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# SYNOPTIC CONDITIONS OF THE TORNADO OCCURRENCE IN THE PODHALE REGION ON 29 MAY 2001 AND ITS NATURAL AND ECONOMIC IMPACTS

*Abstract*: The paper presents meteorological conditions and the mechanisms of action concerning the occurrence of the tornado, which crossed above Orawsko-Jordanowskie Foothills and Nowotarska Basin on 29 May 2001. Apart from synoptic situation, a characteristic of satellite images showing cloudiness, thunderstorms and precipitation accompanying the tornado was presented, too. The cartographic and photographic documentation allowed determine the range and influence of the tornado, concerning both natural environment and technical infrastructure. Large areas of agricultural land were covered with garbage created by the tornado, which is a threat for the functioning of those ecosystems. The changes were classified with special focus on permanent ones, which stimulate further changes in the environment.

*Keywords:* tornado, causes, mechanism, effects, Southern Poland

## 1. Introduction

Tornadoes are a kind of air vortex arising in the cumulonimbus cloud, in the form of a column or funnel cloud whose wider end emerges from the cloud base and reaches the water surface, creating a waterspout, or the ground surface, forming a landspout. It usually covers a belt 100-200 metres wide. Tornadoes usually occur either in a cold front zone or before it, in a strongly developed storm of thermal origin, at high vertical temperature gradients (Schmuck 1952, Janiszewski 1966, Burchard 1970).

The first Polish scientific explanations of the tornado phenomenon date back to the early 19th century (Skrodzki 1821). There are few contemporary studies, mainly of a popular-scientific nature (Schmuck 1952, Janiszewski 1966, Burchard 1970). In Poland, the only effort to brief views on the structure and origins of tornadoes was taken up by R. Wiśliński (1967/1968). However, there is a great number of foreign works, mainly American ones, on the physics and climatology of tornadoes. In the USA, tornadoes cause extensive damage, especially in the states of Kansas, Mississippi and Alabama (Petterssen 1964). Comprehensive studies on tornadoes using radar and satellite techniques were conducted by Professor T.T. Fujita from the University of Chicago, who developed a tornado intensity scale (F0-F6) for assessing wind velocity inside the tornado on the basis of the damage done by the storm (McDonald 2001).

In Poland, tornadoes are rare and poorly documented phenomena. However, information on this markedly local phenomenon appears in the media almost every year. In southern Poland, tornadoes were recorded on 20 May 1988 in the Myślenice area, on 12 June 1993, in Alwernia and on 30 August 1996, between Konina and Niedźwiedź near the town of Mszana Dolna. Among the published descriptions, the tornadoes recorded in Kołomyja on 13 June 1876 (Sławiński 1877) and in Szczecin Voivodship on 25 August 1956 (Parczewski, Kluźniak 1959) are remarkable. To date, the best descriptions of the causes and effects of tornadoes concerned the ones affecting Rawa Mazowiecka and Nowe Miasto on 15 May 1958 (Rafałowski 1958, Morawska 1959).

A unique description of the pressure changes during the tornado in Rzeszów was published by J. Michalczewski in the translation of the manual by S. Petterssen (1964), page 44. On 20 May 1960, between 12 and 2 pm UTC, the pressure dropped by ca. 10 hPa. It then rose rapidly by 8 hPa. Wind velocity measured at the station was 40 m/s (Salomonik 1960). In some cases it is difficult to determine whether damage in forests was caused by hurricane winds (e.g. on 27 June 1961), or whether a tornado could have contributed to this (Salomonik 1961).

On 29 May 2001, at around 4 pm, there was an extremely strong tornado in the Orawsko-Jordanowskie Foothills bordering the Podhale region to the north, which caused considerable damage to the natural environmental and infrastructure along a section of 11.5 kilometres (Fig. 1). It moved from the Żeleźnica slope in the Podhalańskie Range, towards Nowotarska Basin, via a belt 150-200 metres wide, and covered parts of six villages: Bielanka in the Raba Wyżna commune, Pieniążkowice (the Czarny Dunajec commune), Pyzówka, Morawczyna, Trute, Ludźmierz in the Nowy Targ commune and the western edge of the town of Nowy Targ.

The aim of this study is to interpret the mechanism of tornado origin, and its impacts in synoptic and meteorological terms, and summarise losses in nature and infrastructure. The presented complex approach to the phenomenon is of documentary character. It is based on analyses of satellite photos, field mapping of the changes along the entire route of the tornado, interviews with residents and photo documentation.

## 2. Areas affected by the tornado

The air vortex arose in the convergence of two V-shaped valleys, below the Trzy Kamienie Mt., about 2.5 kilometres to the northeast of Żeleźnica (912 m a.s.l.), in Orawsko-Jordanowskie Foothills (Fig. 1). First, it headed to the northeast but, after bouncing from the left valley slope, it changed its direction to the southeast, crossing another two V-shaped valleys (625 m n.p.m. at the bottom) and the mountain ridge separating those valleys (660 m a.s.l.). It then hit Na Grapie Forest and, moving over the ridge (730 m a.s.l.), headed towards the settlements of Zającówka, Krzysiówka and Bykówka in Bielanka. Having crossed the stream of Bielanka (640 m a.s.l.), the tornado moved along the slope towards the agriculturally cultivated flat ridge (720 m a.s.l.)

