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CLIMATE CHANGE AND EXTREME EVENTS

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Abstract. *The characteristics of extreme weather events- heat waves and heavy precipitations and their potential relation with the climate change process due to the antropogenic greenhouse effect are assessed. For this purpose the observational data and climate model predictions for extreme events existing in international and national scientific publications are examined*

Keywords: climate change, extreme events, heat wave, heavy

1.Introduction

In this paper the potential impact of climate change on extreme weather events is discussed. There is increasing concern that extreme events may be changing in frequency and intensity as a result of human influences on climate. Climate change may be perceived most through the impacts of extremes, although these are to a large degree dependent on the system under consideration, including its vulnerability and capacity for adaptation and mitigation. An extreme weather event becomes a disaster when society and/or ecosystems are unable to cope with it effectively. The existing scientific literature shows that observational meteorological data as well as the climate model predictions for the future society development scenarios make evident an increasing frequency of occurrence of the extreme weather events with the temperature increase of the Earth due to antropogenic greenhouse gases. The trend in the global numbers of great natural catastrophes since 1950 shows a significant increase in the largest weather-related disasters - from about 1 event in the 1950s to about 5 in recent decades while geophysically caused disasters (earthquakes, tsunamis, volcano eruptions) have increased from 1 to less than 2 in the same time [1]. Weather related disasters therefore are the major contributor to increasing losses due to natural disasters.

Aspects of extreme weather events including *heat waves, heavy precipitation* are examined in this paper. Section 2 presents the glossary of specific terms. Theoretical considerations regarding the occurrence probability of the extreme events are discussed in the Section 3. Section 4 deals with the observational data regarding the extreme weather events whose frequency and intensity were modified by the warming of climate. Section 5 presents the state of the extreme events as is predicted by the climate change models for emission scenarios of greenhouse gases. Conclusions are given in the Section 6.

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2. Glossary of specific terms

The IPCC (Intergovernmental Panel on Climate Change) definitions of *climate change, climate variability and extreme event* are used [2] and the definition of American Meteorological Society for the *heat wave and heavy precipitation* [4] .

Climate change: Climate change can be defined as a change in the state of climate identified by changes in the mean and/or the variability of its characteristics, that persists for extended time intervals, usually decades or longer. Climate change can be induced by natural processes or external factors or by anthropogenic changes in the composition of atmosphere and land use. According to the UNFCCC (United Nations Framework Convention on Climate Change) the climate change is defined as *"a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods"*.

Climate variability: Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Extreme event: An extreme weather event is an event that is rare at a particular place and time of year. An extreme event is normally as rare as or rarer than the 10th or 90th percentile of the observed probability density function. Single extreme events cannot be simply and directly attributed to anthropogenic climate change, because there is always a finite probability the event to occur naturally. When a pattern of extreme weather persists for some time, such as a season, it may be considered as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season).

Heat wave (also called hot wave, warm wave.): Heat wave is a period of abnormally and uncomfortably hot and usually humid weather. To be a heat wave such a period should last at least one day, but conventionally it lasts from several days to several weeks [4].

Heavy precipitation (heavy rain)**:** Heavy precipitation is a rainfall whose intensity has a value greater than 0.76 cm per hour or more than 0.076 cm in six minutes [4].

3.Theoretical considerations

In what follows an explanation is given for the increase of the probability of the extremely hot days in case of the average temperature rise as it is the case under global warming process. Let consider the Figure 1 where the two curves represent the typical frequency distribution patterns for measurements of average summer temperatures with means equals to 15.3^{0}C (climatological mean) and 16.9^{0}C (a warmer climate), respectively. The left-hand curve is for a location in central England where weather records have been carried on for 300 years. The plots fit the usual Gaussian distribution, with values near the average occurring most often and more extreme values occurring less. In a warmer climate the temperatures have the same distribution pattern, the curve keeps the same shape but is shifted on the right having the mean equals to 16.9 ^{0}C [5].

