Mountain waves occurrence in Polish Carpathians and their influence on aviation operations

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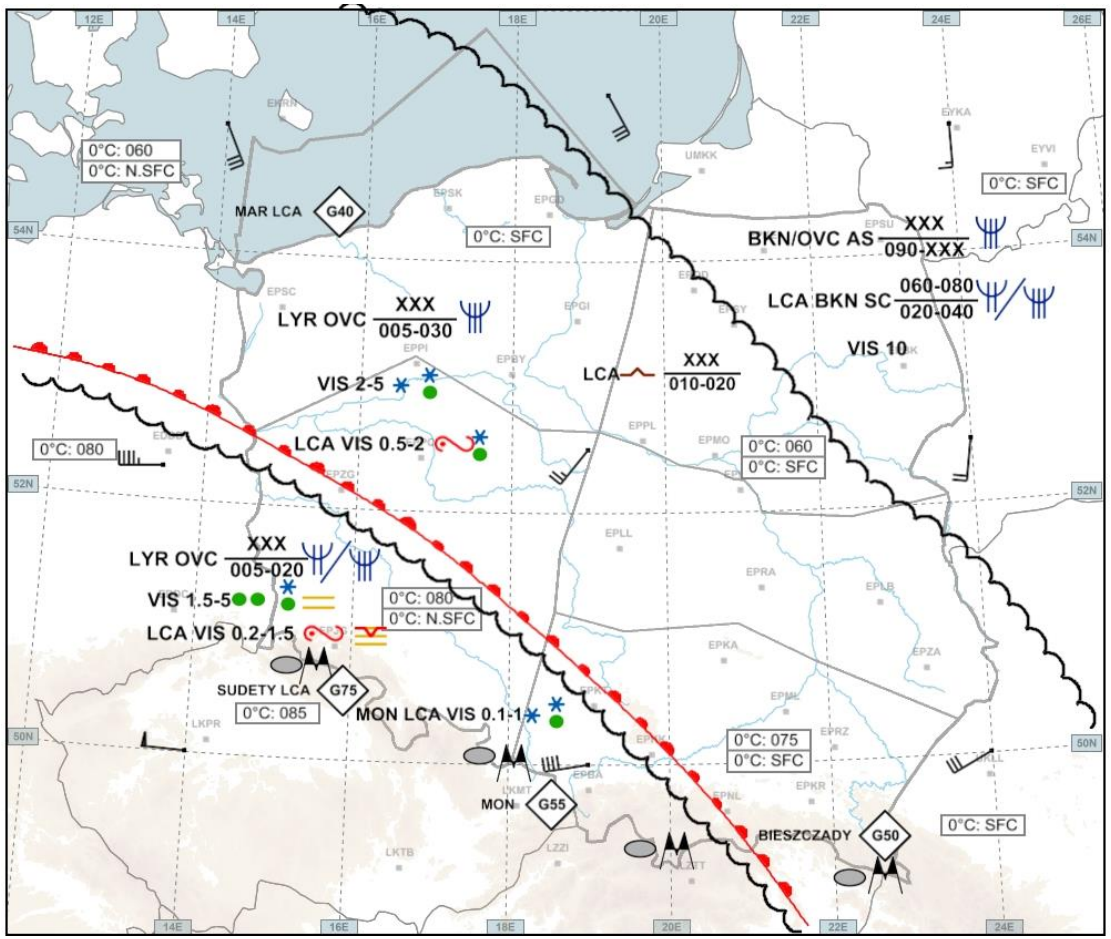
MOUNTAIN WAVES IN AVIATION WEATHER

Instytut Meteorologii i Gospodarki Wodnej
Państwowy Instytut Badawczy



FORECAST ISSUED BY MWO (FIR WARSZAWA)

SIGWX Chart SFC - FL100

VALID AT 06.01.2025 00 UTC

NOTES

and CB imply hail, MOD/SEV ICE and TURB, gusts

TCU implies MOD/SEV ICE and TURB, gusts

implies MOD/SEV ICE

implies VIS < 1 KM

MOD/HVY precipitation marked or when it reduces VIS < 5KM

Pressure in hPa, speed in knots (KT)

Visibility in kilometers (KM)