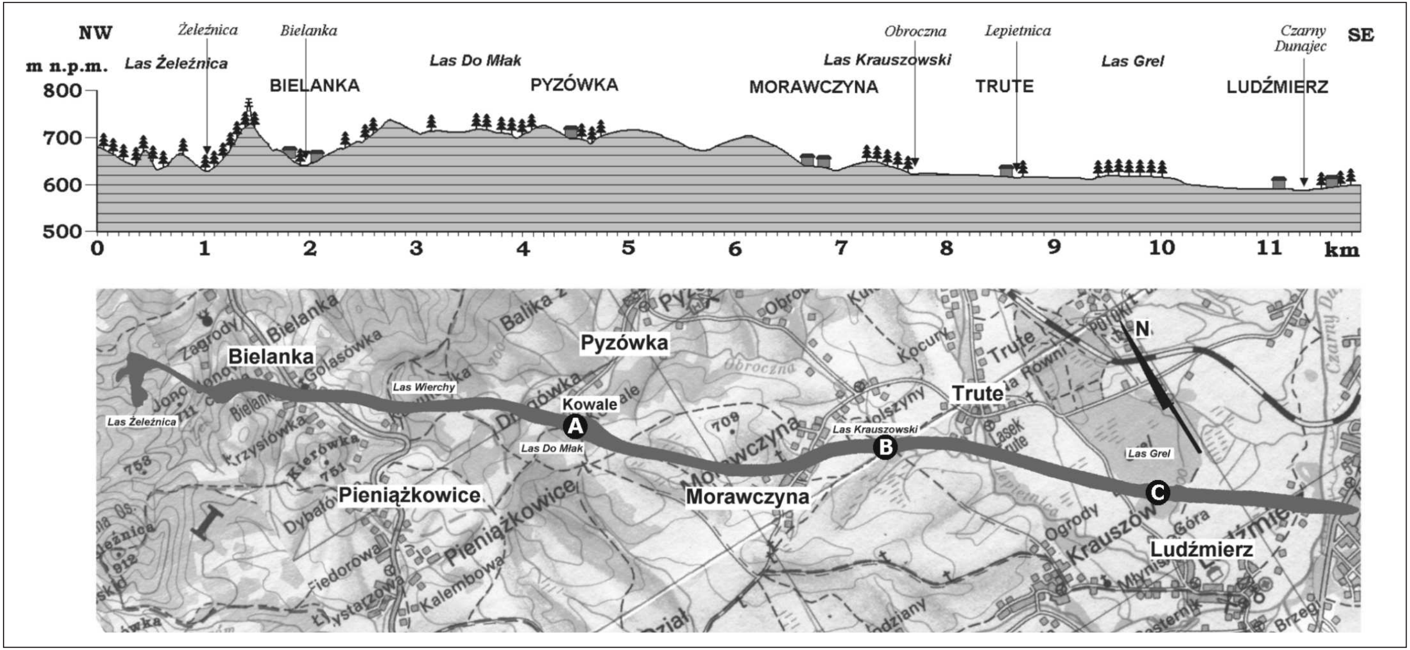


Fig. 1. Map and hypsometric profile of the route of the tornado in the Podhale region

Ryc. 1. Mapa sytuacyjna i profil hipsometryczny trasy trąby powietrznej na Podhalu separating Bielanka, Pyzówka and Pieniążkowice. Having passed the ridge and crossed over the hill (730 m a.s.l.), moving over the settlement of Kowale in the southern part of Pyzówka, the tornado passed over another deeply-cut V-shaped valley (690 m a.s.l. at the bottom) and a steep forested slope (Do Młak Forest, Fig. 2A). Then it reached the wide, agriculturally cultivated flattened hilltop (720 m a.s.l.) separating Pyzówka from Morawczyna. From this point, the tornado moved along the slope towards Morawczyna, obliquely hitting the buildings of the village arranged in the ribbon development. It then shifted towards the east and moved over the village axis along

