11.10 STRATOSPHERIC MOUNTAIN WAVES: Observations and Modeling for A Proposed Sailplane that will use these waves to reach 100,000 feet

Elizabeth J. Carter *
Firnspiegel LLC, Kings Beach, California
Edward H. Teets, Jr.
NASA Dryden Flight Research Center, Edwards, California

1. INTRODUCTION

A research project currently underway is phase one of an effort for a sailplane to use stratospheric mountain waves to reach an altitude of 100,000 feet. Once into the stratosphere, the mountain waves propagate upward with increasing strength, generally maintaining a constant energy, defined as: air density x vertical-wind-component^2 (derived from the Palm-Eliasson theory). The object of this study is to determine the conditions favored for mountain wave development.

A few of the best wave events and a few of the events in which waves are extinguished at the tropopause have been analyzed in detail. This analysis involved investigating the atmospheric conditions (satellite for location, radar, and observational meteorological data at tropospheric and stratospheric levels) for each case. These wave cases have been modeled using the Fifth Generation Penn State/NCAR (National Center for Atmospheric Research) Mesoscale Model (MM5). The model is being used to: (1) verify the strength, location, structure, and frequency of occurrence of strong mountain waves, (2) to determine the structure of the polar vortex in the Southern Hemisphere and how it relates to the stratospheric mountain waves, and (3) for forecasting these stratospheric mountain waves in near real-time for the field campaign to reach 100,000 feet (30.5 km) using a sailplane.

2. THE PERLAN PROJECT

The word *Perlan* is an Icelandic word meaning pearl. Perlan is the name given to this project and is inspired by mother-of-pearl or nacreous clouds occasionally seen at high altitudes and high latitudes. The mother-of-pearl or Polar Stratospheric Clouds (PSC's) are present in the northern hemisphere when wave outbreaks are ongoing.

There are two phases of the Perlan Project. Phase one uses a certified production DG505M sailplane to reach 62,000 feet to demonstrate the feasibility of the project. This phase requires the use of pressure suits in an unpressurized cabin. Phase 2 of the project is to soar to 100,000 feet which will require a special pressurized high altitude sailplane.

The world record for altitude in a sailplane is 49,009 feet set by Bob Harris in 1986 over Mt. Whitney in the Sierra Nevada mountain range of California. The previous records were set by Paul Bikle in 1961 also over Mt. Whitney (46,267 feet) and prior to that the record was held by Larry Edgar set in 1952 over the Sierra (44,255 feet).

3. WHY NEW ZEALAND AND/OR SWEDEN?

Strong stratospheric mountain waves have been identified in data from Sweden and the south island of New Zealand. In Sweden the northern mountains easily perturbed the low level flow over the mountains generating tropospheric waves with the smaller northern hemisphere Polar Vortex residing over this region at high altitudes. New Zealand is favorable, even though it's located at lower latitudes because of the great size of the southern hemisphere Polar Vortex which can extend into the lower latitudes. It has been determined that the first attempts to reach 100,000 feet in a sailplane will take place in New Zealand. Based on current aircraft limitations phase one is limited to 62,000 feet. An important key to understanding these waves is the polar vortex. It is known that these waves propagate into the middle and upper stratosphere when the outer region of the polar vortex lies above a strong tropospheric wind band, above mountainous terrain.

4. HOW TO GET TO 100,000 FEET

Although phase 1 is to get to 62,000 feet much will be learned about how to get to 100,000 feet. One of the most significant feats will be getting through the tropopause and into the stratosphere. As the Perlan sailplane reaches higher altitudes the Mach number will be increasing (0.07 at sea level, 0.33 at 70,000 feet, and 0.66 at 100,000 feet) and the Reynolds number decreasing (1.46×10^6 at sea level, 4.41×10^5 at 70,000 feet and 2.07×10^5 at 100,000 feet). Soaring at higher Mach numbers and lower Reynolds numbers cause lift and control challenges with the sailplane. Figure 1 is a plot of vertical speed versus altitude for wave conditions over the south island of New Zealand on 25 June 1994. The difference between the line of constant wave energy and the sailplane sink seed is the sailplane climb rate. On this particular day the stratospheric mountain waves appear to have enough energy to give the Perlan sailplane enough rate of climb to reach 100,000 feet.