Altitude in hectofeet AMSL

Wind on FL050 Based on WAFC London model

Check SIGMET and AIRMET information

Only FIR WARSZAWA will carry the full set of required information

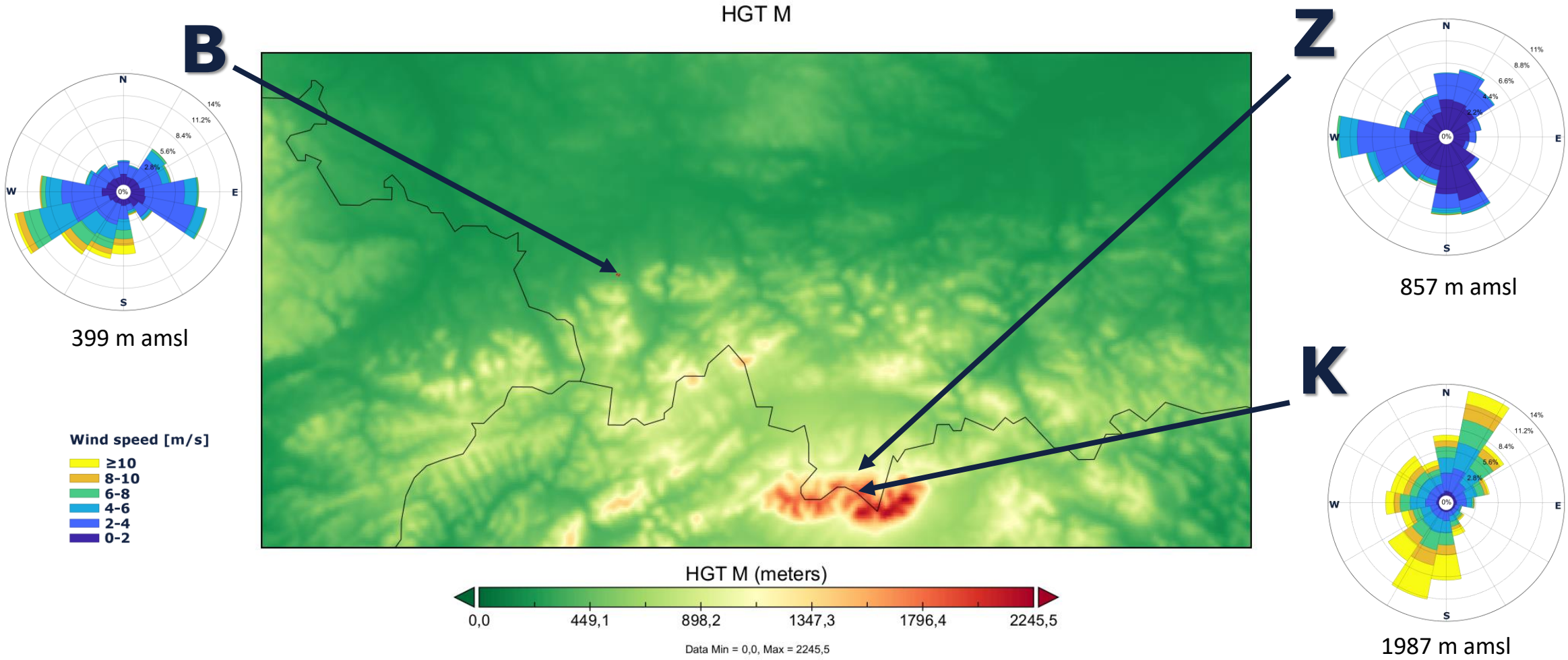
SYMBOLS

- Boundary of significant weather area
- Boundary of significant weather subzone
- Warm front
- Cold front
- Secondary cold front
- Occluded front
- Convergence line
- Shower rain, shower snow, shower sleet
- Rain, drizzle, freezing precipitation
- Snow, sleet, blowing snow
- Thunderstorm, hail
- Mist, haze, smoke
- Fog, freezing fog
- Moderate, severe icing
- Moderate (MOD), severe (SEV) turbulence
- Mountain obscuration, MOD/SEV mountain wave
- Surface gust > 30 KT (max gust value inside square)
- Center of atmospheric low/high
- 0°C level, Wind direction and speed

Downslope windstorms in Poland

Instytut Meteorologii i Gospodarki Wodnej
Państwowy Instytut Badawczy

Wind roses (1991-2020) for WMO stations within MTW range in Southern Poland.