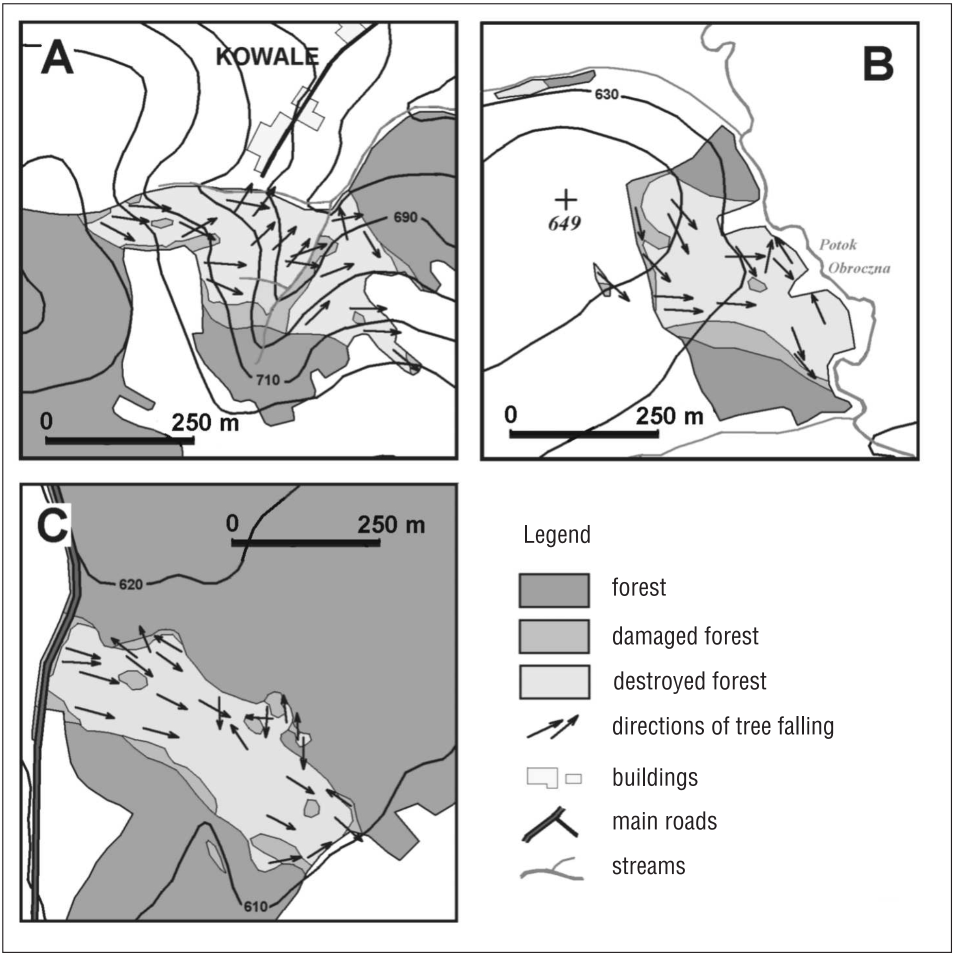


Fig. 2. Destruction in forests: A. Do Młak Forest (on the Kowale), B. Krauszowski Forest, C. Grel Forest. Locations of forests marked on Fig. 1

Ryc. 2. Zniszczenia w lasach: A. Las do Młak (nad Kowalami), B. Las Krauszowski, C. Las Grel. Lokalizacja lasów zaznaczona została na ryc. 1

a 750-metre-long section, causing the most severe damage in the buildings, along its entire route. The tornado then crossed an asymmetric, flat-bottom valley of a stream (627 m a.s.l.) and, turning southeast, it climbed along the slope up to the summit (649 m a.s.l.). There, via Krauszowski Forest (Fig. 2B), the tornado headed towards the shallow flat-bottom valley of the Obroczna stream and, travelling along this stream, reached Trute. Here the tornado hit the buildings located on the southern boundary of the village, cut through the wide, terraced Lepietnica valley (616 m a.s.l.) in the direction of Grel Forest (Fig. 2C) growing on the late glacial clay alluvial fan five metres above the Lepietnica flooded terrace. The fan, with its axis pointing to Ludźmierz, separates the valleys of Lepietnica and Czarny Dunajec. Having crossed the southern part of the forest, the tornado reached the bottom of the Czarny Dunajec Valley and lost its energy on the right, high bank of the valley.

## 3. The causes and evolution of the phenomenon

According to the data provided by the Institute of Meteorology and Water Management and information published in the press, the storm came from Beskid Śląski Mts. and Beskid Żywiecki Mts., and intensified while crossing the Babia Góra range (1,725 m a.s.l.). The tornado was observed at 2 pm UTC in Bielanka, above the school and an old chapel; it was preceded by a storm and rain from dark cumulonimbus clouds. Also in Pyzówka, in the settlement of Kowale, a narrow "swinging" funnel was visible. The tornado's passage through the forest was accompanied by a loud bang and the cracking noises of trees breaking. Broken trees lifted upwards were observed. The tornado was accompanied by heavy rain and hail. Unfortunately, there is no meteorological station on the route of the tornado. In Obidowa, a storm with hail was recorded between 3:35-3:45 pm (1:35-1:45 pm UTC). The data from the Institute of Meteorology and Water Management collected at the stations nearest to the tornado showed that the precipitation of rain and hail accompanying the storm did not exceed 20 mm (Obidowa 16.4 mm, Kowaniec 18.4 mm, Zawoja 13.2 mm and Osielec 11.2 mm). At the final stage, the "sucking in" of water from the Czarny Dunajec River was observed.