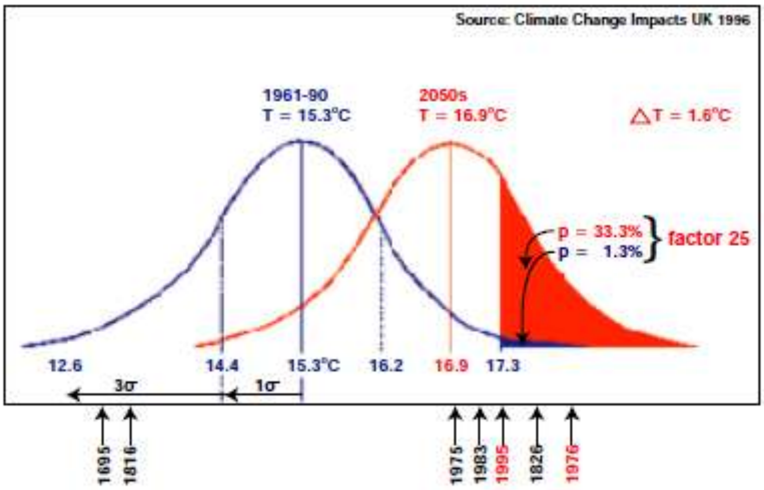

Figure 1.Increasing probabilities of extreme: Summer temperatures in Central England [5]

In this example the average temperature has increased by 1.6^{0}C, but if the numbers of summers with average temperatures above 17.3^{0}C are compared, a large change between the two distributions can be seen. The actual difference quantified by comparing the areas under each of the curves to the right of the 17.3 line, amounts to a factor of 25

In other words, the figure shows that a temperature increase of 1.6^{0}C will increase the probability of a so-called hot summer from 1.3/100 per year to 33.3/100 per year in England. Thus, an increase in the mean temperature will lead to a significant increase in the probability (p) of very warm summers.

4.Observational data on changes in extreme events

Since 1950, the number of heat waves has increased and there were widespread increases in the number of warm nights. The extent of regions affected by droughts has also increased as precipitation over land has slightly decreased while evaporation has increased due to warmer conditions. In the main, numbers of heavy daily precipitation events that lead to flooding have increased, but not everywhere. Tropical storm and hurricane frequencies vary significantly from year to year, but evidence suggests obvious increases in intensity and duration since the 1970s. Changes in tracks and intensity of storms in the extratropics, point out variations in major features of the atmospheric circulation, such as the North Atlantic Oscillation. Variations in different types of extreme climate events have been observed in many regions of the world. The warm nights or hot days are those exceeding the 90th percentile of temperature, while cold nights or days are those falling below the 10th percentile. In probability distribution terms, heavy precipitation is defined as daily amounts greater than the 95th (or for‘very heavy’, the 99th) percentile [2, 3].

4.1 Heat waves

Figure 2 shows that in the last 50 years for the land regions, there has been a significant decrease in the annual occurrence of cold nights and a significant increase in the annual occurrence of warm nights. One may see that decreases in the occurrence of cold days and increases in hot days, are generally less marked. As may be noticed from Figure 2, the distributions of minimum and maximum temperatures have not only shifted to higher values, compatible with global warming, but the cold extremes have warmed more than the warm extremes over the last 50 years. More warm extremes result in an increased frequency of heat waves. In the majority of mid-latitude regions there are indications on the observed trend towards fewer frost days associated with the average warming. In Figure 2 the extreme temperatures are defined on the basis of 1961 to 1990 values, as maps for the 10th percentile: (a) cold nights and (b) cold days; and 90th percentile: (c) warm nights and (d) warm days. Trends were calculated only for grid boxes that had at least 40 years of data during this period and had data until at least 1999. Black lines enclose regions where trends are significant at the 5% level. Below each map are the global annual time series of anomalies (with respect to 1961 to 1990). The red line indicates decadal variations. Trends are significant at the 5% level for all the global indices shown [6].

