ON THE CONCEPT AND EMPIRICAL TENDENCIES OF WEATHER AND CLIMATE EXTREMES

JÁNOS MIKA[1]

ABSTRACT. The recent IPCC Special Report (IPCC SREX, 2011) provides a comprehensive overview of meteorological extremes and their various aspects. The present paper responses to the core concepts of the Report, arguing the still unclear definition of the extremes, and recommend a clear classification of weather vs. climate extremes. We also dedicate a sub-Section to the statistical and physical considerations on how the extremes may change parallel to the global warming. Another sub-Section refers to further difficulties that hamper the empirical establishment of the trends in the meteorological extremes. Modelled results are not similarly presented, but a dicsussive chapter is given to explain why these embedded models are not yet perfect for estimating the changes in extreme events. Finally we expose the AR4 results (IPCC, 2007) on meteorological extremes at temperate latitudes, and briefly compare them with those in the IPCC SREX (2011) Report.

Keywords: *Weather extreme, climate extreme, natural disaster, climate change, IPCC*

1. Introduction

The *impact areas* of extreme meteorological events cover wide ranges. The disadvantageous impacts of extreme meteorological events include: floods, excess water, droughts, rainstorms, hails, heat waves, strong UV radiation, early and late frosts, snow jams, wind storms, forest and bush fires, effects of new pathogens and pests. There is little doubt that society as a whole has become more sensitive to extreme weather, since population and infrastructure continues to grow in areas that are vulnerable to the weather and climate extremes. As it is seen in *Fig. 1*, weather extremes play a sorrowful important role among the natural disasters in global and in European comparison, especially concerning the economical losses.

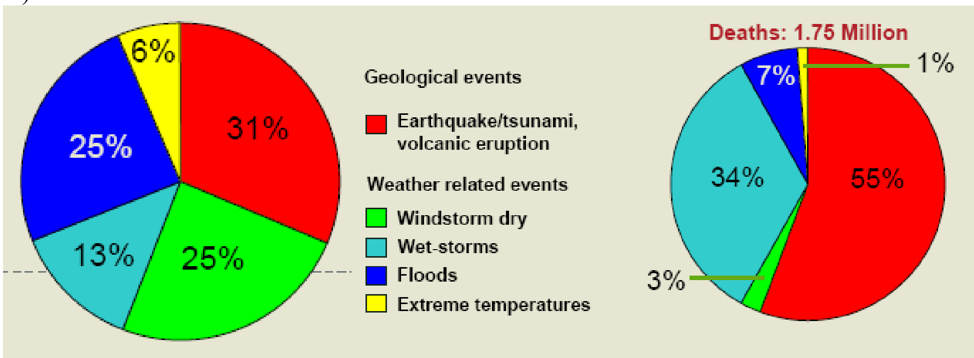
According to these Figures, the reasons not related to meteorology cause 31 % of economical losses, but 55 % of fatalities at the global scale. In Europe these numbers are 20 and 23 %. Globally wet storms are the most dangerous (25 % in the losses, i.e. equally dangerous with the floods, and 34 % considering the deaths), whereas in Europe the storms (32 %) and the hydrological extremes (25%) cause the most losses, but 55 % of the fatalities were caused by the heat waves.

---

[1] Department of Geography, Eszterházy College, H-3300 Eger, Leányka 6, Hungary.
mikaj@ektf.hu

The recent IPCC SREX Report (2011) assesses how exposure and vulnerability to weather and climate events determine the impacts and the disaster risk. It also evaluates the influence of climate variability and changes on the extremes.

a.)



b.)