The synoptic situation of 29 May 2001 did not feature parameters especially favourable to the occurrence of the tornado (Fig. 3). It was a typical north-western cyclonic situation (NWc), often occurring in May. The localisation between the low pressure center (994 hPa) from above Russia and high pressure center (1,027 hPa) over the Bay of Biscay caused an advection of polar maritime air masses, subsequently, old, warm and fresh air from the north-west. Thunderstorm clouds arose in the cold front area, in the form of parallel systems extended along the lines of the air currents (Fig. 4). A radio sounding in Poprad (at 12 pm UTC) indicated that the velocity of the northwestern wind above the Carpathians at the altitude of ca. nine kilometres reached 45 m/s. The tornado formed near the occlusion point visible on the synoptic map from 6 pm UTC, i.e. at the point where the three air masses met.

Storm clouds (cumulonimbus) originated due to the high instability in the lower layers of the troposphere. It was computed from the vertical temperature profile over Poprad (at 12 pm UTC) that the average temperature gradient in the air layer up

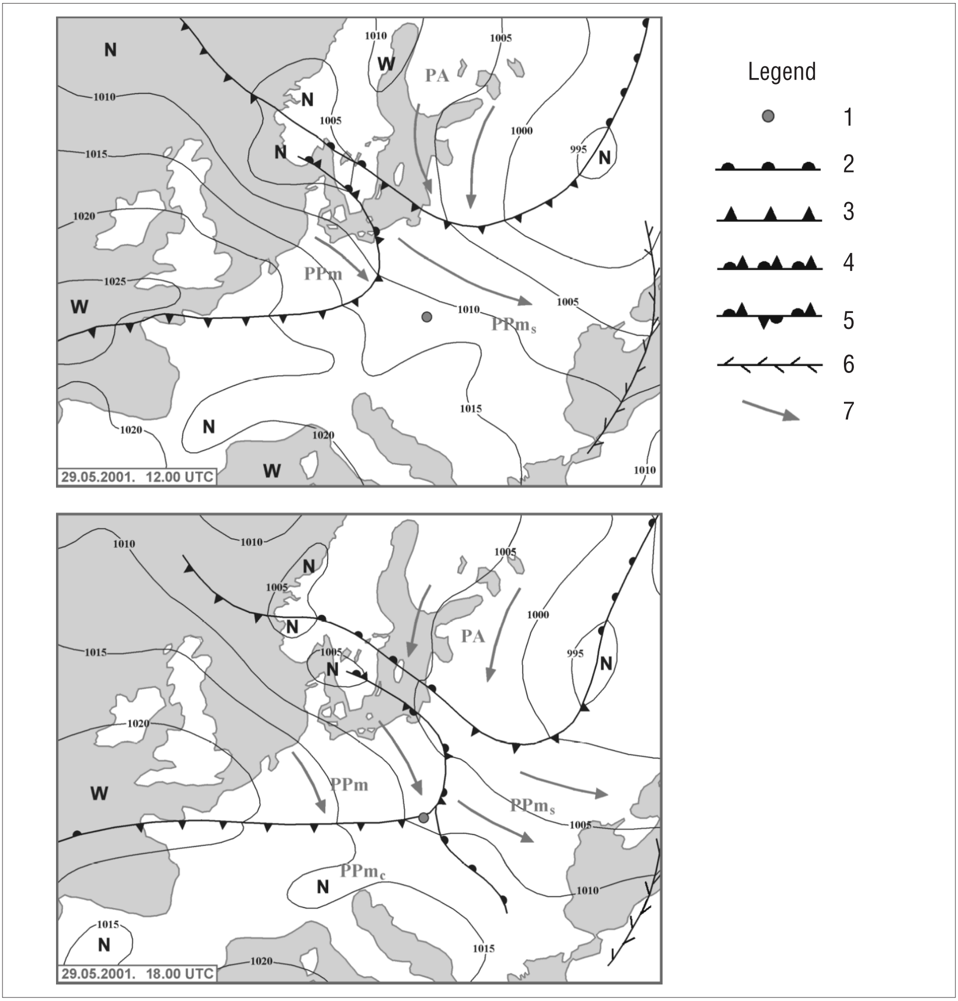


Fig. 3. The synoptic situation over Central Europe on 29 May 2001, at 12 and 6 pm UTC (according to synoptic maps from Deutscher Wetterdienst). Legend: W – high pressure center, N – low pressure center, PA – arctic air, PPm – fresh polar maritime air, PPmc – warm polar maritime air, PPms – old polar maritime air, 1 – the venue of the tornado occurrence, 2 – warm front, 3 – cold front, 4 – occlusion front, 5 – stationary front, 6 – discontinuity line, 7 – directions of air mass advection