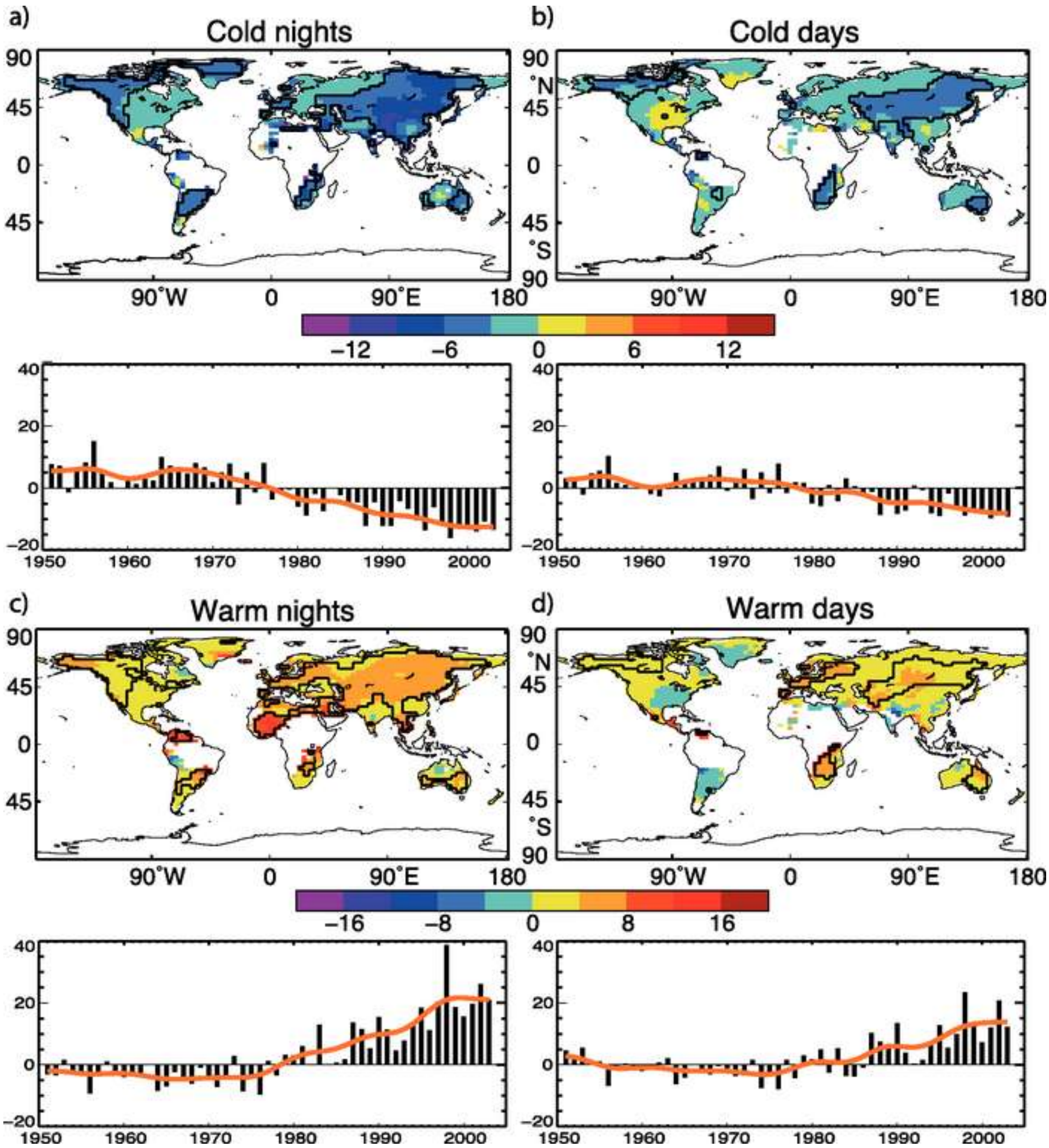

Figure 2 .Observed trends (days per decade) for 1951 to 2003 in the frequency of extreme temperatures[2,6]

4.2.Heat waves in Romania

Since 2000, extreme hot and dry summers were quite frequent over Romania and 2007 was among the hottest ones. After the summer 1946, considered the hottest and one of the driest in Romania over the whole observational period

1901-2006, a couple of similar extreme events were recorded over the recent period 2000-2007 [7]. This period was characterized by significant temperature and precipitation anomalies, which by intensity, duration and spatial extension were between the most pronounced ones in Romania over the entire observational period. In order to estimate the long-term trend in the summer mean temperature in Romania, two data sets were analysed: the longest available observational time series at 14 stations (1901-2007), uniformly distributed over the Romanian territory, and the second one consisting in the data from other 94 stations for the period 1961-1990. The spatial average of the summer mean temperature anomalies (relating to 1961-1990) derived from the corresponding values recorded at the 14 stations is presented in Figure 3.