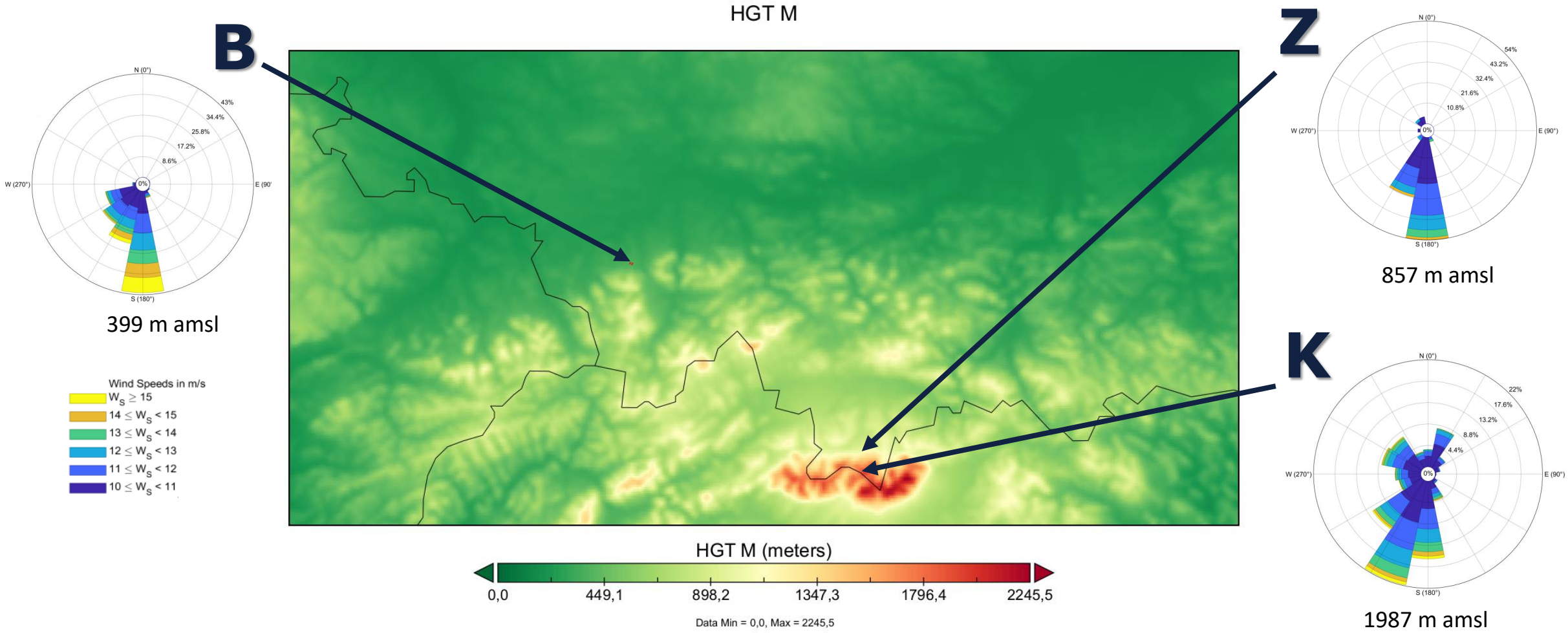


Map: WRF 1km domain used for hi-res modeling of case studies.

Downslope windstorms in Poland

Instytut Meteorologii i Gospodarki Wodnej
Państwowy Instytut Badawczy

Wind roses (1991-2020) for WMO stations within MTW range in Southern Poland: **wind speed >= 10m/s**



