states:

"By this time a complete new storm cloud pattern has formed behind (or on the cold side) of the baroclinic zone.

Figure 1. NOAA-NESS weather satellite picture taken at 2045 GMT (1245 PST) on April 8, 1977.



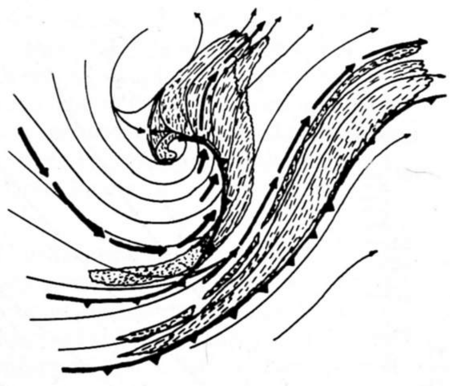


Figure 2. Schematic for the 4th Phase of development for "Cold Air Vortex" from The Structure and Evolution of Winters Storms by Roger B. Weldon.

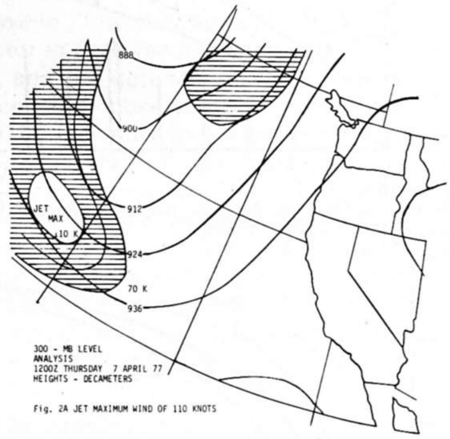


Fig. 2A JET MAXIMUM WIND OF 110 KNOTS

Usually, as the new system develops, the older jet baroclinic zone and its cloud system weakens – in effect becoming partly isolated from its previous cold air supply, and with the development of warm moist air aloft in advance of the new system.

If the new cyclone continues to develop beyond this stage, it is likely that the new frontal zone will catch up to the old one in the south quadrant of the low and the frontal zones will merge into one in that area. The double jet and cirrus structure in the northeast quadrant are likely to continue for a longer period of time, but with the newer jet zone becoming dominant. (Figure 2).

Additionally, the dynamics associated with this cloud pattern for a "cold air vortex" is similar to the dynamics for developing surface fronts and vorticity involving the jet maximum at the 300-mb level as presented in Jet Stream Meteorology (Reiter, 1963).

Case study – Meteorological analysis and aviation activity

This study commences with focusing on an analysis of meteorological data at the 300-mb level 24 h prior to wave