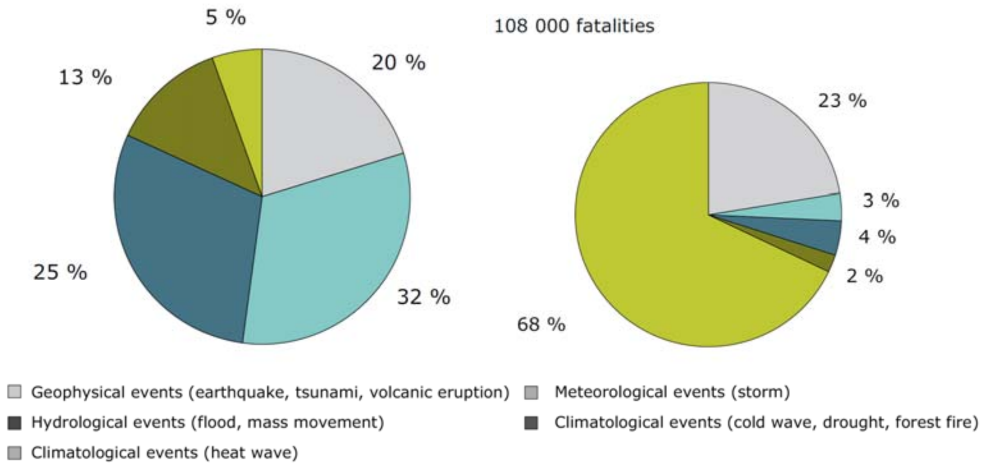


Figure 1 Relative distribution of economical loss (left) and number of fatalities (right) caused by natural disasters: a.) Global mean in 1950-2005 (Hoeppe at al., 2006); b.) Europemean (EU+5 countries) 1980-2009 (EEA, 2010). (The grey-scaled colours, arranged in clockwise order in the diagrams, correspond to left-to-right and then up-to-down order in the below-listed legends.)

The Special Report considers the role of development in trends in exposure and vulnerability, implications for disaster risk, and interactions between disasters and development. The Report examines how disaster risk management and adaptation to climate change can reduce exposure and vulnerability to the extremes, thus, reduce disaster risk, as well as increase resilience to the risks. These aspects of the Report are presented in *Fig. 2*, as a good multidisciplinary scheme of the issue.

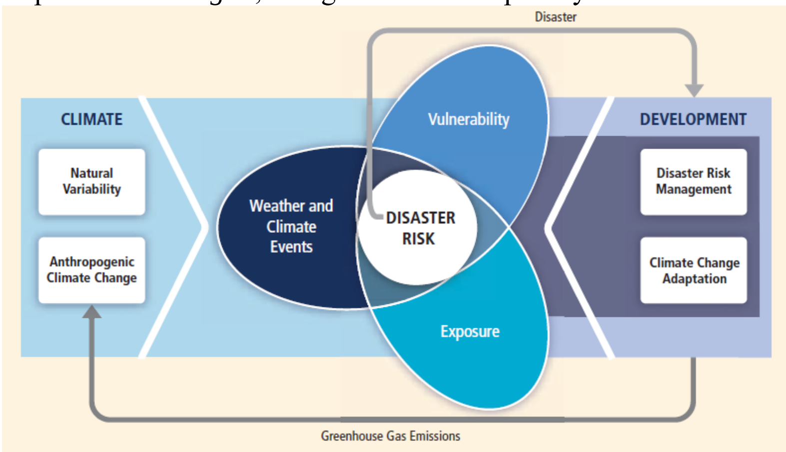


Figure 2 Core concepts of natural and anthropogenic factors causing meteorological extremes, as well, as condition determining the risks and general ways of response by the society, as exposed by IPCC SREX (2011: Fig SPM.1).

2. DEFINITION OF WEATHER AND CLIMATE EXTREMES

The IPCC (2007) Glossary says "An extreme *weather event* is an event that is rare at a particular place and time of year. Definitions of *rare* vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of the observed probability density function." Later, it states "When a pattern of extreme weather persists for some time, such as a season, it may be classed 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)."