Ryc. 3. Sytuacja synoptyczna nad Europą Środkową w dniu 29 maja 2001 r. o godz. 12 i 18 UTC (wg map synoptycznych Deutscher Wetterdienst). Objaśnienia: W – wyż, N – niż, PA – powietrze arktyczne, PPm – powietrze polarno-morskie świeże, PPmc – powietrze polarno-morskie ciepłe, PPms – powietrze polarno-morskie stare, 1 – miejsce wystąpienia trąby, 2 – front ciepły, 3 – front chłodny, 4 – front okluzji, 5 – front stacjonarny, 6 – linia nieciągłości, 7 – kierunki napływu mas powietrza

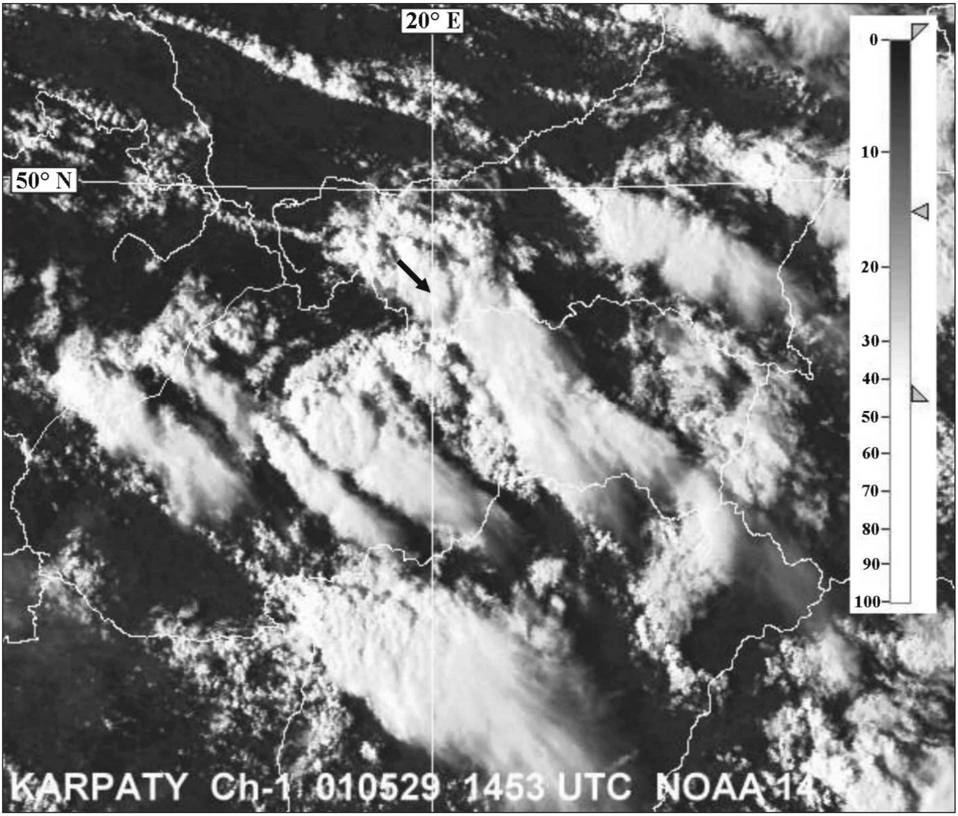


Fig. 4. Satellite photos of cloud cover (NOAA 14, channel 1 – visible) over the Western Carpathians on 29 May 2001, at 2:53 pm UTC. The arrow points at the location where the tornado occurred (according to data from the Satellite Station of the University of Silesia in Sosnowiec). White lines indicate country borders, larger rivers and geographical grid: 50° N and 20° E)

Ryc. 4. Zdjęcie satelitarne zachmurzenia (NOAA 14, kanał 1 – widzialny) nad Karpatami Zachodnimi w dniu 29 maja 2001 r. godz. 14:53 UTC. Strzałką zaznaczono miejsce wystąpienia trąby powietrznej (wg danych Stacji Satelitarnej Uniwersytetu Śląskiego w Sosnowcu). Białymi liniami zaznaczono granice państw, ważniejsze rzeki oraz linie siatki geograficznej: 50° N oraz 20° E)

to 1.5 kilometre was as much as –1.20 K/100 m, and –0.98 K/100 m up to the altitude of three kilometres. The 0°C isotherm was found at the altitude of 2,950 metres, which favoured the occurrence of hail. The tornado occurred in warm, unstable air, just before the cold front passage. Its occurrence was preceded by a pressure drop of more than 4 hPa in four hours (Fig. 5). The highest atmospheric instability was between 11 am and 2 pm UTC, i.e. just before the tornado occurred, which approximately documents the fluctuations of the vertical temperature gradient between Kasprowy Wierch and Zakopane (Fig. 6).

