DEFINITION OF METEOROLOGICAL EXTREME EVENTS

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ABSTRACT

The destructive and harmful consequences caused by extreme meteorological events like hurricanes or snow storms are intuitively obvious. However, the conception and meaning of phrases like “extreme” or “adverse” is not that obvious or even commonly understood. There are several analogous words/terms having a somewhat similar meaning but quite often a notably different context. Such terms can address the extremity, severity, harshness, rarity, or impacts of weather events quite differently and from different perspectives. “Adverse” when related to meteorology may be defined as “atmospheric conditions at a specific time/place that are highly unfavorable for a particular target sector which is vulnerable to such conditions“. In the present context, we are essentially focusing on the road transport sector (road networks, traffic conditions). First, a clear discrimination and distinction needs to be made between common or recurrent weather events like rain, snow, wind as opposed to their more extreme or rare modes like snow storms, hurricanes or tornadoes, which all can have high impact on transportation. The present paper defines and elaborates on the following four terms, all characterized by strong multi-dimensionality in meteorology: extreme - severe - high-impact - rare.

1. INTRODUCTION

The society has become more and more vulnerable to devastating extreme and severe weather and climate events causing damage to infrastructures and property. Such adverse weather conditions have obviously also significant impacts on all transport modes including the road transport and affecting traffic operations, traffic flows and, consequently, road safety. It was found out in the recent European EU FP7 Project EWENT that the average weather related road accident costs amount to 20.7 billion euro, annually (Nurmi et al, 2013) [1]. Strong gusty winds and heavy precipitation often cause traffic delays and jams. Snowfall, blizzards and low temperatures lead to challenging driving conditions and put heavy demands on costly road maintenance actions. Winter maintenance has a crucially important role in keeping the road transport expenditures tolerable especially in the northern countries and mountainous areas but also in various parts of the globe during cold spells. Mitigating actions against harmful and destructive adverse weather events are intuitively and implicitly obvious and necessary. Effective weather sensitive traffic management calls for state-of-the-art Maintenance Decision Support Systems (MDSS), Road Weather Information Systems (RWS) and, as guidance input for such systems, high quality road weather forecasting services.

A recent undertaking (2008-2012) under the COST (European Cooperation in Science and Technology) umbrella, Action TU0702, had as its one fundamental objective to understand the impacts of adverse weather on traffic operations and to develop, promote and implement strategies and tools to mitigate such impacts [2]. It was realized at the very early stages that a common clarification on what is meant and understood by “adverse” weather was a prerequisite for the success of this multi-disciplinary COST Action.

The meaning and conception of “adverse weather” is not trivial, obvious or uniquely and generally understood. This follows from the fact that there are some seemingly analogous words and terms which may, however, have a quite different meaning. The context of all of them can be notably different, and hence they can address the severity, extremity, harshness, rarity, or impacts of the weather events quite differently and from different perspectives. Generally speaking, “adverse weather” can be considered as being composed of five quite different elements or dimensions: (a) operational, (b) economical, (c) ecological, (d) social, (e) cultural/geographical. In the context of road transport operations, one way to define “adverse weather” is to put it as: “atmospheric conditions at a specific time and place that are highly unfavourable to optimal traffic conditions“. We want to make a clear discrimination and distinction between common or recurrent weather elements and variables like rain, snow, wind, etc as opposed to their severe, extreme or rare counterparts like snow storms, hurricanes or tornadoes, which all can have high impact on the road networks and traffic conditions.

The four terms (i) “extreme”, (ii) “severe”, (iii) “high-impact”, and (iv) “rare” will be defined in the next paragraph. The focus of this paper is to try make the terminology clear and precise, and to understand the different nuances between these different terms and words and to elaborate them further in the context of winter road transport.

2. DEFINITION AND INTERPRETATION OF THE TERMINOLOGY

Stephenson (2008) provided a comprehensive essay on the definitions of extreme weather and climate related terminology [3]. He emphasized that the multi-dimensional nature of adverse weather events must not be overlooked, because such events usually address attributes like rate of occurrence (probability), magnitude (intensity) as well as temporal and spatial scales.