To the author's view, this compilation is a limitation compared to of the way how the term "climate extreme" is most often used. The difference is that monthly or seasonal temperature anomalies can well be beyond the above rarity limit, even if they do not cover any day with a weather extreme. Furthermore, monthly or seasonal excess water may well be combined by moderate, but repeated diurnal precipitation amounts, as well.

The IPCC SREX (2011) defines the topic in its SPM (page 2.), as follows: „Climate Extreme (extreme weather or climate event): The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. For simplicity, both extreme weather events and extreme climate events are referred to collectively as 'climate extremes'." But, this definition is even less exact and bears both above problems of the IPCC (2007) definition.

Hence, for we recommend to define extreme events as follows: *Meteorological extremes* are events that are *rare and have high impact*. Both rarity and impact are needed for an event to to be considered a meteorological extreme e.g. the permanent drought in Sahara (not rare) or the amazing optical phenomena (no impact) are not meteorological extremes.

An event has high impact by virtue of its intensity or duration. *Weather extremes* are the rare events that are of high impact mainly due to the intensity of one or more observed atmospheric variable. By contrast, *climate extremes* are those rare periods of time that have high impact due to the sustained duration of one or more observed atmospheric variable. More detailed distinction is given below.

2.1 Weather extremes

The professional surface-based observations of the Global Observing System provide weather measurements, including air temperature, wind speed, wind direction, precipitation, cloud cover, humidity, sunshine hours and visibility, etc. taken regularly over the Globe. Firstly, we list the extreme weather events from the so-called synoptic codes, which indicate the events that are worth observing and archiving.

In codes *(http://www.srh.noaa.gov/jetstream/synoptic/ww_symbols.htm)* by WMO for the observations, the candidates for extremity, depending on their frequency and impact, are as follows: *Haze, mist, fog, dust whirl, sand whirl, duststorm, sandstorm, freezing rain, ice fog, ice needles, ice sleet. drifting snow, blowing snow, depositing rime ice, rain shower, snow shower, shower of hail, thunderstorm (observed lighting and thunder), squall lines, funnel cloud, tornado.*

Having the continuous thermodynamic state indicators, above or below a certain frequency and/or impact threshold is another class of extremes, e.g. temperature below zero, or rainfall above 20 mm. These are also weather extremes.

The environmental extremes, e.g. avalanches, forest fires or strong coastal waves, are at least affected by meteorological extremes, but not considered in this study. The operational practice provides information about these mixed events, too.

2.2. Climate extremes

By the above definition, climate extreme is a longer-term (monthly or seasonal) mean or frequency of variables or events, which are rare of potentially high impact. The climate extremes may be time averages or frequencies of events above a given diurnal threshold of a single meteorological variable. These averages or frequencies are often combined into *univariate indices*. Typical indices include the number or fraction of cold/warm days/nights etc. above the 10^{th} percentile, or the 90^{th} percentile, generally defined with respect to a pre-selected reference period.

In 1998, a joint WMO-CCl/CLIVAR Working Group formed with the purpose of climate change detection. One of its task groups aimed to identify the climate extreme indices and completed a climate extreme analysis over the world where appropriate data were available. These indices are given in more recent source by van Engelen et al., (2008), see *http://eca.knmi.nl/indicesextremes*. Another set of indices including uni- and multivariate indices, used in most of the European countries, is listed by Eitzinger et al, (2008). Some other examples are wind-based (Della-Marta et al., 2009) or pressure-based (Beniston, 2009) indices.

Extremity of weather or climate and the effects caused by them are often too complex to be expressed by a single meteorological variable. In other words, these climate extremes occur in the multi-dimensional phase-space of variables. Using more variables, however, does not establish a linear sequence of the extremities. Hence, most often the multivariate extremities are arranged into a single index.

For example, the thermal comfort index is calculated by means of the *physiologically equivalent temperature*, PET, based on the human energy balance (Matzarakis et al., 1999). For calculating this weather extreme, four meteorological parameters (air temperature, relative humidity, wind speed and cloudiness) as well as some assumed physiological parameters are used.