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* *Corresponding author address*: Elizabeth J. Carter, Firnspiegel LLC, 8130 North Lake Blvd., P.O. Box 2720, Kings Beach, California 96143-2720 U.S.A.; email: ecarter@weatherextreme.com

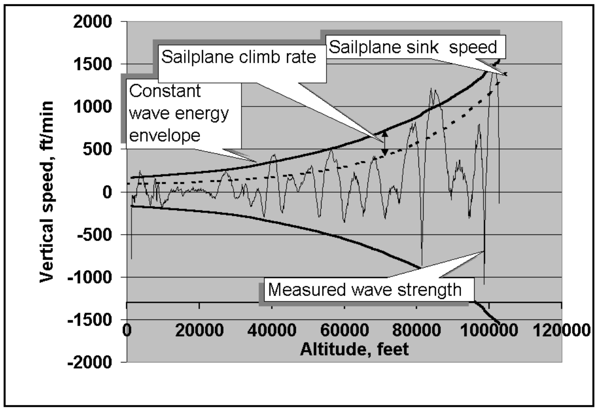

Figure 1. Vertical speed (feet per minute) versus altitude (feet) over Lauder, New Zealand on June 25, 1994. Sailplane sink rates and corresponding estimated sailplane climb rate are plotted.

An example of good stratospheric mountain wave conditions is the soundings plot in Figure 2. This is a plot of rise rates (m/s) versus geopotential height (in meters). The wave is very strong well up through the 100,000 foot level (30,500 m).

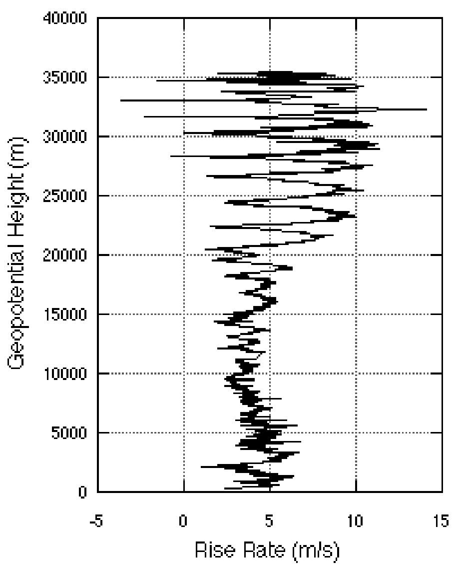

Figure 2. Rise rates (m/s) versus geopotential height (m) during a wave event (2221 GMT June 3, 1998) at Lauder on the south island of New Zealand.

5. THE METEOROLOGICAL SITUATION

The polar vortex is a necessary meteorological component for getting a sailplane to 100,000 feet using stratospheric mountain waves. Generally, the vortex begins to form in November in the northern hemisphere (NH) (in May in the Southern Hemisphere – SH), peaks in January in the NH (July in the SH) and dissipates due to planetary wave forcing in early April in the NH (early October in the SH) (Randel and Newman, 1998; Ahrens, 2000). Though Zhou et al. (2000) have shown that the SH polar vortex lasted approximately two weeks longer in the 1990's than the 1980's and the NH polar vortex lasted four weeks longer in the 1990's than in the 1980's. Also, the NH vortex is more unstable than the SH vortex due to the larger amount of land mass in the vortex region in the NH. The NH vortex is frequently disturbed, weakened or even broken by strong large-scale planetary wave propagation (Zhou, et al., 2000).

<u>What is needed to get the wave going</u>:

- Strong winds at ridge top and perpendicular to the ridge in a stable atmosphere.
- Strong winds increasing with altitude to supply the energy.
- A weak tropopause as not to reflect energy in the zone allowing increasing wind speed with altitude on up into the stratosphere.

The structure of the polar vortex during good wave events is very similar and nearly mirror themselves over the southern and northern hemispheres during their respective vortex seasons. Figure 3 is a cross section showing the structure of the polar vortex over the southern hemisphere during a good wave event in June of 1998.

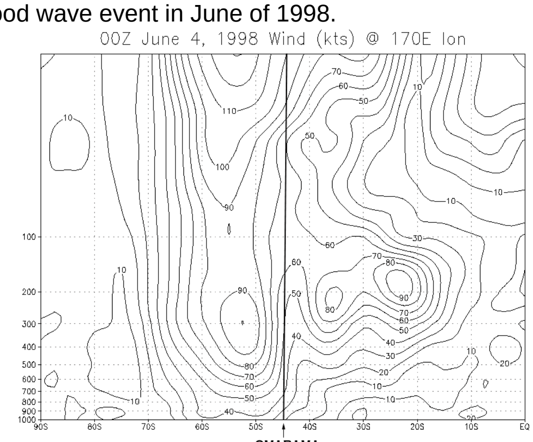

Figure 3. Cross section of winds (knots) versus pressure (mb) over the southern hemisphere (along 170 degrees E longitude) from the equator to the south pole. The latitude of the staging location in Omarama New Zealand is labeled on this graph. This particular cross section is during a wave event over New Zealand in June of 1998.