A brief account follows of the terms, which all are characterized by strong multi-dimensionality in meteorology and climatology:

- ***i. Extreme weather***
- ***ii. Severe weather***
- ***iii. High-impact weather***
- ***iv. Rare weather event***

i. “Extreme” is defined in dictionaries/thesauruses as adjective *“exceeding the ordinary, usual or expected; having highest limit or degree; or being outermost; greatest; stringent; or very violent”.* Extreme events often cause large damage or consequences to the society. Flash flooding, as an example, may result from extremely heavy local rainfall, whereas flooding over large geographical areas typically is associated with large amounts of rain during an extended time. On the other hand, electricity lines falling down may result from heavy snowfall and/or storm force winds. Notorious health effects, especially for the elderly, are caused by extremely high temperatures, whereas very low temperatures will increase energy consumption dramatically and also prevent outdoor actions and activities. Extreme low temperatures will cause malfunctioning of vehicle motors using diesel oil as fuel.

An extreme event can be generalized as having an all-time maximum value and/or exceeding a pre-measured high, or low, threshold. By definition, extreme events are generally also rare events (see later), e.g. having a one per cent (1 %) probability of occurrence during a given time period at a given location.

ii. "Severe" may be defined as adjective meaning *"rigorous; violent; very strict; unsparing; hard to endure; and inflicting (physical) discomfort"*. Severe weather events can cause losses of human lives, huge monetary losses or have destructive effects on the environment. Severe events can in principle be estimated by analyzing expected long-term losses (risk analysis). The probability of the event needs to be known as well as the level or extent of exposure to the event (e.g. number of exposed people).

Severity of an event is a function of both the meteorological event itself and the state of human affairs affected by the event. In the traffic sector, increased traffic volumes naturally lead to increased exposure to meteorological features affecting the traffic.

iii. "High-impact" is defined in dictionaries/thesauruses as noun *"having shocking or striking effect or influence".* High-impact meteorological events are typically also severe events. It is quite customary to make a separation based on time scales, i.e. between short-duration and long-duration weather events. Examples of high-impact events with a relatively short life cycle are rapidly moving strong cyclones, or convection-induced heavy precipitation cells associated with strong vertical motion of air, or rapid freezing of the road surface due to the cooling of the lowest atmospheric surface layer resulting from outgoing long-wave radiation. An example of a long-duration weather event is the so-called blocking high pressure over a large area, typical for the northern hemisphere springtime, which can give rise to a prolonged heat wave and draught. The monsoon circulation is another example of high-impact weather, in the tropics, with a long life cycle.

The World Meteorological Organization (WMO) promotes using the term "high-impact" rather than "severe" to cope with events covering all time scales.

iv. "Rare" is adjective meaning *"uncommon; unusual; infrequent; seldom occurring or found".* Rare events have a low probability of occurrence (e.g. 0.1 %). Because the society and the environment are not adapted to rare events large damages often occur. Hence, despite rarity, high vulnerability can lead to large losses.

The most common meteorological phenomena and events causing adverse effects for road transport are:

- Precipitation, or rainfall
  - Rainfall intensity or accumulation (causing flooding)
  - Rainfall type (rain, snow, freezing rain, sleet)
  - Time extent of precipitation
- Visibility
  - Fog
  - Heavy rainfall or snowfall
  - Drifting snow
  - Dust, smoke, haze
- Wind
  - High wind speed
  - Strong cross-traffic wind speed

- Blizzard
    - Combination of snowfall, heavy winds and poor visibility
- Temperature (of air or road surface)
    - Low or freezing temperature causing low surface friction
    - High temperature
- Humidity
    - Formation of hoar frost causing low surface friction

Statistically speaking most of these variables follow a continuous distribution. However, they are often considered as, or transformed into, binary or dichotomous values to indicate that the events will either happen or not, like there is heavy precipitation (e.g. more than 50 mm during six hours), or there is poor visibility (e.g. visibility less than 50 m). All of the variables can also be considered as multi-category events, e.g. rainfall can be stratified into several mutually exhaustive categories, where one of the categories is a "rare event category" (e.g. with a less than 0.1 % probability of occurrence at a given location). Likewise for wind speed, temperature, etc.

