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The effect of weather on transportation: Assessing the impact thresholds for adverse weather phenomena

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ABSTRACT

Transportation is strongly affected by adverse weather. This was experienced in many parts of Europe during the cold winter 2009/10, when snow, ice and sub zero temperatures occasionally paralyzed road and rail transport as well as aviation. The interannual variability in weather conditions is significant, especially in Central and Northern Europe and harsh winters occur occasionally.

The probability distribution of adverse and extreme weather events can be assessed using a suite of indices. For this purpose, threshold indices for different weather phenomena were defined taking into account the impact of weather and climate extremes on all transportation sectors. This procedure enables a European wide analysis of probabilities of hazardous events in the "present climate" as well as in the projected future climate using climate model simulations. The investigations were carried out in the EU/FP7 project EWENT.

Here we concentrate mainly on road transport and winter conditions. Strong wind, heavy snowfall and low temperature typically result in traffic jams and increased accident rates in spite of effective maintenance operations. Thus, blizzard is a good example of an event that is hazardous for road transportation (as well as for other transportation means). Based on this study, it is suggested that the impact thresholds for the blizzard are: 24h snowfall ≥ 10 cm, daily mean temperature ≤ 0^{o}C and maximum wind gusts ≥ 17 m/s. With these criteria, the frequencies of occurrence (probabilities) of blizzards in different parts of Europe can be estimated, in the present and future climate.

Keywords: Adverse weather, impact threshold, wind gust, blizzard

1 INTRODUCTION

Adverse weather conditions can cause disturbances for all transport means. During wintertime, low temperature and snowfall result in road traffic accidents and jams, as well as delays or cancellations of trains or flights. Snowfall clearly increases daily road traffic accident rates, as found by Andreescu and Frost [1] and it can be double to fourfold compared to the daily mean (Rauhala and Juga [2], and Juga [3]). In Europe, long lasting cold spells have lately caused the closure of some airfields due to shortage of de-icing chemicals and also substantially disturbed inland waterway transport due to ice-cover formation. This was experienced especially during the winter 2009/10 in many parts of Europe. Strong wind gusts can have a negative impact on transportation in any season as falling trees can block the roads and railways and cause for example severe electricity cuts (Rauhala and Juga [2]).

The impacts of extreme weather on transportation have been investigated in the present EU/FP7 project EWENT. The goal has been to determine impact thresholds for different weather parameters, showing substantial impacts on different transport means. Applying these threshold values, the frequencies and probabilities of harmful weather events in different parts of Europe can be estimated from the transportation point of view. The motivation is to understand better the impact of certain weather phenomena on transportation and study their occurrence in the current and future climate.

2 METHODOLOGY

The impact threshold definition process started with a review of the literature and existing body of knowledge on the impacts of extreme weather phenomena on transport system. The survey consisted of more than 150 research papers published in national and international journals and books, reports of research projects and research councils (Leviäkangas et al. [4]). Although we focused mainly on the European cases, quite many of the publications deal with extreme weather impacts from Canada, the USA and Australia. Each weather phenomenon was considered separately, including the delineated disruptive level and thresholds for it, the reported impacts and/or consequences on different transportation modes (road, rail transportation, aviation, navigation), and the country/city where the weather parameter had occurred. The phenomena included were: windstorm (wind gusts), snowfall/blizzard, hail, thunderstorm, tornadoes, flash floods/rainfall, volcanoes, extreme temperature (cold, hot), lightning, fog, freezing rain, frost and drought.

In addition, a collection of hazardous weather events and their impacts on transportation in Europe was produced, based mainly on media reports. The database includes more than 190 cases of different weather situations/ phenomena and their impacts on society from 1 January 2000 until 10 September 2010. Twenty-seven large autumn or winter storms that passed through the whole of Europe (or at least a large part of it) during the 10 year period were identified. More than half of the listed events were associated with heavy rain (79), heavy snow (59) or strong wind (81). Low temperature was the dominating weather parameter in 15 of the listed events, and 11 events appeared to be related to high temperatures. Hail was involved in 20 and ice in 13 events. Fog was involved in eight and low visibility in eight traffic events. Landslides due to heavy rain had an impact on transport in 14 events (Leviäkangas et al. [4]).