Meteorological analysis of the synoptic and upper air data from the Scandinavia region of the NH and from the New Zealand of the SH during good and poor wave conditions from 1994 through the present has resulted in the following summaries of good stratospheric mountain wave conditions for the Perlan project. Prefrontal conditions produce the best conditions for a successful mission (62,000 feet or 100,000 feet). In both New Zealand and Sweden during the postfrontal period the winds at all levels are generally strong and close to being perpendicular to the mountains. Good to excellent wave conditions often last from the prefrontal period through the frontal and postfrontal periods.

The probable field location in New Zealand is at approximately 45° south latitude and in Sweden is at almost 68° north latitude. Thus, one key difference between the SH and the NH is that meteorological conditions conducive for good stratospheric mountain wave conditions is the jet stream location. A strong polar jet directly over the mountains in Sweden during the NH winter months and a frontal passage is most desirable. The best wave scenario in New Zealand is when the polar jet lies to the south and the subtropical jet (STJ) to the north of the islands during a frontal passage in the SH winter months. When New Zealand lies in between this double-jet structure the strong westerly/southwesterly winds are able to propagate from the surface on up into the stratosphere.

6. MODELING THE ATMOSPHERIC CONDITIONS

Stratospheric mountain wave cases (both good and poor) over New Zealand and over Scandinavia have been modeled using the Penn State/NCAR MM5 modeling system. The MM5 model has multiple-nest capability, nonhydrostatic dynamics, four-dimensional data assimilation capability, uses terrain-following coordinates, multiple physics options, and is portable to a wide range of platforms.

An example of a good wave day over New Zealand is in Figure 4. This graph was produced using a 1km horizontal resolution domain over the northeast portion of the south island of New Zealand. This is a 12-hour forecast of the wave conditions (valid 2359Z 26 June 1996).

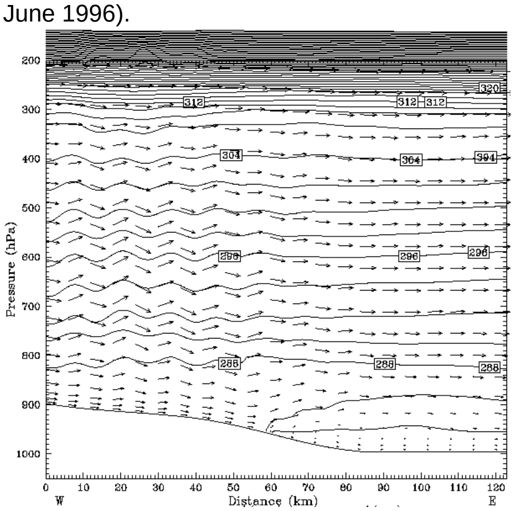

Figure 4. 12-hour forecast of wave conditions over a portion of New Zealand using MM5 output of potential temperature (K) and circulation vectors.

The MM5 model along with meteorological analysis software will be used in near-real time in the field to forecast the weather conditions and the stratospheric mountain wave conditions. The meteorologists will be in constant contact with the pilots during their attempts to reach high altitudes.

7. CONCLUSIONS

The modeling and meteorological data analysis performed to-date indicate that the best stratospheric mountain wave conditions required to get to either 62,000 feet or 100,000 feet sometime between late June and early September in New Zealand or between February and early April in Sweden are as follows:

a) The subtropical jet must be north of New Zealand and not directly over the south island. When the SJT is directly over New Zealand the influence of the polar vortex (specifically strong upper-level westerly winds) is extinguished.

b) During prefrontal conditions the stratospheric mountain waves are the strongest, especially at upper levels.

c) During prefrontal situations in their respective winter months, the winds at all levels are strong and generally impact the southern Alps in New Zealand and the mountains of Sweden approximately perpendicularly producing conditions conducive for reaching the stratosphere in a sailplane.

d) The MM5 model results of both the troposphere and the stratosphere from New Zealand and from Sweden compare well with the actual observations available.

e) Though generally strongest during prefrontal conditions, good to excellent stratospheric wave days frequently last from the prefrontal through the frontal and postfrontal portions of the storm.

8. ACKNOWLEDGEMENTS

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