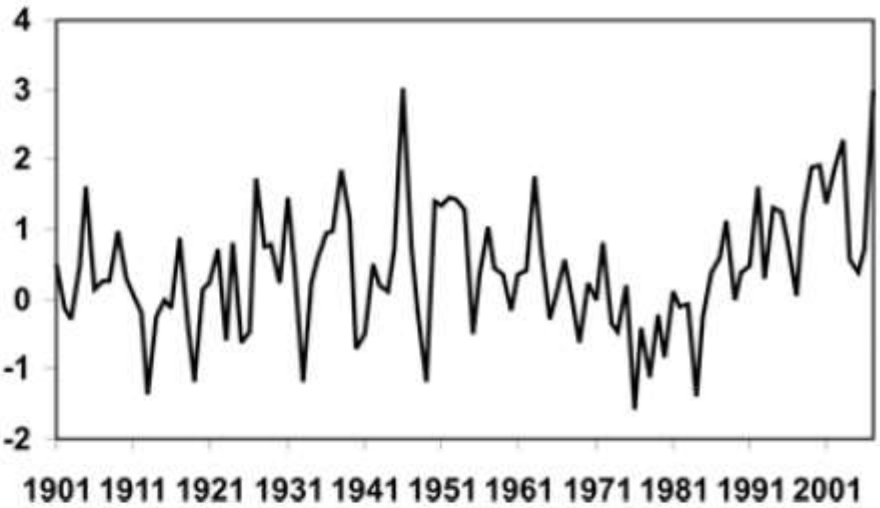

Figure 3. Summer anomalies (^{0}C) of the mean air temperature spatially averaged over Romania for the period 1901-2007 [7]

Figure 3 shows that the summers of 1946 and 2007 are the highest peaks of same magnitude of anomaly with respect to the 1961 to 1990 mean (3^0C) over the two sub-periods, being followed by the summers 2003, 2000, 2002 and 1999. Temperature anomalies of the first 6 warmest summers in Romania derived from the data sets measured at 14 and 94 stations are presented in Table 1.

Tabel 1. Spatial average of temperature anomalies of the first 6 warmest summers in Romania derived from the data sets of 14 stations over the period 1901-2007 and from the data sets of 94 stations over the period 1961-2007[7]

14 stations (1901-2007)		94 stations (1961-2007)	
1946	3. 0	2007	3. 0
2007	3.0	2003	2.3
2003	2.3	2000	1.9
2002	1.9	1999	1.8
2000	1.9	2002	1.7
1999	1.9	1963	1.7

Spatial distribution of the summer temperature anomalies for the year 2007 is presented in Figure 4, using the common data set measured at 94 stations.