Finally, the warning practices of the European Weather Services were also considered when assessing the impact thresholds. Also, some relevant cases were investigated more thoroughly, for example the Gudrun windstorm in Northern Europe during January 2005 and the “Western European snow” in the beginning of February 2009.

3 RESULTS

This paper focuses mainly on wintertime phenomena. Impact thresholds for snowfall, wind gusts and cold spell (Tables 1-3) were assessed so, that each parameter has three threshold values based on the severity of impacts. The threshold indices can be applied over the entire continent, the lowest values may occur in most parts of Europe in the present climate. Table 4 shows the defined impact thresholds for the blizzard (a combination of snowfall, wind gusts and low temperature). Using these impact thresholds, it is possible to calculate the present climatology of harmful weather phenomena in Europe and estimate the changes in the future (up to the 2050’s), based on regional climate model simulations, see Vajda et al. [5].

Table 1. Impact thresholds for snowfall (Rs; 1 mm precipitation equals approximately to 1 cm of snow).

Threshold	Impacts	Consequences
Rs ≥ 1 cm/24 h	Local slipperiness (when T_road < 0 ^{o}C and salting not carried out).	Somewhat increased car accident rate.
Rs ≥ 10 cm/24 h	Reduced friction and slipperiness on roads. When combined with low temperature and wind, rail points may get stuck.	Increased accident rate in road traffic (double accident rate compared to the mean), possibly delays and cancellations in road and rail traffic as well as in aviation.
Rs ≥ 20 cm/24 h	Slippery roads and airfield pavements, accumulated snow banks. Poor visibility. (Snow accumulation of 20 cm/24h or more doesn’t occur very often in lowland districts).	Disturbed traffic, high accident rate, closed roads (for example: trucks stuck in snow banks, Sweden, highway E4, on 17 Dec. 2009), airfields temporarily closed, plenty of delays and cancellations of trains.

Table 2. Impact thresholds for wind gusts (Wg)

Threshold	Impacts	Consequences
Wg ≥ 17 m/s	Trees can fall down over roads and cars as well as over railway electricity lines.	Suspension of small boat operation, local/occasional problems in road and rail traffic.
Wg ≥ 25 m/s	Plenty of fallen trees. Reduced visibility due to the blowing snow or dust.	Electricity cuts, delays and cancellations in air, rail and road traffic. Ferry traffic is disturbed, only the biggest ships might cruise.
Wg ≥ 32 m/s	Huge amount of fallen trees, wide and long-lasting power failures possible. Reduced visibility, high waves on the sea, especially if the event lasts for a longer period.	Ferries stay at the harbour, airfields are closed. Large material damages. Some railway lines might be closed for several days.

Table 3. Impact thresholds for daily mean temperature (T)

Threshold	Impacts	Consequences
T ≤ 0 °C	This is an important threshold related to slipperiness (ice formation, form of precipitation: rain, sleet, snowfall, freezing drizzle). The temperature is rather a modifier of hazardous conditions than a main cause. Low temperature combined with precipitation and wind can have a disruptive affect on traffic.	Increased accident risk in road traffic. The occurrence of freezing drizzle might be hazardous for aviation and road traffic. Premature deterioration of road and runway pavements due to freeze-thaw cycles.
T ≤ -7 °C	The effect of salting for ice removal decreases in low temperatures. So, even relatively small amounts of snowfall can cause slippery road conditions. Rail points may get stuck by drifting snow. Ice formation on rivers may start.	Increased accident risk, delays and cancellations in road and rail traffic. Inland waterway transport might be disrupted if there are many cold days in a row.
T ≤ -20 °C	Some vehicles might have fuel problems. Rivers get ice-covered, if a long lasting cold period. Dangerous wind chill conditions occur when moderate winds prevail.	Public transport may encounter breaks due to fuel problems (Oslo, winter 2009/10). Riverboat traffic is stopped. Limitations for the transport personnel working outdoors.