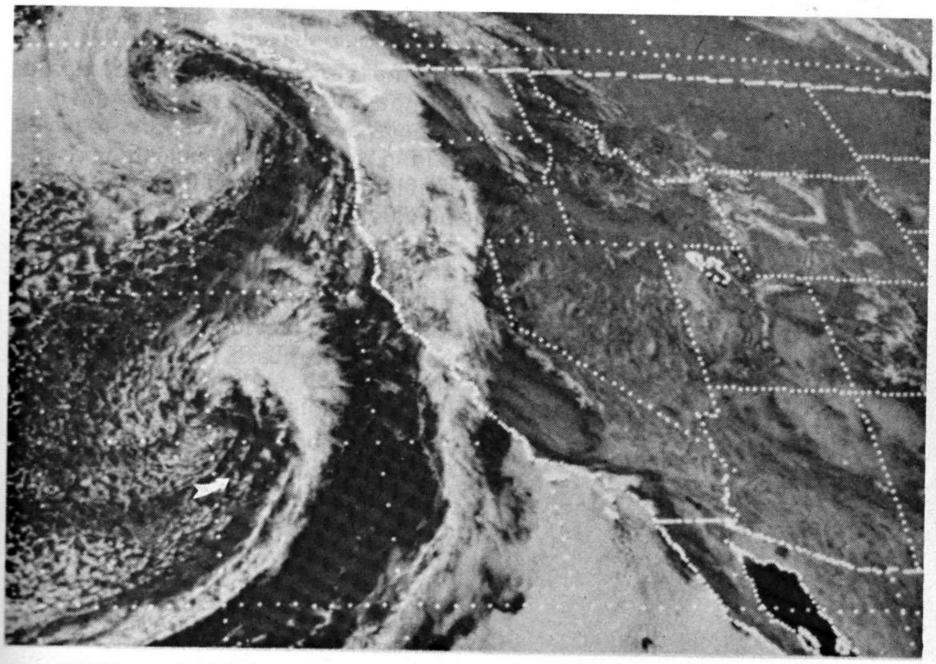


Figure 3A. Taken at 1715 GMT (0915 PST).

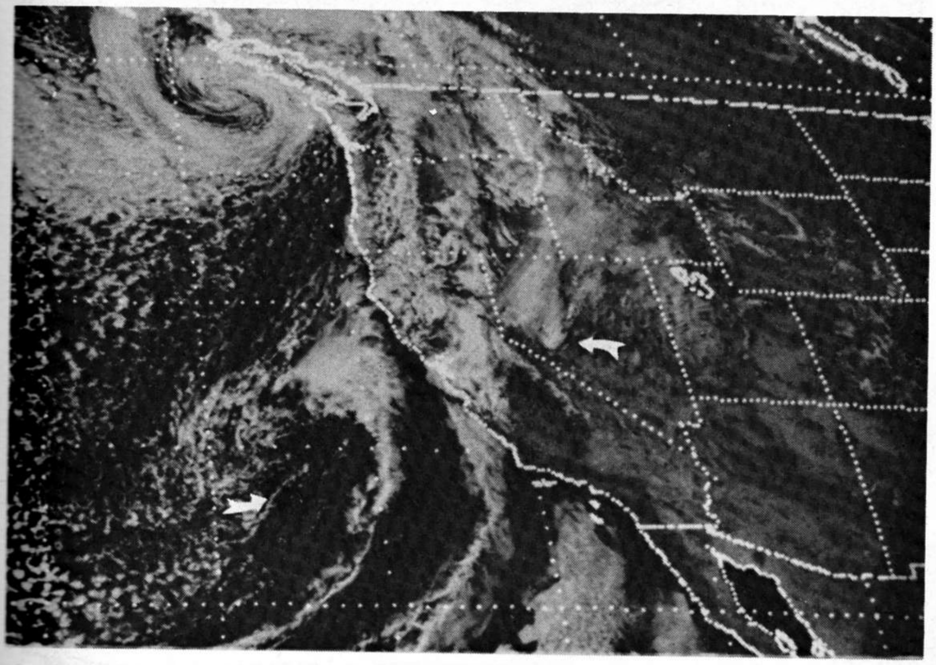


Figure 3B. Taken at 2015 GMT (1215 PST).

development (Figure 2A). Observe the jet maximum wind isotach pattern of 110 knots (57 mps).

Its path can readily be tracked on the time-lapse film loop as it moves southeast after crossing the top of the ridge of high pressure with an axis along 150° west longitude in the Gulf of Alaska. Temporary stalling takes place near the pivotal lower point on the axis of a sharp trough of low pressure near 130–135° west longitude, then the jet maximum begins to move again toward the north central California coast with nearly 25–30 knots (14 m/s). This stalling of a jet maximum when passing through the bottom of a sharp trough has also been observed in the trajectories of constant-pressure balloons (see Palmen and Newton, 1969). One can follow the strong jet movement as it translates east toward California and Nevada where a Sierra wave is being generated (Armstrong and Hill, 1976). See Figures 3A, B and C.

The decaying front nearly stalls along the northern California coast and is being overtaken by the newer jet baroclinic zone, in accordance with Weldon's observations. Mostly clear skies are present in the lee of the Sierra at daybreak about 1400 GMT (0600 PST). The Sierra wave is barely discernible from the ground as fragmented wisps of rotor cloud over the Truckee Meadows and Carson Valley, but as yet not noticeable by satellite pictures.

