SOME EXPERIMENTS ON LEE WAVES NEAR SMALLER MOUNTAINS

Carsten Lindemann, Inst. f. Weltraumwissenschaften der Freien Universität Berlin

Presented at the XXVI OSTIV Congress, Bayreuth, Germany.

Abstract:

Parameters of lee waves have been measured by an instrumented motorglider at the Harz mountains - a small mountain range with irregular shape. The measurement results have been checked by classical methods of synoptic scale diagnostic and prognostic parameters. In particular, the Lester-Harrison Nomogram (Hafner et.al., 1993) has been taken for the quantification of wave parameters and its relation to severe weather connected to rotors. Prognostic parameters will be given related to this and similar mountain ranges, which can be used for nowcasting as well.

Introduction:

Lee waves were detected in the thirties by glider pilots; the physics were mainly understood during the next two decades. Large measurement programs such as Sierra Wave Project and ALPEX seemed to have solved nearly all physical problems. Now general wave forecast is done regularly by the US ETA model and others and can also be developed out of DM of German Weather Service and with much more detail out of smaller scale LM. But several details must be improved in forecast such as the computation of momentum transport, the wave parameters of lower mountains, and the orographic effects on the lines of rotor bands.

And at least lee waves are still a fascinating phenomena of the atmosphere combining strong horizontal wind with intensive up - and downdrafts sometimes through the whole troposhere and even higher. Severe weather can result in the lee of larger and higher mountain ranges such as Alps, Rocky Mountains, Andes etc., but the oscillating effect of these lee waves has also been discovered even in the vicinity of smaller hill ranges only 300 m above ground level. When the conditions are very favorable, those waves can extend up to 8 km, as has been tested by a glider pilot in Northern Germany. One area of interest in Northern Germany could not be tested because of political reasons: the Harz Mountains. The border divided it into two parts with essential air space restrictions. For about 6 years the flight measurement group of the Free University Berlin uses an instrumented motorglider time by time to discover the wave parameters of these irregularly shaped mountains. Mainly the Lester-Harrison-Nomogram has been taken to qualify wave parameters.

Lee waves near small mountain ranges

There are a lot of small mountain ranges with elevation of less than 600 m above normal ground level in Britain and in Germany, where lots of flights have been done during the last 40 years. Even elongated hills of a little more than 100 m above normal ground level can produce lee waves, if the critical parameters are very sensitively fulfilled. The wave oscillations do not normally reach the tropopause but in ideal conditions wave flights have been done up to 8000 m leeward of the Deister, a small hill range in northern Germany only 300 m above ground level (31st of October, 1968). It has been detected very early (LINDEMANN 1971), that these waves are very sensitive to thermal convection, which can reach the primary oscillating stable level of 1000 to 2000 m above ground level necessary for wave development and often destroy this stable layer. A lot of information has been collected especially for Northern Germany, for the French Alps, and latest for the Harz mountains.

The results for the flights at the Harz were compared to flight results of the Riesengebirge (now in Poland), a very regular shaped mountain range up to 1600 m (1200 m above ground level). Wave parameters of wave length and amplitude were detected. The position of the rotor bands and the connected intensity for the identification of possible flight hazards were discovered.

Measurement results

A motorglider ASK 16 was instrumented with sensors of temperature, humidity, height, vertical velocity, speed, GPS navigation and a logger system. Wind measurements could only be done from time to time by a GPS based flight procedure. On line measurement of wind vector was not possible because of lack of a reliable heading sensor. The flights were started at Lusse airport, about 100 km to the NE of the eastern edge of the Harz. It took about 45 minutes to 1.5 hours to cover that distance. This had the advantage that on this track for 255° more than one oscillation of the lee wave could be detected. The flights for measurement normally started at 900 m to detect the rotor bands and at 1500 m to detect the laminar flow. After having found the main updraft of the wave, the engine was stopped in order to make the motorglider most sensitive for vertical currents and to gain maximum altitude in gliding mode. An altitude of 4200 m was reached on the 28th of December, 1998 and more than 4600 m could be gained on 17th of January 1999. This flight must be stopped because of approaching sunset.

FIGURE 1 shows an example of verical currents and oscillations leewards of the Harz mountains a height of about 1200 m. Up to five waves could be discovered mostly connected with lenticular clouds. The wavelengths (in kms) refer to about 0.6 times average lower tropospheric wind component in m/s. The first wave, however, is about 3/4 the distance to the top of the lee slope forcing the initializing downdraft for wave development.

A strong turbulent updraft (rotor flow) in the vicinity of the Brocken (1100 m MSL) had a laminar flow of the wave itself at top, but because of decrease of wind aloft, this flow extended only 500 m higher. A second wave could also be found. The wind speed was quite low averaging 10 m/s, but the Brocken wind measured on the top was about 16 m/s. The wind speed on this mountain is very often up to 70% higher than the surroundings because of the venturi effect of this single peak.