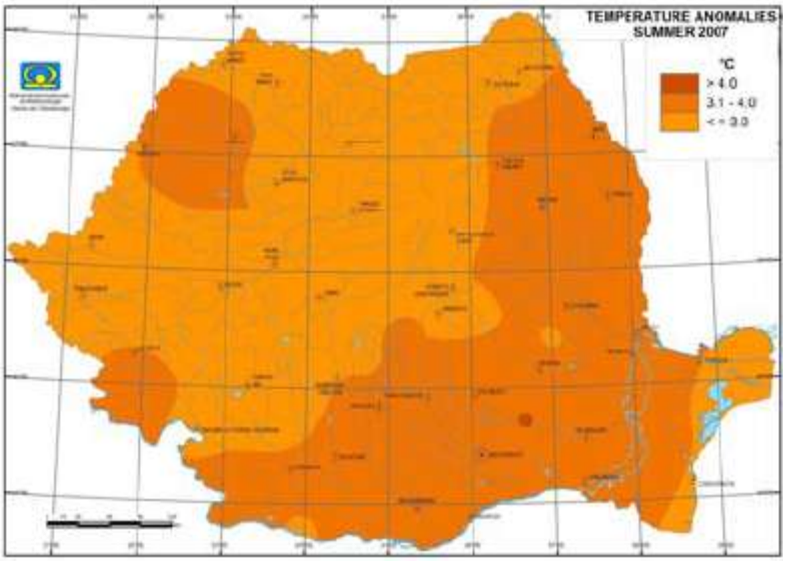

Figure 4. Summer temperature anomalies (^{0}C) relative to the period 1961- 1990 for the year 2007 [7]

One may see that the highest seasonal temperature anomalies were recorded over the south-eastern regions with values between 3^{0}C and 4^{0}C over large areas.
A statistically significant long-term warming trend of Romanian summers over the last 107 years (1901-2007) was identified (0.6 ^{0}C) on spatial average. The

spatial distribution of the linear trend over 1961-2007 for the 94 stations emphasized a warming trend of about 1.6-2^{0}C over most of the country, which is statistically significant at the 5% level.
The summer 2007 is distinguished by a high persistence of dog days (daily maximum temperature greater or equal to 35^{0}C).

4.3. Heavy precipitation

A significant indication of a change in precipitation extremes consists in the observed increases in heavy precipitation events over the mid-latitudes in the last 50 years, even in areas where mean precipitation amounts are not increasing. The physical basis for changes in precipitation refers to modifications in type, amount, frequency, intensity and duration of precipitation. Observed increases in atmospheric water vapour result in increases in intensity, but this will imply reduced frequency or duration if the total evaporation rate from the Earth's surface is not changing. In the IPCC-Third Assessment Report [3] one states that it is likely that there has been a statistically significant 2 to 4% increase in the frequency of heavy and extreme precipitation events when average is performed over the middle and high latitudes. Many studies indicate that the dynamic of rainfall statistics through the second half of the 20th century is dominated by variations on the interannual to inter-decadal time scale and that trend estimates are spatially incoherent. In Europe, at main part of stations the observations emphasize increasing trends in the number of moderately and very wet days during the second half of the 20th century [2]. Also, for the contiguous USA, it were found statistically significant increases in heavy (upper 5%) and very heavy (upper 1%) precipitation of 14 and 20%, respectively. This increase occurred particularly during the last three decades of the 20th century and is most clear over the eastern parts of the country. Moreover, there is evidence from Europe and the USA that the relative increase in precipitation extremes is higher than the increase in mean precipitation, and this is considered as an increasing contribution of heavy events to total precipitation. Variations in precipitation extremes are less coherent than for temperature. Figure 5 shows that the global average over the land surface indicate that the percentage contribution to total annual precipitation from very wet days (above 5%) is higher in recent decades than in earlier decades. In this figure trends are only calculated for grid boxes where both the total and the 95th percentile had at least 40 years of data during this period and had data until at least 1999. The observed trends refer to the contribution to the total annual precipitation from very wet days (95% percentile). The anomalies (%) of the global annual time series (with respect to 1961 to 1990) are defined as the percentage change of contributions of very wet days from the base period average (22.5%). The smooth red curve indicates decadal variations [2, 6].