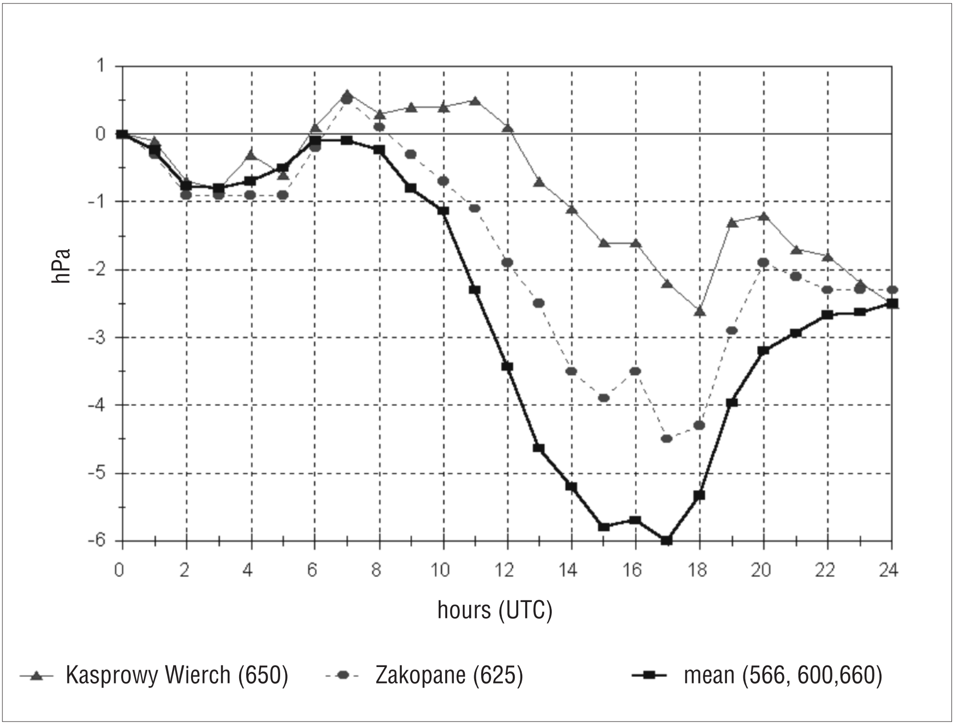


Fig. 5. Changes in atmospheric pressure on 29 May 2001 in Southern Poland (pressure variations from the value noted at 00 UTC). The international numbers of stations of the Institute of Meteorology and Water Management in brackets: 566 – Cracow, 600 – Bielsko, 660 – Nowy Sącz, 625 – Zakopane, 650 – Kasprowy Wierch

Ryc. 5. Zmiany ciśnienia atmosferycznego w dniu 29 maja 2001 roku w Polsce Południowej (odchylenia ciśnienia od wartości o godzinie 00 UTC). W nawiasach podane są międzynarodowe numery stacji IMGW: 566- Cracow, 600 – Bielsko, 660 – Nowy Sącz, 625 – Zakopane, 650 – Kasprowy Wierch

## 4. Mechanism of action

The inhabitants state that the attack by the tornado on specific buildings lasted between several and a dozen or so seconds. The largest element that was lifted into the air was the roof of a building in Trute, transported for ca. 200 metres, from the right to left side of Lepietnica.

It seems that the basic sucking-in and destruction level was around two to four metres above ground level: it is supported by the height of broken trees in forests and the absence of damage to crops along the whole route of the tornado. Young trees were preserved in a better state, which indicates the impact of the sucking and twisting force slightly above ground level, irrespective of its shape. That probably explains no

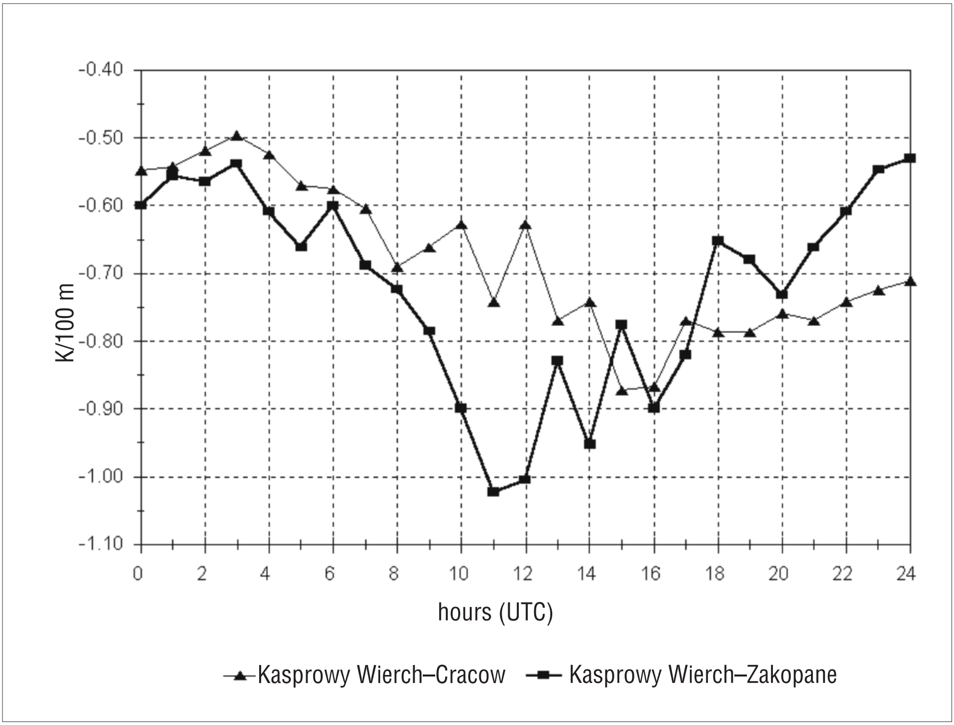


Fig. 6. Vertical gradients of air temperature (K/100 m) in the profiles:
Kasprowy Wierch – Cracowand Kasprowy Wierch – Zakopane on 29 May 2001