The following two figures, incorporated from the COST Action TU0702 framework [2] illustrate the interpretation of the above terminology utilizing real observed meteorological data. First, Figure 1 shows a 50-year time-series of observed temperatures at weather station Sodankylä in northern Finland, which is notorious for its severe wintertime weather conditions. The upper-left figure shows the entire dataset revealing a very wide observed temperature range. Summertime temperatures have exceeded +30 ^{o}C, and wintertime temperatures can fall below -45 ^{o}C at this location. The upper-right figure points out the few cases when these extreme high and low values were reached during the 50 years. Here *"extreme"* and *"rare"* can be considered synonyms. Extremity can also be defined statistically as shown in the lower-left figure. The 5 % quantiles at the warm and cold parts of the distribution are discriminated by temperature values of +18 ^{o}C and -23 ^{o}C, respectively. *"Scarce"* would be a more appropriate definition than *"rare"*, here. The cases are by no means severe or extreme but e.g. for a southern European -23 ^{o}C might feel as extreme and severe. Finally, the lower right figure demonstrates how there may occur *"high-impact"* weather events having nothing to do with severity, extremity or rarity. Temperatures around plus/minus one ^{o}C temperature band can be notorious in causing the freezing of road surfaces. Such are, however, very common wintertime features of high latitude weather and in the Nordic countries, whereas in southern Europe they would also be regarded as rare high-impact events.

Figure 2 is another way to visualize the dataset of Figure 1. The histograms show the frequency of observations along the y-axis as a function of the temperature shown on the x-axis in Sodankylä, Finland (left), and in a hypothetical location (right). What we want to highlight here is that while the temperature range of plus/minus one ^{o}C (highlighted in yellow) is always of high-impact - causing slipperiness - it can be either a very common feature in a cold climate (Finland, left) or a relatively rare event (artificial location, right).

A similar approach as applied and showcased above for interpreting the concept and manifestation of adverse weather could be adapted for various other meteorological variables, if and when there are extensive long-term weather observation datasets available.

