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THE IMPACT OF MOUNTAIN LEE WAVES ON THE NEAR-SURFACE ATMOSPHERIC PRESSURE AND LOCAL AIR CIRCULATION IN THE FORELAND OF THE POLISH TATRA MOUNTAINS

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During the period 2012-2015, the Institute of Geography and Spatial Organization of the Polish Academy of Sciences worked on the research project entitled "The impact of mountain lee waves on the near-surface atmospheric pressure and local air circulation in the foreland of the Polish Tatra Mountains". This project was financed by the National Science Centre of Poland (DEC-2011/03/N/ST10/05629), and was supervised by Jakub Szmyd, also involving Paweł Milewski as a contractor.

The object of the study was mountain lee waves occurring in the northern foreland of the Tatra Mountains. These buoyancy perturbations are excited in the flow of air over a mountain range and propagate on the lee side of the topographic barrier. The formation mechanism is analogous to the wave motion of water in a river behind the step of the bed rock. During occurrence of Foehn winds in the study area the amplitude of lee waves can be up to 1000 meters and wavelengths can reach about 25 kilometres.

The main aim of the project was to study the influence of lee waves on the near-surface pressure field. It was hypothesized that lee waves induce formation of positive and negative pressure anomalies, which are arranged alternately, and their intensity decreases with distance from the mountains. This distribution is considered to be determined by wave motion periodicity (repetition of wave crests, troughs and ascending and descending wave currents which appear between them) and gradual wave damping with movement away from the mountains. The project involved complex studies of specifics of the lee waves

in the northern foreland of the Tatra Mountains using a variety of measurement tools, including, for the first time in the Carpathians, a ground-based network of atmospheric pressure measurements.

In order to achieve the project's aim, a special network of meteorological measurements and observations was created, being unique to the Carpathians. Forming the basic element of the network were 9 meteorological stations: 6 stations acquired from the project budget, 2 stations of the Institute of Meteorology and Water Management, and 1 station of the Podhale State Higher Vocational School in Nowy Targ. The stations were placed along a linear transect of approximately 30 km in length (Kasprowy Wierch-Nowy Targ) located perpendicular to the latitudinal course of the main ridge of the Tatra Mountains (Fig. 1). At each station the following

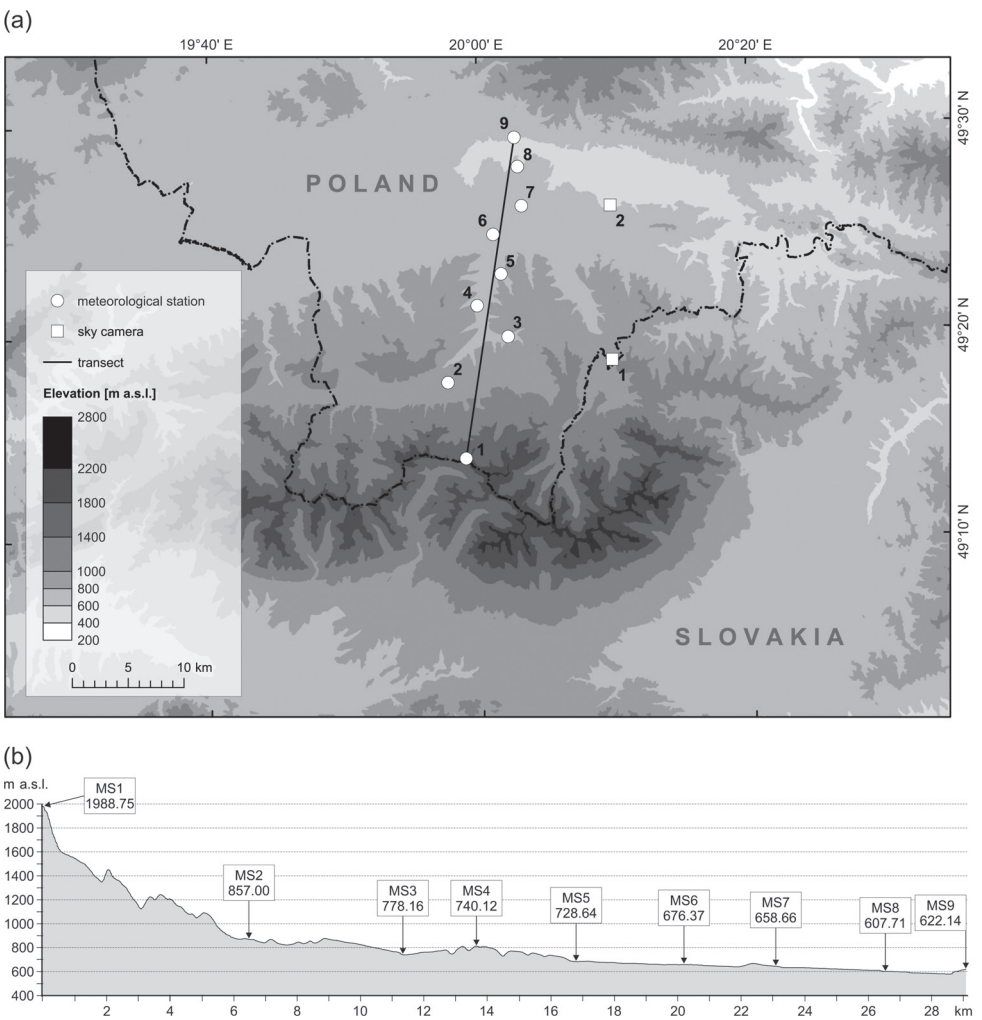

Figure 1. The orography of the Tatra Mountains with locations of the meteorological stations (MSs) and sky cameras (a) and transect of terrain Kasprowy Wierch (MS1) – Nowy Targ (MS9) with approximate locations of MSs 2-8 (b) (numbers in boxes indicate height above sea level of the barometers at each station)

parameters were recorded: wind speed and direction (at 10 m), atmospheric pressure, air temperature and humidity (at 2 m). The network also consisted of 2 automatic cameras purchased from the project budget. Spherical panoramas of the sky made by the cameras were used to document cloud patterns occurring above the transect. Meteorological measurements and observations were recorded from December 2012 to January 2015.