Table 4. Impact thresholds for the blizzard: snowfall (Rs), wind gusts (Wg) and daily mean temperature (T)

Threshold	Impacts	Consequences
Rs ≥ **10 cm/24h** Wg ≥ **17 m/s** T ≤ **0 °C**	Fallen trees, snow banks, slippery roads and runways, poor visibility, rail points may get stuck.	Increased rate of injuries and accidents in road traffic (2-4 times more accidents compared to the mean), delays, and cancellations in all transportation modes.

4 EXAMPLES OF ADVERSE WINTER WEATHER CASES

We have collected below some cases in which winter weather phenomena show high impact on society and transportation. The impact thresholds presented in Section 3 can be compared and validated with these cases.

4.1 Snowfall

In the UK, Heathrow airport was closed and London buses stopped running due to sub-zero temperatures and snowfall up to 10 cm in London on 1-2 February 2009. Massive delays and traffic jams resulted and the total costs of the event were estimated at 1.3 billion pounds in lost work, as found by Grumm [6]. The snow storm caused big problems for transportation in France and Belgium as well.

4.2 Wind gusts

The Gudrun storm on 8-9 January 2005 is a good example of an intensive low pressure affecting a large area and causing extensive damage. The storm moved from Ireland over Scandinavia to Russia. All transport means were badly disrupted, for example in Sweden railway traffic stopped totally due to fallen trees and road transport also suffered badly due to blocked roads. The maximum wind gusts in Denmark during the storm were as high as 46 m/s.

In Finland, a wind storm on 10 November 2008 with gusts up to 29 m/s caused wide electricity cuts (Rauhala and Juga [2]). Especially the rail traffic is sensitive to electricity cuts caused by fallen trees.

A recent example of a high-impact wind storm is the Christmas storm 2011 in Finland. A stormy westerly wind after the passage of a low pressure system caused extensive forest damage and electricity cuts. In Southwestern Finland there were several roads and one main railway line blocked by fallen trees. The observed maximum wind gusts in Southern Finland were as high as 31.5 m/s (Figure 1), almost exceeding the highest impact threshold ($W_g \geq 32$ m/s, see Table 2). The impacts and consequences in this case were comparable to those presented in Table 2, thus being a good validation of the highest impact threshold, 32 m/s.

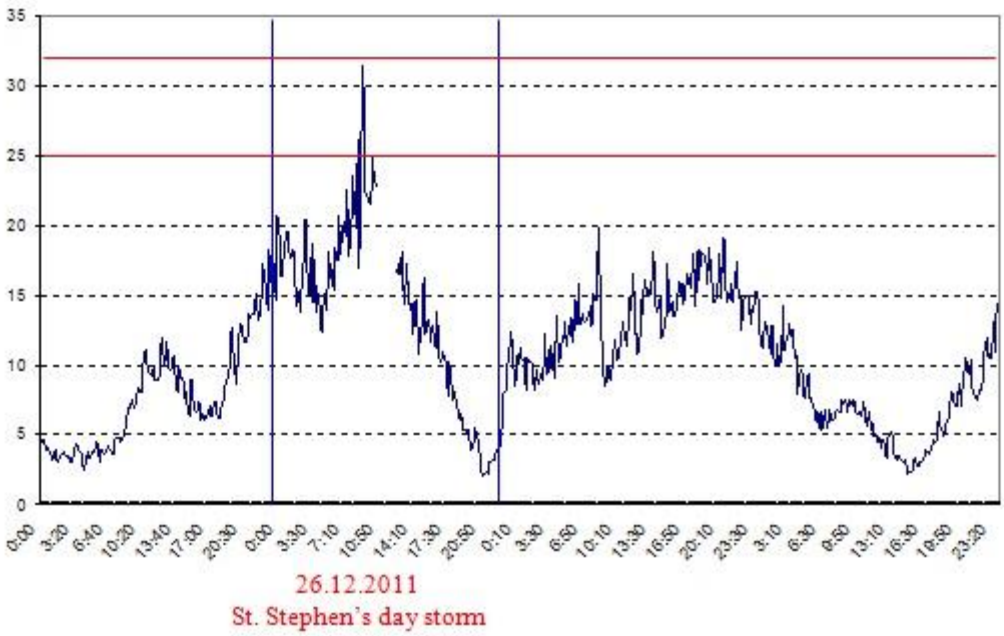

Figure 1. Observed maximum 3 second wind gusts (m/s) during 10 minute time slots at Espoo Sepänkylä in Southern Finland during 25-28.12.2011. The maximum observed wind gust was 31.5 m/s on 26 December.