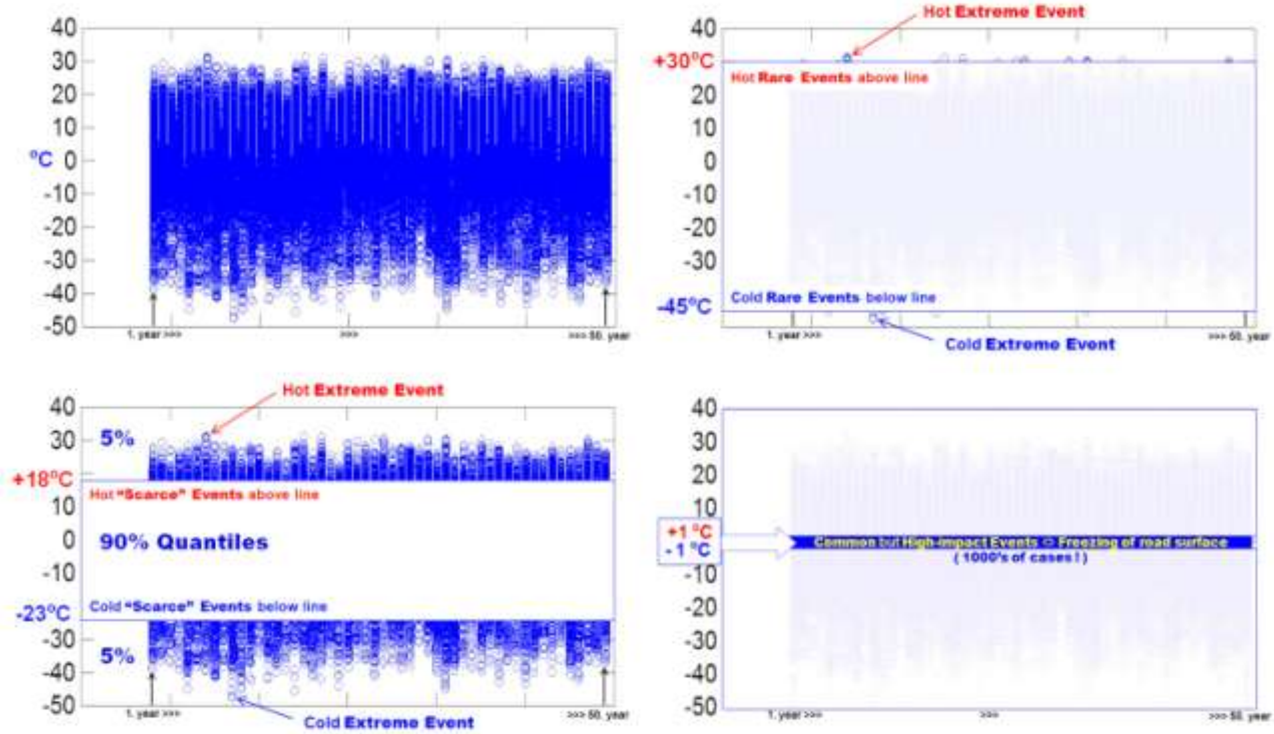

Figure 1 – 50 years of observed temperatures at weather station Sodankylä, northern Finland. The upper-left part has each dot representing one observation value, each vertical string of dots covering one calendar year with three observations per day, totalling 54750 observations (50* 3* 365). High/low values of +30/-45 °C, respectively, are defined as hot/cold extreme events in the upper-right part (the middle portion of dataset is “dimmed” to highlight the extreme cases). The extremity is pre-defined statistically in the lower-left part by assuming the hot/cold thresholds at 5 % probabilities (hence 90 % of the observations are now “dimmed”). The lower-right part demonstrates the commonness of the plus/minus one °C temperature band, prone to freezing of the road surface covering thousands of observations through the years