Soaring flight begin shortly after 1500 GMT (0700 PST). Aero-tows from Minden airport are toward the southwest in the lee of Freel Peak (elevation 3316 m). Soaring pilots begin wave flying within 1 km of ground level in the Carson Valley at this time.

By early afternoon the developing wave clouds are visible well to the east of the Sierra between Walker and Pyramid Lakes in western Nevada (Figure 3B). The Sierra wave clouds continue their growth downwind from the mountain barrier throughout the day as the jet maximum approaches.

While weather satellite pictures illustrate the progress of the Sierra wave during the day, weather instrumentation located at ground level was used to record surface wind conditions. Surface effects of the Sierra wave are increasing winds at ridgetop levels. A remote automatic weather station operated by Desert Research Institute (DRI) atop Peavine Mountain (elevation 2519 m) 19 km northwest of Reno, Nevada, records the gusting winds and changing temperatures accompanying the Sierra wave. The strong surge of wind shortly after 1700 GMT (0900 PST) scoured out the stable air trapped in the lee side valleys. See Figure 4.

The wave length measured from the crest of the Sierra to the mid-point of the wave cloud downwind indicated a length of 90–100 km, that remains nearly constant throughout the day. This wave length is nearly the same as long lee waves near the mountains of southwestern Alberta as described by Lester (1976). The wave height was calculated from a cross-section between the radiosonde observing stations at Oakland, California and Winnemucca, Nevada by comparing the temperature profile on the cross-section with known temperatures of the wave cloud tops derived from infrared satellite pictures. A maximum height of 11 km (36,000 ft) was determined by this procedure. (See Figures 5 and 5A).

It is interesting to note that on the Oakland 0000 GMT radiosonde taken April 9, 1977 (1600 local PST) there is a wind speed of 106 knots (55 m/s) at 300-mb that corroborates the approaching jet maximum as determined by the cloud motion and initially analyzed at 110 knots (57 m/s), see (Figures 3C and 5A).

Another very important aspect regarding the Sierra wave was the variety of general aviation pilot reports received during the day. They indicated considerable turbulence for conventional powered aircraft. On the other hand sailplane pilots experienced relatively smooth flights by concentrating their efforts in the primary wave lift staying mainly along the ridges near the southeast corner of Lake Tahoe until sunset that day.

4. Conclusion

This case study illustrates that the triggering mechanism for the Sierra wave is inherent in the approach of a strong