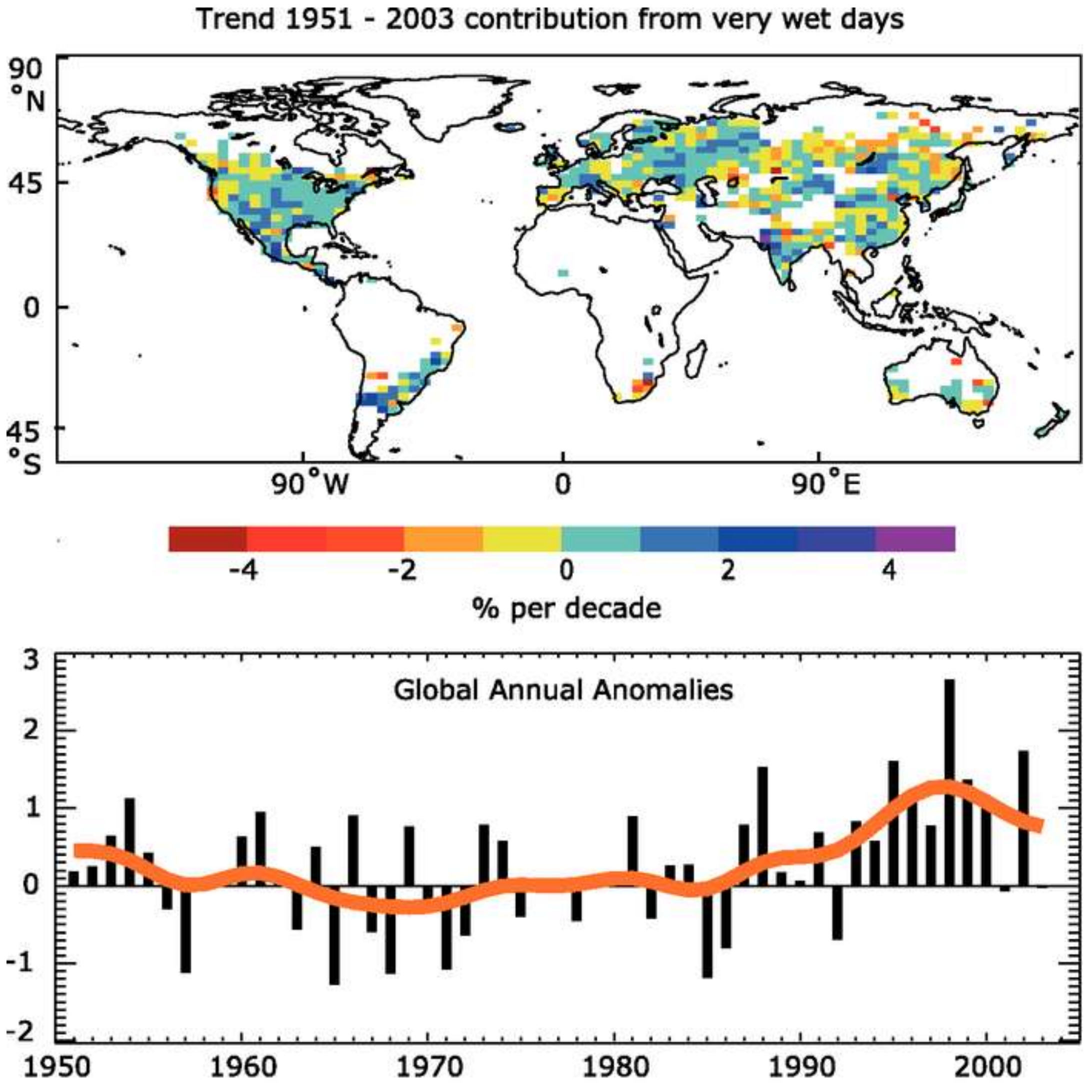

Figure 5. Observed trends (% per decade) for 1951 to 2003 from very wet days (95th percentile) and global annual anomalies (%) (with respect to 1961 to 1990)[2, 6].

5. Model predictions regarding climate change impact on extreme events

There is evidence from modeling studies that the frequency and intensity of extreme events are expected to change as Earth's climate changes, and these changes could occur even with relatively small mean climate changes. Changes in some types of extreme events have already been observed, as for instance, increases in the frequency and intensity of heat waves and heavy precipitation events. In a warmer future climate, there will be an increased risk of more intense, more frequent and longer-lasting heat waves. The European heat wave of 2003 [8] as well as that of 2007 from Romania [7] are examples of the type of extreme heat event lasting from several days to over a week that is likely to become more common in a warmer future climate

Climate modeling studies anticipate the following variations of the characteristics of extreme events :

>*for temperature*

- the decrease in the daily (diurnal) temperature range in most regions
- a warmer climate will have fewer frost days
- a decline in the frequency of cold air outbreaks (i.e., periods of extreme cold lasting from several days to over a week) in Northern Hemisphere winter in most areas. Exceptions could occur in areas with the smallest reductions of extreme cold in western North America, the North Atlantic and southern Europe and Asia due to atmospheric circulation changes.