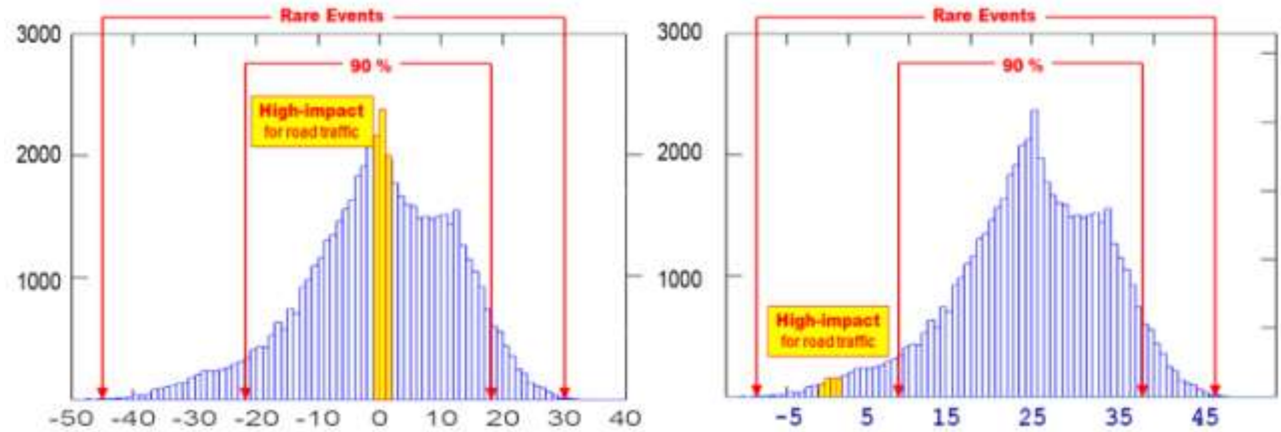

Figure 2 - Left: Same dataset as in Figure 1, but represented as a histogram. The extreme high/low temperature thresholds of +30/-45 °C and the 90 % quantiles are indicated, as well as the plus/minus one °C temperature interval (highlighted in yellow). Right: Using exactly the same distribution, the temperature scale of the x-axis has been artificially shifted to illustrate potential/hypothetic conditions in a warm climate. There, the thresholds for extreme high/low temperatures would be c. +45 °C and -7 °C, respectively.

Table 1 – Meteorological parameters, thresholds and action messages used as guidance alerts on selected Spanish test highways in the EU FP7 Project FOTsis [4].

Parameter/Event	Thresholds	Action message
Snow / Sleet	" Any snowfall, incl. hail "	" Minimize your speed "
	≥ 2 cm/h or ≥ 10 cm/6h or ≥ 1 cm/h + T ≤ -10C	" Stop driving "
Rain	1 - 5 mm/h	" Control your speed "
	5 - 10 mm/h	" Minimize your speed "
	≥ 10 mm/h	" Stop driving "
Freezing rain	Rain ≥ 1 mm/h + Tair < 0C	" Stop driving "
	Rain + Tsurface < 0C	" Stop driving "
Visibility	Visibility ≤ 400 m	" Control your speed "
	Visibility ≤ 250 m	" Minimize your speed "
	Visibility ≤ 80 m	" Stop driving "
Blizzard	Max wind gust ≥ 17 m/s & Tmean ≤ 0C (24 hrs) & Precip ≥ 10 mm (24 hrs)	" Stop driving "
Wind, mean	≥ 12 m/s	" Control your speed "
	≥ 17 m/s	" Minimize your speed "
	≥ 21 m/s	" Stop driving "
Wind, gust	≥ 17 m/s	"Control your speed"
	≥ 25 m/s	" Minimize your speed "
	≥ 32 m/s	" Stop driving "
Surface Friction	≤ 0.4	"Control your speed"
	≤ 0.3	" Minimize your speed "
	≤ 0.2	" Stop driving "
Surface condition	Damp	" Control your speed "
	Wet	" Control/Minimize your speed "
	Snow on the road	" Stop driving "
	Ice on the road / Black ice	" Stop driving "

In a recently established, practical real-time test application within the ongoing EU FP7 Project FOTsis (www.fotsis.com), alerts against adverse weather events are being specified and delivered to road end-users in Spain following pre-specified critical threshold values for selected meteorological variables [4]. Weather events are classified into different levels of severity per variable as shown in Table 1, where the respective alert thresholds are complemented by associated textual recommendations (right-hand-side column). These alerts are then delivered to the road users as explicit text messages via a specifically established dedicated ITS (Intelligent Transport System) network to guide driving behavior. The thresholds were defined taking carefully into account the specific local climatological conditions in Spain. For other geographical locations the individual variable thresholds would definitely be different. In practice the required weather forecast applications to produce the necessary weather alerts are being provided by the Finnish Meteorological Institute highlighting the international and multi-disciplinary nature of the FOTsis project. Similar procedures will be potentially followed for other dedicated test highways in some other participating countries (Germany, Portugal) in the forthcoming phases of the project.

3. SUMMARY

Quite detailed definitions have been provided of the not very commonly or unanimously understood terms, “extreme”, “severe”, “high-impact”, and “rare” in relation to adverse weather. The conception and adoption of these terms have been further deepened by illustrative examples and distributions based on a large climatological temperature dataset providing implications especially for the road transport mode. It is further emphasized by a brief example of the EU FP7 project FOTsis, that applying and understanding such definitions is highly essential and beneficial in practical end-user oriented ITS applications.

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