Ryc 6. Gradienty wysokościowe temperatury powietrza (K/100 m) w profilu
Kasprowy Wierch – Cracow i Kasprowy Wierch – Zakopane w dniu 29 maja 2001 r.

bodily injuries to people who stayed outside the buildings, in the tornado impact zone. Forest complexes, buildings, power supply lines and other facilities were mainly affected.

Field studies in the forests on the slopes of Żeleźnica, over Kowale, in the Krauszowski Forest and in Grel indicate a complete destruction of trees over a 150-200 m wide belt (Fig. 2, Phot. 1and 2). In addition to the main destruction zone, there are parallel, narrow ten-metre-wide corridors "cut" in the forest by the tornado. They are located in the nearest neighbourhood, but separated from the main zone by sections of forest which were not bent and did not suffer damages, which testifies a high diversification of wind velocity in the tornado's closest vicinity. The crowns of most trees in all the damaged forests lay to the east or southeast, according to the direction in which the tornado moved. The SE-NE cross-like arrangement of tree trunks was also often recorded, with the trunks lying transversely or even facing in the opposite direction to the movement of the tornado (Fig. 2, Tab. 1). An especially chaotic arrangement of tree trunks, reflecting the spinning air movement occurred in Do Młak Forest and in Grel. In Do Młak Forest, it was recorded that the tornado spun a thick tree around its axis (Phot. 3).

Tab. 1. Directions of crowns of trees fallen by the tornado in forests

Tab. 1. Ukierunkowanie koron leżących w lasach drzew, przewróconych przez trąbę powietrzną

| Forest | Direction of fallen trees |
|---|---|
| Żeleźnica Forest | E, ESE, SE |
| Do Grapy Forest | SE, SSE |
| Nad Bielanka Forest | SE, S, E, NE |
| Wierchy Forest | E, NE |
| Do Młak Forest | E, ESE, ENE, NE, SE, NNE, SSE, NW |
| Krauszowski Forest | E, SE, NNW, SSE |
| Forests near streams on the Obroczna and Lepietnica | SE, E, N |
| Grel Forest | ESE, E, WNW, N, NW, S, NNE |

Damage in forests is diversified and clearly related to the characteristics of the substratum and forest-type. In the section between Bielanka and Krauszowski Forest on the Morawczyna there are spruce-type forests growing on the thin soil layer, originating from sandstone and slate of the Magurian nappe. The skeletal nature of the soil makes tree roots penetrate gaps in rocks occurring shallowly under the soil and, due to this, trees are more strongly attached to the substratum. The tensile strength of roots (180 kg/cm$^2$ in the case of spruce) and the substratum keeping index determined by the endurance of roots located within 1 m$^3$ soil, amounting to 4,800 kg/m$^3$ (Rokita 1970), play an important role. The majority of trees in these forests are broken or twisted at a height of two to four metres.

The Grel Forest, being a type of humid spruce forest, grows on the late Pleistocene alluvial fan of Lepietnica comprised of deep, strongly humid clays. A number of entire trees were fallen there, creating formations comprised of roots and soils, with a shallow plate-like root system 20-30 cm thick, joined by the soil layer. Thus, not only trees but also the top soil layer were destroyed in the Grel Forest (Phot. 4).

In the montane alder-type forest by the stream on the Lepietnica inundation terrace only some alders were destroyed, while the remaining trees were only permanently bent. The higher resistance of the alder forest to tornado pressure is attributed to the high elasticity of the tree trunks and a very tangled root system, which form a compact mass together with the soil. The tensile strength of the alder roots was calculated by Z. Rokita (1970) at 140 kg/cm2, and the substratum keeping index at 5,580 kg/m$^3$.

Agricultural land and meadows were relatively the least affected, but they were littered to a large extent with material spread by the tornado.

## 5. Effects of the tornado

Forest damage is the most visible and permanent effect of the tornado. All forest complexes on the tornado's route were completely destroyed along a belt 100-200 metres wide (Fig. 2), and numerous trees growing close to the belt were damaged. The most extensive damage was suffered by the forests of Żeleźnica, Do Młak, Krauszowski and Grel. The area of destroyed forest calculated from field mapping is presented in Tab. 3. Similar widths of the belt in the forest indicate an equally strong impact along the entire route. Over the coming years, until young trees grow (afforestration of the plots is planned), further damage to trees on exposed forest boundaries should be expected, due to stronger winds. Thus, the forest line may recede from the already damaged belts.