FIGURE 2 is presenting the typical positions of the lines of updrafts under lee waves conditions with airflow out of the S to SW. The first line is quite close to the NE edge of the mountain range. The distance is governed by wind speed. The rotor bands below the laminar updrafts of the waves seldom extend to more than 1200 m. The rotors immediately in the lee of the Brocken are very turbulent, the aircraft had -.5 to + 2.2 g even under those relatively low wind velocity. The positions of the first wave and thus of the first rotors seem not to change as much as the wave oscillations behind proportional to wind speed. They seemed even more to be governed by the shape of mountains ahead. A prognostic procedure for nowcasting can already be determined for the range of positions, in this stage already interesting for safety of general aviation.

FIGURE 3 is the Lester-Harrison Nomogram for surface pressure gradient over the mountains referred to a distance of 320 kms and the maximum perpendicular wind component at a height interval between mountain top and 2000 m above. Two values for the Riesengebirge are shown as well in this diagram 21 and 17. Very well developed systems could be detected there. Especially on the 17th of October, 1998 the winds were much stronger with 70 kts over the Harz area and only 34 kts over the Riesengebirge. The Harz had a downdraft in lee but no real oscillations of large amplitude. Referring to literature data (CORBY 1958), (LINDEMANN 1985) this can be valid for mountains from lowest altitudes up to more than 2000 m.

The maximum vertical velocities in laminar flow in those areas (Harz, Riesengebirge, Provence etc.) were detected for maximum windspeed in that mountain referred levels at about 35 to 45 knots. The lower wind speed with the same amplitude produces higher vertical velocities.

FIGURE 4 shows the range experienced for maximum vertical velocity out of this and the other mentioned data. For the Riesengebirge up to twice as much vertical velocity (and turbulence in the rotors) in relation to the values of the Harz was detected. The diagram shows the real mean vertical velocity for the Riesengebirge which is comparable to the maximum value for the Harz.

Prognostic and nowcasting wave parameters for the Harz

Maximum vertical velocity of the waves, most turbulence in the rotors and highest vertical extent is shown for the following values:

General wind direction between 180 and 240°
Wind speed minimum 25 kts at 500m above ground
Wind speed 35 to 50 kts at 500 hPa
Stable stratification or 1-2° inversion in a small layer at about 1300 to 2200 m
Wind at Brocken 30 to 50 kts
Surface winds leewards more than 13 kts
Pressure gradient between Erfurt and Magdeburg 2 to 4 hPa
No showers in lee up to 30 km distance

Outlook

Wave oscillations at the Harz mountains are relatively rare for many and large data sets. However, specified general prognostic criteria can be given. The typical position of rotor bands can be detected.

For further measurements activities should be aimed at the New Zealand Alps and on the Andes, which are climatologically for the whole Southern Hemisphere in an area with much more wind even in summertime. The waves in the Northern Hemisphere are a typical winter phenomenon.

Literature:

Corby, G.A. and J.S. Sawyer: The airflow over a ridge: The effects of the upper boundary and high level condition. Quart. J.Roy. Met.Soc. 84 (1958)

Lindemann, C.: Die Provence macht's möglich. Aerokurier 6/1985

Hafner, Th. Et al: Handbook of Meteorological Forecasting for Soaring Flight, WMO Technical Note No. 158 Geneva 1993