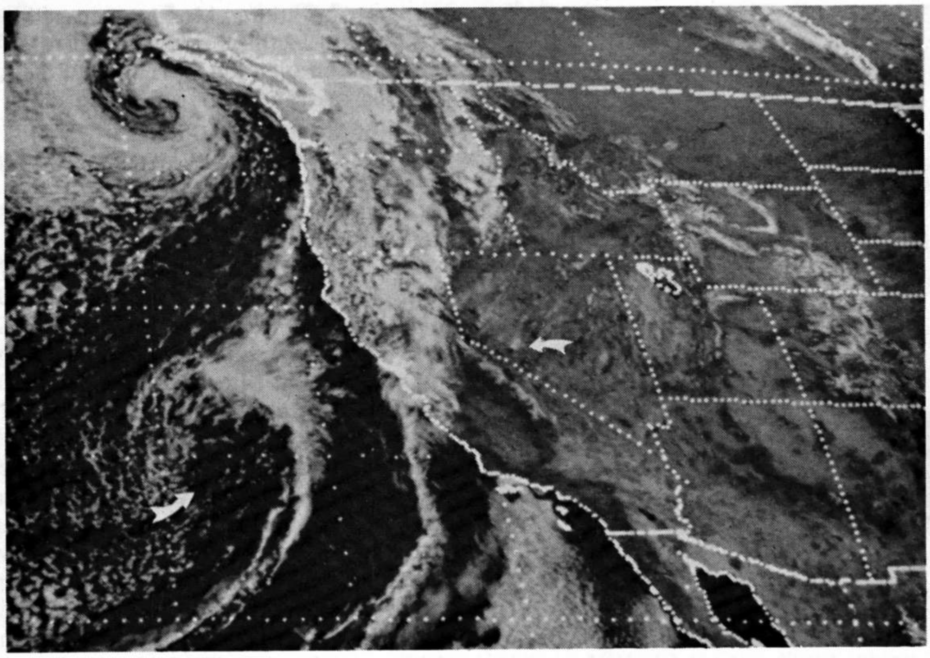


Figure 3C. Taken at 2315 GMT (1515 PST).

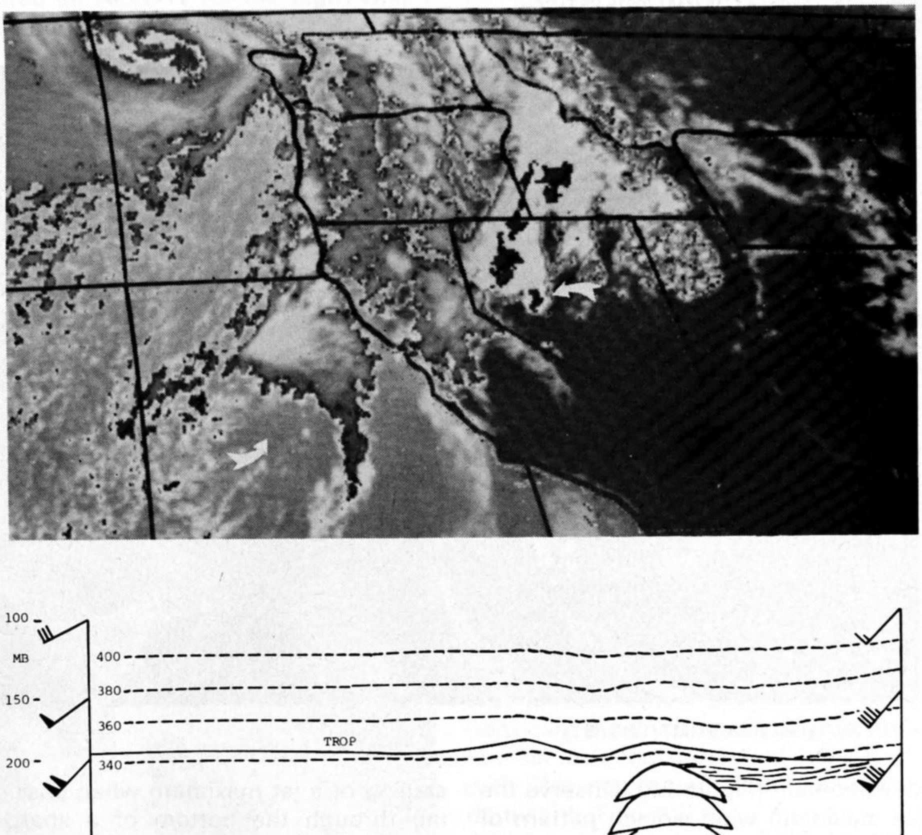


Figure 5. NOAA-NESS weather satellite picture taken at 2315 GMT (1515 PST), April 8, 1977, with enhanced infrared features (HB-scale).