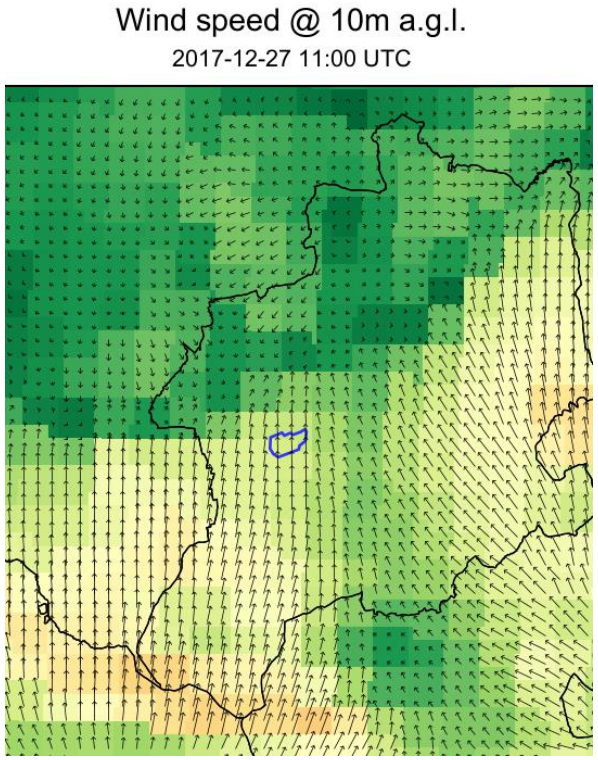
Map: WRF 1km domain used for hi-res modeling of case studies.

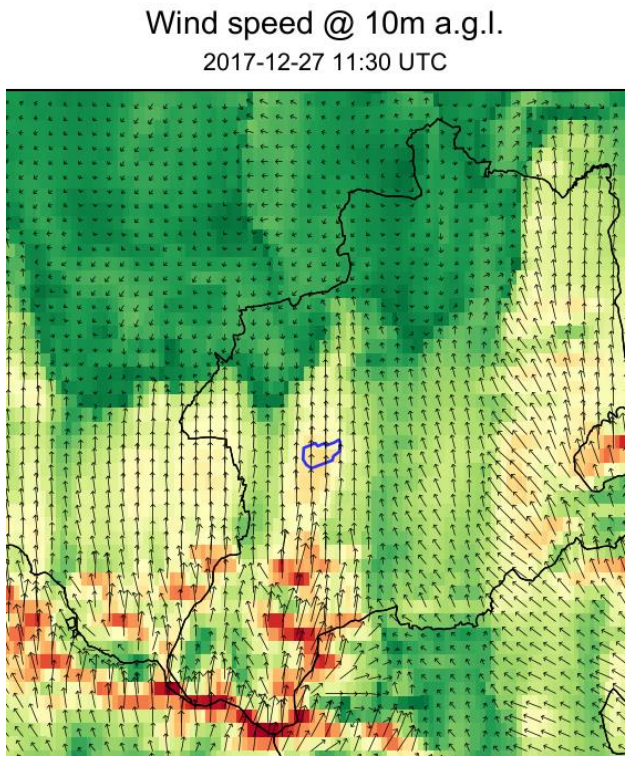
CASE STUDY: SITE B 2017

Cesna plane overturned by a sudden wind gust during landing operation.

WRF 200m domain modeling shows dynamic increase of wind speed at the time of landing consistent with the weather station observations.

Case studies model animations:





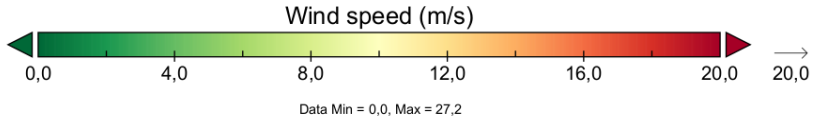
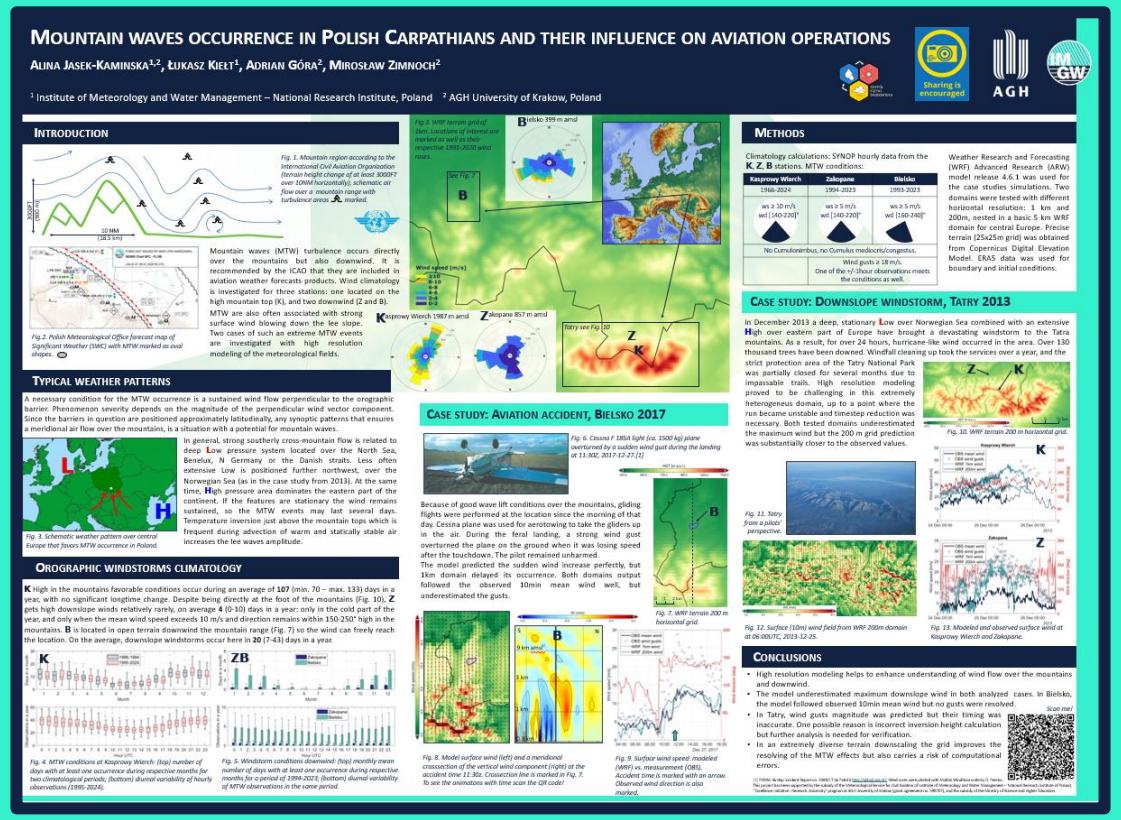


Photo: PKBWL Airship Incident Report no. 3389/17 (in Polish)

This project has been supported by the subsidy of the Meteorological Service for Civil Aviation of Institute of Meteorology and Water Management – National Research Institute of Poland, "Excellence Initiative - Research University" program at AGH University of Krakow (grant agreement no. 598707), and the subsidy of the Ministry of Science and Higher Education.



Mountain waves occurrence in Polish Carpathians and their influence on aviation operations

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Introduction

Fig. 1. Mountain region according to the International Civil Aviation Organization (terrain height change of at least 3000FT over 10NM horizontally); schematic air flow over a mountain range with turbulence areas marked.

Fig. 2. Polish Meteorological Office forecast map of Significant Weather (SWC) with MTW marked as oval shapes.

Mountain waves (MTW) turbulence occurs directly over the mountains but also downwind. It is recommended by the ICAO that they are included in aviation weather forecasts products. Wind climatology is investigated for three stations: one located on the high mountain top (K), and two downwind (Z and B). MTW are also often associated with strong surface wind blowing down the lee slope. Two cases of such an extreme MTW events are investigated with high resolution modeling of the meteorological fields.

Typical weather patterns

A necessary condition for the MTW occurrence is a sustained wind flow perpendicular to the orographic barrier. Phenomenon severity depends on the magnitude of the perpendicular wind vector component. Since the barriers in question are positioned approximately latitudinally, any synoptic patterns that ensures a meridional air flow over the mountains, is a situation with a potential for mountain waves.

Fig. 3. Schematic weather pattern over central Europe that favors MTW occurrence in Poland.

In general, strong southerly cross-mountain flow is related to deep **L**ow pressure system located over the North Sea, Benelux, N Germany or the Danish straits. Less often extensive Low is positioned further northwest, over the Norwegian Sea (as in the case study from 2013). At the same time, **H**igh pressure area dominates the eastern part of the continent. If the features are stationary the wind remains sustained, so the MTW events may last several days. Temperature inversion just above the mountain tops which is frequent during advection of warm and statically stable air increases the lee waves amplitude.