4.3 Low temperature

On 18 December 2009, all transportation modes in Western Europe were substantially disturbed by the advection of arctic air from northeast and the related freezing temperature (in Brussels ca. -10 ^{o}C). Eurostar trains stopped running and many airfields had to be closed. Slippery conditions on roads prevailed for many days due to low temperatures and occasional snowfalls.

4.4 Blizzard

On 23 November 2008, a blizzard across southern Finland caused a snow accumulation of 30 cm in 24 hours and wind gusts up to 27 m/s. This resulted in a double, locally even fourfold amount of car accidents compared to the daily mean (Rauhala and Juga [2]). The blizzard caused also wide electricity cuts.

5 DISCUSSION AND CONCLUDING REMARKS

The impact thresholds for different winter weather phenomena should be regarded only as indicative of showing the negative impacts on transportation. Linking the weather phenomena and their impact according to the defined threshold indices with the different transport system indicators allows us to predict the consequences of extremes on the various transport services and infrastructure. The consequences of adverse and extreme events depend significantly on the climate region and preparedness of the country they eventuate, but also many other factors, such as the transport mode, the time of the occurrence (weekday or weekend, rush hour), and also the damages and costs of the events. For example, a snow fall resulting in 5 cm snow cover during the morning rush hours can be enough to induce massive car pile-ups as it happened in southern Finland on 17 March 2005 (Juga et al. [7]); even thought Finnish drivers are customized with snowy and slippery road conditions.

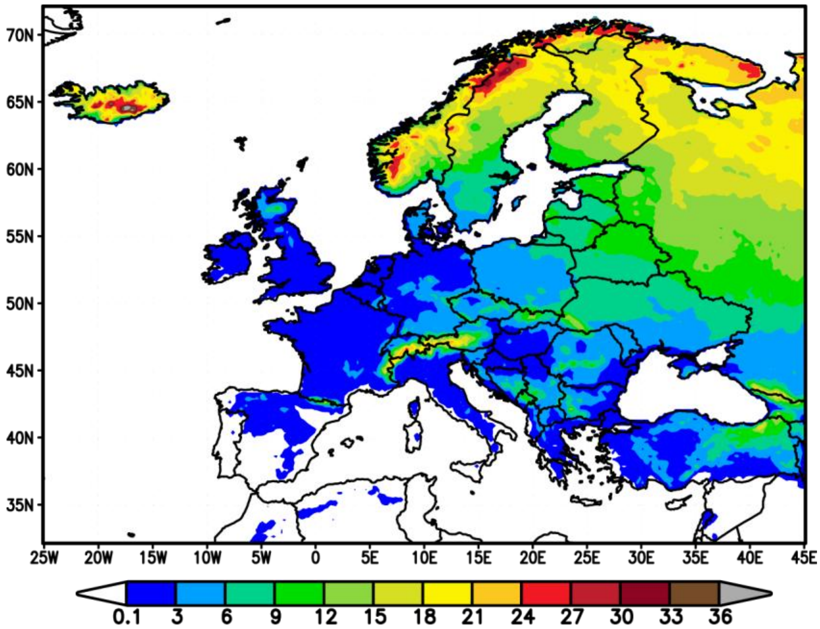

Figure 2. Frequency-based probability (in percent) of daily snowfall exceeding 1 cm/ 24 hours during the period 1971-2000 (based on E-OBS data).

An example of the impact threshold based probability maps is presented in Figure 2: The probability (in percent) of snowfall exceeding 1 cm/ 24 hours over Europe during years 1971-2000. The identified extreme weather indices allow us to provide a European-wide climatology of the adverse and extreme winter phenomena and to assess the expected changes in the probability of the extremes (Vajda et al. [5] and [8]). On the other hand, it provides valuable information to public safety authorities and transport system stakeholders, operation and transport service providers to improve the adaptive capacity and reduce the risk and costs of damages.

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