Examples of Vertical Velocity Profiles in the Lee of Harz Mountains

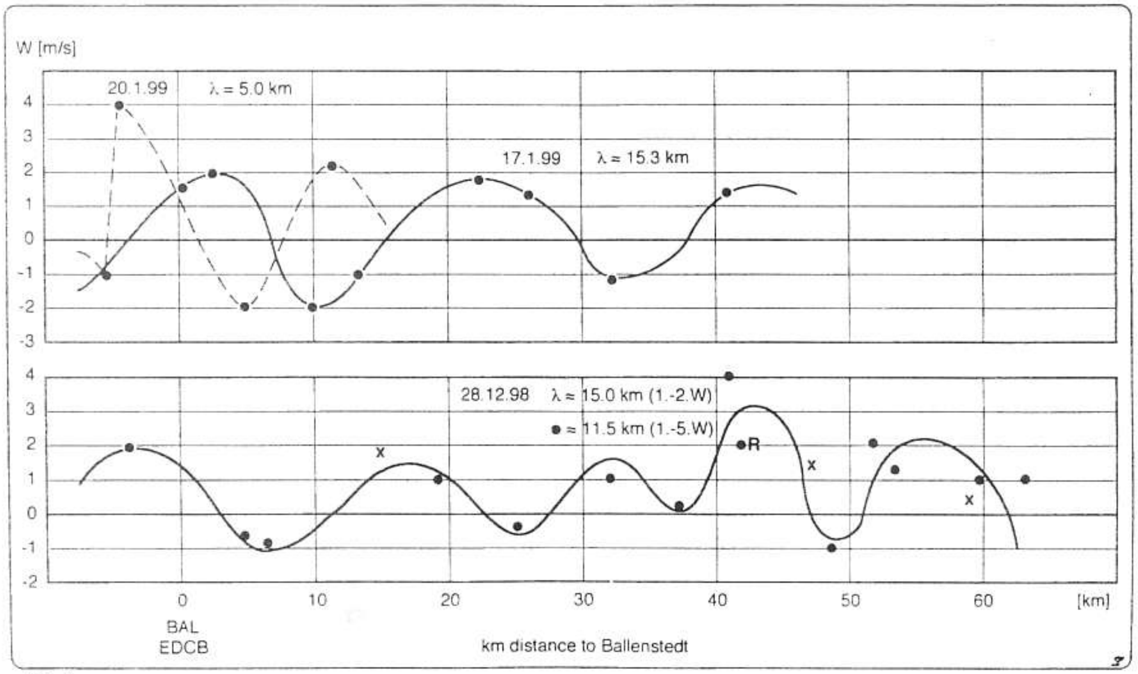


Fig. 1

LEE WAVE AT HARZ MOUNTAINS IN S-SW-WINDS
typical Position of Updrafts

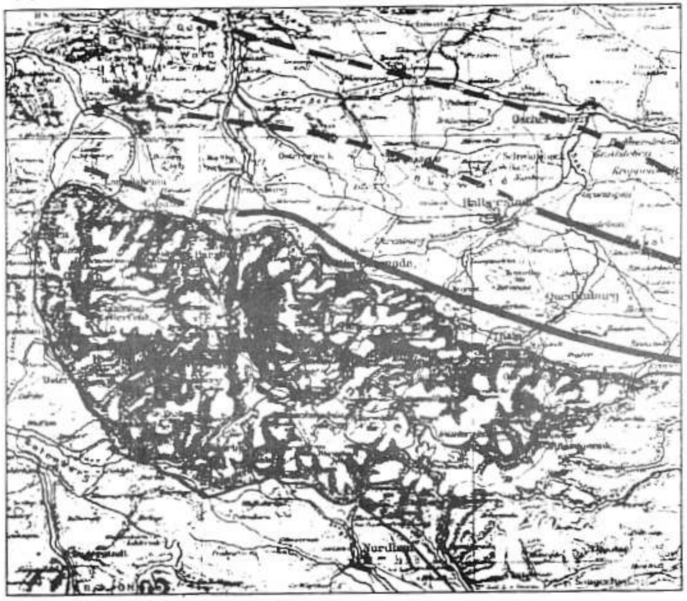
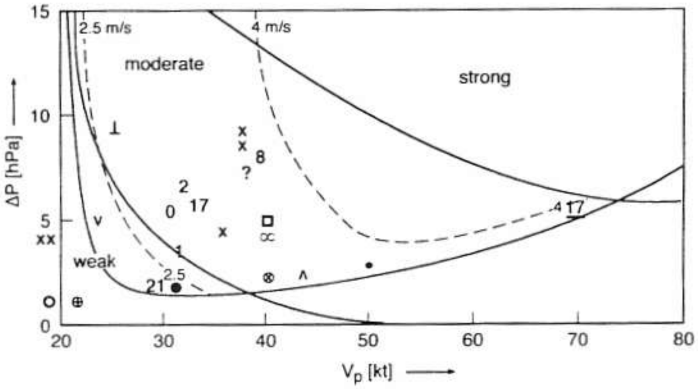


Fig. 2

LESTER-HARRISON NOMOGRAM FOR THE PREDICTION OF WAVE INTENSITY

Vertical: pressure gradient over the mountains related to 320 km

Horizontal: maximum perpendicular wind component between mountain top and 2000m above



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•	26.12.98		●	4.12.96	
o	30.12.98		1	15.11.69	
□	28.12.98		2	31.10.98	
∞	2.01.99		$\underline{17}$	17.10.98	Harz
xx	6.01.99		17	17.10.98	Riesengebirge
⊥	3.01.93		?	16.01.93	
⊕	7.10.93		∧	17.01.95	
x x	17.01.93		21	21.01.72	Riesengebirge
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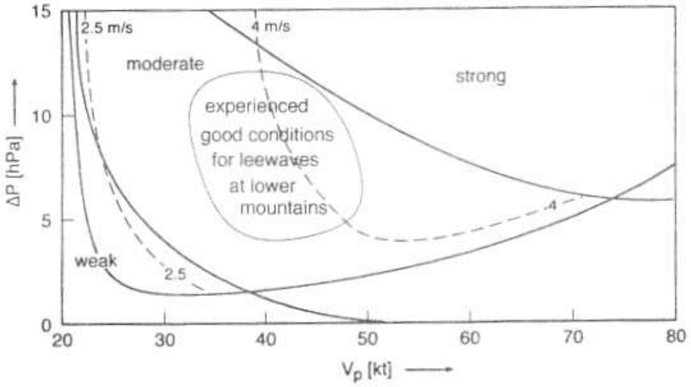

Fig. 4