3. SCALES AND OBJECTS BEARING EXTREME EVENTS

Specific concern at the middle latitudes are caused by thunderstorms, tornadoes, hail, dust storms and smoke, fog and fire weather. These small-scale severe weather phenomena, that are sparse in space and time, may have important impacts on societies, such as loss of life and property damage. Their temporal scales range from minutes to a few days at any location and typically cover spatial scales from hundreds of meters to hundreds of kilometres. These extremes are accompanied with further hydro-meteorological hazards, like floods, debris and mudslides, storm surges, wind, rain and other severe storms, blizzards, lightning. For example, mudslides disrupt electric, water, sewer and gas lines. They wash out roads and create health problems when sewage or flood water spills down hillsides, often contaminating drinking water. Power lines and fallen tree limbs can be dangerous and can cause electric shock. Alternate heat sources used improperly can lead to death or illness from fire or carbon monoxide poisoning.

Mean frequency of several weather extremes is displayed in frequency maps e.g. by Burt (2007). These maps indicate that majority of extremes belong to more than one climate belt. Putting all kinds of extremities together, they also demonstrate us, that practically all continents experience one or the other types of meteorological extremes.

3.1 Time and space scales

Atmospheric objects exhibit fairly arranged space and time scales. Either drawing the meteorological extremes in the space (x-axis) and time (y-axis) system of coordinates (Fig. 3a), or doing the same with the atmospheric objects (Fig. 3b), we observe a diagonal distribution of the objects of both drawings. This means, small scale objects are generally short lived, whereas large-scale objects spend more time in the atmosphere.

On the other hand it also means that there are no fast developing extremes which cover large areas and also we do not experience long-term individual extremes or objects which threaten just small areas. Fig. 3a provides a comprehensive list of meteorological extremes, whereas Fig. 3b is a brief summary of the atmospheric objects leading to the various meteorological extremes.

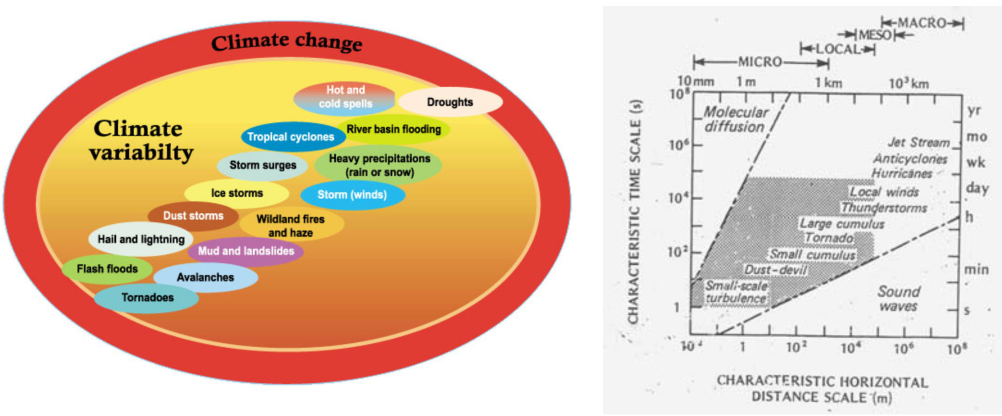


Figure 3 Characteristic space (horizontal) and time (vertical) scales of a.) weather and climate extremes and b.) atmospheric objects. Sources: a.) WMO (2006), b.) Oke, 1979.

3.2 Circulation objects

Weather extremes are immediately caused by specific weather objects. In developing climate extremes circulation processes also play well recognized role. In the following we briefly survey these objects from the largest scale blocking anticyclones to the smallest scale convective systems. Besides these individual objects, there are even longer-time patterns of the circulation, like the El-Nino - Southern Oscillation or North Atlantic Oscillation, which are not individual circulation objects, but which support specific objects to develop.