>*for rainfall*

- increased summer dryness and winter wetness in most parts of the northern middle and high latitudes
- summer dryness indicates a greater risk of drought. Along with the risk of drying, there is an increased chance of intense precipitation and flooding due to the greater water-holding capacity of a warmer atmosphere. This has already been observed and is projected to continue because in a warmer world, precipitation tends to be concentrated into more intense events, with longer periods of little precipitation in between
- wet extremes are projected to become more severe in many areas where mean precipitation is expected to increase, and dry extremes are projected to become more severe in areas where mean precipitation is projected to decrease
- increase in extreme rainfall intensity

In Figure 6 one presents the changes in rainfall intensity predicted for the Central USA with doubling of CO2 concentration in the atmosphere [9]

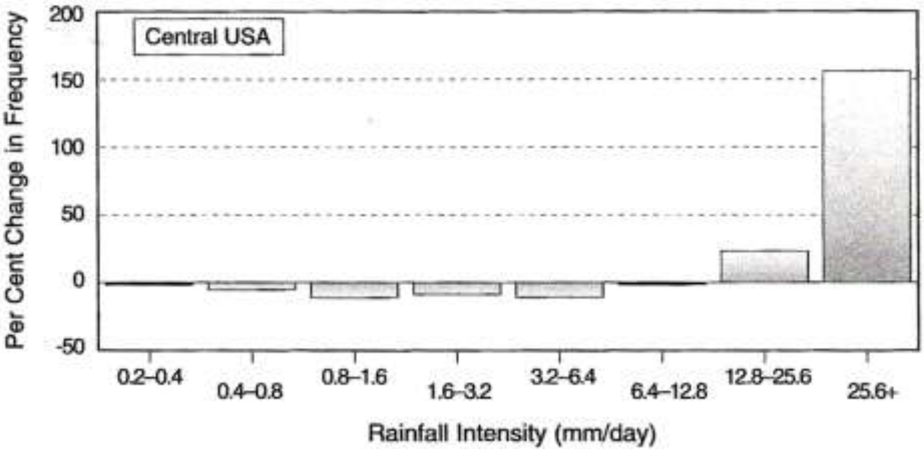

Figure 6.Changes in rainfall intensity with doubling of carbon dioxide [9]

One may see that the predictions of climate models indicate that heavy rainfall will become more frequent while light rainfall will occur less often in a warmer climate.

Over Northern Hemisphere land, an increase in the likelihood of very wet winters is projected over much of central and northern Europe due to the increase in intense precipitation during storm events. Similar results apply for summer precipitation, too. These changes projected by the climate models are in fact extensions of trends already underway.

6.Conclusions

The type, frequency and intensity of extreme events are expected to change as Earth’s climate warms in response to increasing atmospheric greenhouse gases resulting from human activities, and these changes could occur even with relatively small mean climate changes. The observational data confirm the gradual reduction of the number of frost days over most of the mid-latitude in recent decades. In agreement with this warming trend, the number of warm nights increased between 1951 and 2003, cold nights decreased, and trends in the number of cold and warm days are also consistent with warming, but are less marked than at night. In a warmer future climate, there will be an increased risk of more intense, more frequent and longer-lasting heat waves. Typical examples of extreme heat events that is likely to become more common in a warmer future climate, are the European heat wave of 2003 and that taking place in Romania in 2007. In case of precipitation, analysis show increases in heavy events for the majority of observation stations, with some increase in flooding. This result applies both for areas where total precipitation has increased and for areas where total precipitation has even decreased. Increasing trends are also reported for more rare precipitation events, although results for such extremes are available only for a few areas. In a warmer future climate, most climate models (Atmosphere-Ocean General Circulation Models) project increased summer dryness and winter wetness in most parts of the northern middle and high latitudes. The model predictions indicate that in a warmer world, precipitation tends to be concentrated into more intense events, with longer periods of little precipitation in between. Therefore, intense and heavy downpours would be interspersed with longer relatively dry periods.

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