Severe losses were also noted in the buildings located along the route of the tornado. According to data from commune offices in Raba Wyżna and Nowy Targ, 104 buildings in six localities were either destroyed or seriously damaged (Tab. 2). The highest number, i.e. as many as 48 buildings, were damaged in Morawczyna. The tornado took entire houses with their furnishings (Phot. 5), roofs and parts of roofing (Phot. 6), moving and spreading them along the entire length of the route. In some cases, the whole structure of the building was moved by a dozen centimetres or so in relation to its foundations. Lifting such large masses into the air led to the creation of a belt of litter up to 200 m wide along the entire route of the tornado. Areas of damaged forests and agricultural land were littered (elements of infrastructure and house furnishing could be found among the fallen trees). The spinning movement caused some steel plates to wrap around tree trunks (Phot. 7). Such elements as roofing tiles with protruding nails, twisted steel sheets, eternit, nails, poles and other sharp objects posed an actual threat to automobile tyres and other mechanic equipment used during summer farm work and bodily harm to harvesting people and animals.

Power supply lines were damaged along the route of the tornado and its surroundings, including a high voltage line, which suffered from the breaking of two giant metal line supports: in Bielanka and Trute, and phone lines. On the basis of wind damage, the intensity of the tornado can be rated between F2 (considerable damage) and F3 (severe damage) according to the Fujita scale (McDonald 2001). It means that

Tab. 2. Destroyed or damaged buildings (data from the municipal offices of the Nowy Targ and Raba Wyżna)

Tab. 2. Zniszczone lub uszkodzone budynki wg danych UMiG Nowy Targ i UG Raba Wyżna

| Locality | Number of destroyed or damaged buildings |
|---|---|
| Bielanka | 29 |
| Pyzówka | 12 |
| Morawczyna | 48 |
| Trute | 10 |
| Ludźmierz | 5 |
| Nowy Targ | 2 |
| Total | 106 |

Tab. 3. Areas of destroyed or damaged forests (data from field studies)

Tab. 3. Powierzchnia zniszczonego lub uszkodzonego lasu wg badań terenowych

| Forest name and type | Area of destroyed or damaged forest (hectares) |
|---|---|
| Żeleźnica Forest – spruce forest | 5.8 |
| Na Grapie Forest – spruce forest | 5.1 |
| Nad Bielanką Forest – spruce forest | 0.9 |
| Wierchy Forest – spruce forest | 2.1 |
| Do Młak Forest – spruce forest | 10.6 |
| The forest by the stream in Morawczyna – montane alder forest | 0.1 |
| Krauszowski Forest – spruce forest | 7.4 |
| Nad Lepietnicą Forest – montane alder forest | 0.8 |
| Grel Forest – humid spruce forest | 9.6 |
| Total | 42.4 |

wind speed must have exceeded 70 m/s (250 km/h).

Fallen trees and other objects blocked up all roads and forest cart-roads, in the direct tornado impact zone and its surroundings. Therefore, it was difficult to deliver aid to the people affected by the tornado just after its occurrence.

Changes in the mentality and awareness of inhabitants, who will live in fear for a long time to come, are another serious, but intangible consequence. Similar reactions are observed after floods.

## 6. Conclusions

The described tornado should be classified as one of the most intensive in Poland, between F2 and F3 on the Fujita scale.

It seems that the route of the tornado was connected with the direction of air mass advection, and it was completely independent from land relief and relative height variability of the effected area.

Changes in the landscape due to the creation of deforested belts in forest complexes, changes in the mentality of inhabitants and serious pauperisation due to the loss of property are permanent consequences of the tornado.

Extensive destruction to buildings were short lasting, thanks to substantial assistance from national authorities, the local community and the involvement of many people.

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## Warunki synoptyczne wystąpienia trąby powietrznej w dniu 29 maja 2001 roku na Podhalu oraz jej skutki przyrodnicze i gospodarcze

### Streszczenie

W artykule przedstawiono meteorologiczne warunki powstania i mechanizm działania wyjątkowo silnej trąby powietrznej, która przeszła nad Pogórzem Orawsko-Jordanowskim i Kotliną Nowotarską w dniu 29 maja 2001 roku. Oprócz sytuacji synoptycznej przedstawiono charakterystykę satelitarnych obrazów zachmurzenia oraz burz i opadów towarzyszących trąbie. Na podstawie zebranej kartograficznej i fotograficznej dokumentacji terenowej określono jej zasięg, sposób oddziaływania; opracowano skutki, jakie spowodowała w przyrodzie i straty w infrastrukturze technicznej. Wskazano na znaczne zaśmiecenie dużej powierzchni użytków rolnych i związane z nim zagrożenia. Dokonano klasyfikacji zaistniałych przemian, akcentując skutki trwałe, które dają początek dalszemu łańcuchowi przemian w przyrodzie.

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