The source of data on lee waves was direct measurements of this phenomenon, which were performed during gliding flights in cooperation with Aero Club Nowy Targ (Figs. 2, 3). Measurements were conducted using a GPS receiver installed in a glider and on-board instruments (including a variometer). Data obtained using these devices enabled determination of the position of the lee waves occurring above the meteorological transect, and the speed of wave currents. Conclusions on lee waves were also made on the basis of data from atmospheric soundings in Poprad (Slovakia), synoptic maps, and cloud cover observations. In the latter case above-mentioned spherical panoramas of the sky and satellite images (MODIS sensor installed on satellites Terra and Aqua) were used.

The project's results extended the knowledge of lee waves in the northern foreland of the Tatra Mountains and their role in affecting regional and local weather conditions. It was possible to conclude that the lee waves can cause deformation of pressure fields at a distance of at least 50 km from the main ridge of the Tatra Mountains. During occurrence of lee waves in the study area different types of distribution of near-surface pressure anomalies were detected, including instances in accordance with the distribution described in the hypothesis. Anomalies were most frequent at stations located a short distance from the mountains. The magnitude of the anomalies was usually lower than 1.0 hPa, with a maximum value of 2.5 hPa.

Conclusions on pressure field deformations caused by lee waves were limited by the accuracy of atmospheric pressure measurements. Many pressure anomalies, especially in the northern part of the study area, were of small magnitude, thus the differences in distribution of atmospheric pressure can be explained by errors related to the accuracy of measurements. Additionally, wind gusts were identified as another factor affecting formation of the pressure anomalies. The following relationship was recognized: the higher

Figure 2. Glider during flight aimed at studies of lee waves in the northern foreland of the Tatra Mountains. Photograph was taken on 4 November 2014 at 10:21 UTC in the area of Kościelisko village in the easterly direction (photo by Jakub Świst, Aero Club Nowy Targ)

Figure 3. Towing of a glider during studies of lee waves in the northern foreland of the Tatra Mountains. Photograph was taken on 13 December 2014 at 11:16 UTC in the area of Ratułów village in the southerly direction. Above the Tatra Mountains wave clouds *Altocumulus lenticularis* are visible (photo by Jakub Świst, Aero Club Nowy Targ)

the wind speed, the more frequent the occurrence of negative anomalies and the greater the magnitude of the anomalies. Therefore, in final conclusions it was assumed that the deformations of the pressure field may have been the result of interactions among many factors, including lee waves, whose impacts can often overlap.

The influence of lee waves on local disturbances in the airflow was also documented. They manifest themselves as cases of northerly winds (sometimes long-term and strong), i.e. from the opposite direction to a prevailing advection. The presence of this condition was recognized as being associated with rotors, which are air vortices formed underneath the wave crests.

In project conclusions, the network of the near-surface atmospheric pressure measurements was considered as a reliable tool for investigations into lee waves. The use of this network can greatly facilitate studies in the future and reduce costs, since they will be conducted on the basis of automated ground-based meteorological stations. An enlargement of the network would be beneficial. An additional number of stations should be situated, especially in the vicinity of the mountains where the potential occurrence of pressure anomalies induced by lee waves are more likely. Positive results are also expected as a result of more accurate barometers and more frequent measurements.

The results of the project are primarily scientific, but they may also be of practical value. The network of near-surface atmospheric pressure measurements can be applied in meteorological services for aviation. Data on position and speed of wave currents provided by the network will be a valuable source of information for aviation, improving flight safety (e.g. by directing aircrafts outside of areas with descending wave currents) and reduce its costs (e.g. by directing gliders towards the areas with ascending wave currents).

Parts of the project results were published in 3 papers (Szmyd 2015ab, 2016). Meteorological measurements and observations obtained during the project provide a very valuable and unique source material that can be used in the future in much research, not only focused on lee waves.

References

SZMYD J., 2015a. *Badania tatrzańskiej fali orograficznej z wykorzystaniem lotów szybowcowych* [in:] J. Nyćkowiak, J. Leśny (eds.), Badania i Rozwój Młodych Naukowców w Polsce. Nauki przyrodnicze, vol. 1, no. 1, Poznań: Młodzi Naukowcy, pp. 148-154.

SZMYD J., 2015b. *O północnym przepływie powietrza na Podhalu w trakcie wybranych przypadków wiatru halnego* [in:] J. Nyćkowiak, J. Leśny (eds.), Badania i Rozwój Młodych Naukowców w Polsce. Nauki przyrodnicze, vol. 1, no. 1, Poznań: Młodzi Naukowcy, pp. 155-161.

SZMYD J., 2016. *Influence of lee waves and rotors on the near-surface flow and pressure fields in the northern foreland of the Tatra Mountains*. Meteorological Applications, vol. 23, no. 2, pp. 209-221.

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