Orographic windstorms climatology

K High in the mountains favorable conditions occur during an average of **107** (min. 70 – max. 133) days in a year, with no significant longtime change. Despite being directly at the foot of the mountains (Fig. 10), **Z** gets high downslope winds relatively rarely, on average **4** (0-10) days in a year: only in the cold part of the year, and only when the mean wind speed exceeds 10 m/s and direction remains within 150-250° high in the mountains. **B** is located in open terrain downwind the mountain range (Fig. 7) so the wind can freely reach the location. On the average, downslope windstorms occur here in **20** (7-43) days in a year.

Fig. 4. MTW conditions at Kasprowy Wierch: (top) number of days with at least one occurrence during respective months for two climatological periods; (bottom) diurnal variability of hourly observations (1995- 2024).

Fig. 5. Windstorm conditions downwind: (top) monthly mean number of days with at least one occurrence during respective months for a period of 1994-2023; (bottom) diurnal variability of MTW observations in the same period.

Fig. 6. Cessna F 185A light (ca. 1500 kg) plane overturned by a sudden wind gust during the landing at 11:30Z, 2017-12-27.[1]

Case study: Aviation accident, Bielsko 2017

Because of good wave lift conditions over the mountains, gliding flights were performed at the location since the morning of that day. Cessna plane was used for aerotowing to take the gliders up in the air. During the feral landing, a strong wind gust overturned the plane on the ground when it was losing speed after the touchdown. The pilot remained unharmed.

The model predicted the sudden wind increase perfectly, but 1km domain delayed its occurrence. Both domains output followed the observed 10min mean wind well, but underestimated the gusts.

Fig. 7. WRF terrain 200 m horizontal grid.

Fig. 8. Model surface wind (left) and a meridional crossection of the vertical wind component (right) at the accident time 11:30z. Crossection line is marked in Fig. 7. To see the animations with time scan the QR code!

Fig. 9. Surface wind speed: modeled (WRF) vs. measurement (OBS). Accident time is marked with an arrow. Observed wind direction is also marked.

Methods

Climatology calculations: SYNOP hourly data from the **K**, **Z**, **B** stations. MTW conditions:

Kasprowy Wierch	Zakopane	Bielsko
1966-2024	1994-2023	1993-2023
ws ≥ 10 m/s wd [140-220]°	ws ≥ 5 m/s wd [140-220]°	ws ≥ 5 m/s wd [140-240]°
No Cumulonimbus, no Cumulus mediocris/congestus.		
Wind gusts ≥ 18 m/s. One of the +/-1hour observations meets the conditions as well.		

Weather Research and Forecasting (WRF) Advanced Research (ARW) model release 4.6.1 was used for the case studies simulations. Two domains were tested with different horizontal resolution: 1 km and 200m, nested in a basic 5 km WRF domain for central Europe. Precise terrain (25x25m grid) was obtained from Copernicus Digital Elevation Model. ERAS data was used for boundary and initial conditions.

Case study: Downslope windstorm, Tatry 2013

In December 2013 a deep, stationary **L**ow over Norwegian Sea combined with an extensive **H**igh over eastern part of Europe have brought a devastating windstorm to the Tatra mountains. As a result, for over 24 hours, hurricane-like wind occurred in the area. Over 130 thousand trees have been downed. Windfall cleaning up took the services over a year, and the strict protection area of the Tatry National Park was partially closed for several months due to impassable trails. High resolution modeling proved to be challenging in this extremely heterogeneous domain, up to a point where the run became unstable and timestep reduction was necessary. Both tested domains underestimated the maximum wind but the 200 m grid prediction was substantially closer to the observed values.

Fig. 10. WRF terrain 200 m horizontal grid.

Fig. 11. Tatry from a pilots' perspective.

Fig. 12. Surface (10m) wind field from WRF 200m domain at 06:00UTC, 2013-12-25.

Fig. 13. Modeled and observed surface wind at Kasprowy Wierch and Zakopane.

Conclusions

- High resolution modeling helps to enhance understanding of wind flow over the mountains and downwind.
- The model underestimated maximum downslope wind in both analyzed cases. In Bielsko, the model followed observed 10min mean wind but no gusts were resolved.
- In Tatry, wind gusts magnitude was predicted but their timing was inaccurate. One possible reason is incorrect inversion height calculation but further analysis is needed for verification.
- In an extremely diverse terrain downscaling the grid improves the resolving of the MTW effects but also carries a risk of computational errors.

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