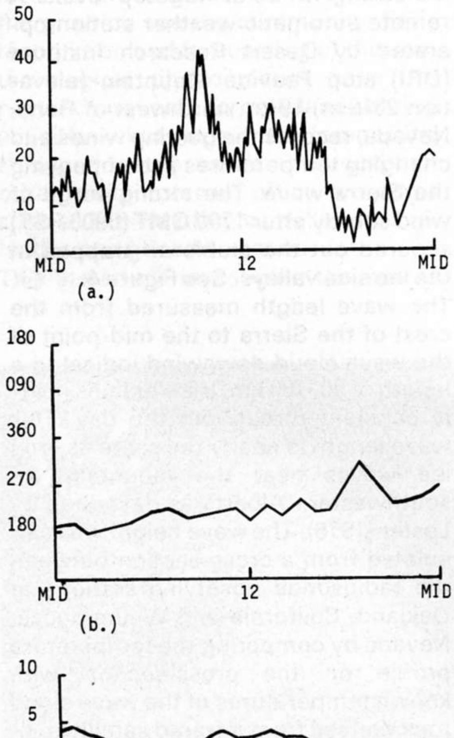
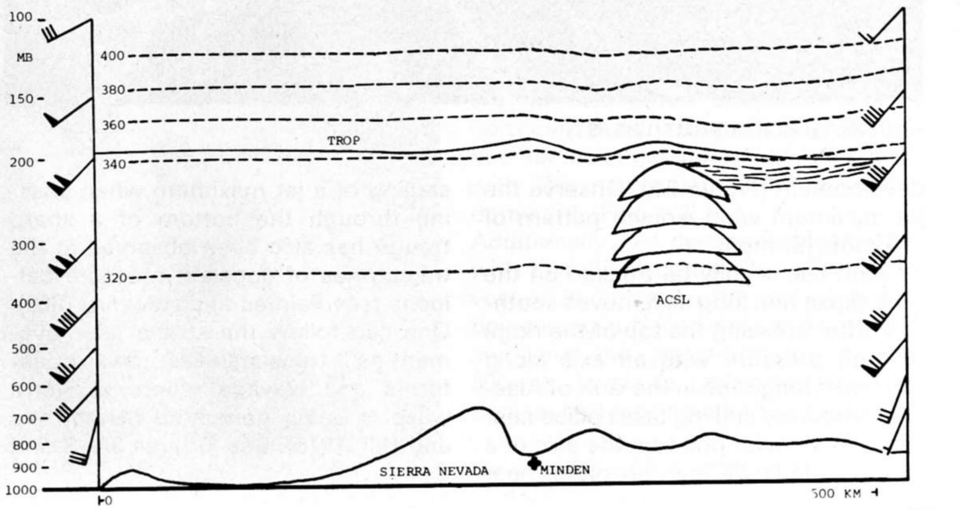


Figure 4. Wind and temperature records for Peavine mountain form the automatic weather station (DRI) for the 24 hour period 8 April 1977. (a.) instantaneous wind speeds at 10 minute intervals in ms^{-1} (b.) wind direction (true North-360°) (c.) hourly temperature in degrees Celsius.



GOOD FRIDAY AFTERNOON
APRIL 8, 1977 1600 PST (APRIL 9, 1977 0000Z

Fig. 5A Wind speed in knots (pennant-50 knots, barb-10 knots, half barb-5 knots. Tropopause height taken from soundings. Potential temperature (dashed lines). Altocumulus lenticularis depicted from artist's observation.

jet wind impulse normal to the mountain barrier. This developing Sierra wave could be readily forecast nearly 24- to 36- hours in advance by 1) recognizing on weather satellite pictures the cloud pattern signature of a jet maximum and 2) close scrutiny of the jet maximum isotach patterns displayed on 300-mb level analysis and prognostic charts prepared by the National Meteorological Center of the National Weather Service-NOAA.

Finally, accurate forecasting of the Sierra wave has direct benefit for a number of interests including general aviation and numerous environmental programs.

5. Acknowledgements

I am grateful to the Pacific Area Soaring Council of the soaring community and my fellow colleagues Dr. Thomas H. Grayson, Tom Cylke and Chris Hill at NWS Forecast Office, Reno; Harold Klieforth at DRI, Reno; Ms. Walda Kennedy at WSO, Bishop, California for their comments and observations. Additionally, I would like to extend my appreciation to the NOAA-NESS staff of the Satellite Field Service Station, Redwood City, California for the weather satellite pictures.

6. References

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