Anticyclones generally bear pleasant sunny weather, with no strong air motions, but long residence time above a given land area may lead to drying of the area. The larger the anticyclones are in their horizontal dimensions, the longer their life-time and slower their transition are. The so called blocking anticyclones of the temperate latitudes may remain for several weeks practically in the same position. Having several such objects in a vegetation season may already cause drought.

Temperate latitude cyclones, as large-sale objects, already bear threats of heavy precipitation and strong gradient winds. Warm fronts of the cyclones are responsible for low-intensity, but several days' long precipitation. Cold fronts of the cyclones may yield large amount and large intensity precipitation. Convective activity in and around the cold front, caused by upward motion of relatively warm air masses, may enhance the gradient wind sometimes causing extremely strong wind.

Convection is a key to extreme weather events. Starting from small cumulus clouds, possibly developing into single-cell local thunderstorms, they are still not subjects of extremes events. Multi-cell thunderstorms, causing heavy rain, sometimes hail and stormy wind are already extremity-bearing atmospheric objects. Single-cell thunderstorms sometimes develop into super-cells, accompanied with devastating wind and hail, heavy rain and maybe with tornado. Not so dangerous, but more complicated are the so called mezoscale convective complexes (MCC), often bearing squall lines, characterized by stormy wind, hail and intensive rain. The most devastating objects of convective origin are the tropical cyclones. Their 3-500 km characteristic diameter develops in coincidence of several conditions leading to accumulation of very high amounts of available potential energy, turning into kinetic energy. In a tropical cyclone, extremely strong winds, intensive rain and hail, causing several meters high waves at the shores may cause infinite harm.

4. climate change and the extremes

4.1 Expectations of changes in the extremes

Statistical and physical considerations suggest that a warmer climate bears more meteorological extremes than the present one. Later, we refer to some further difficulties that hamper the unequivocal establishment of the trends in the extremities.

Statistical considerations. Frequency of an extreme event can generally be enhanced under climate change for two reasons. When the whole distribution is shifted in one direction, with no change in its variance, then the extremes of this direction become more frequent, whereas the opposite extremes become rarer. In the second case, when variance of the distribution changes with no shift in the mean, frequency of extremes on both sides moves in the same direction. Parallel occurrence of the two causes is also possible.

Three metrics can be considered to quantify the trends in the extremes. One of them is to count the number of record-breaking events in a given year. However, it may well happen that hot extremes are setting new records, while cold extremes become less frequent. In such a case, counting the records would probably not indicate a significant trend, though frequency of the opposing extremes changed a lot.

Besides counting the single events, fraction of a given territorial unit can be summarized according to the distribution of local absolute records or probability of falling into e.g. the lower 10 %). Trends of these fractions may be established. A shortcoming of this method is that it needs equal levels of data coverage for the area. This is not always fulfilled, especially for rapid, small-scale weather extremes.

A third approach arises from the fact that extremes often have deleterious economic consequences. The global costs of extreme weather events are already high and rising. It may therefore be possible to measure the integrated economic effects of extremes by the insurance payout as a function of time. However, besides the effects of inflation, this measuring tool would also be influenced by changes in the vulnerability of the insured properties, e.g. by their age, or by their changing exposure in connection with the number of inhabitants or users of the real estate.

Physical considerations. Some physical processes support the hypothesis of increasing extremities parallel to global warming, but some others definitely question that. The most frequent argument for the more intense extremes is the increased energy content of the climate system, including the atmosphere (IPCC WG-I, 2007, Fig. 5.4). Having more thermodynamic energy in the whole system, the energy may be more easily cumulated in a given atmospheric object and region.

Another reasonable assumption is that in a warmer world, water vapour content of the air column is higher (IPCC, 2007: Figures 3.20 and upper Figure of 3.21), hence more latent heat may develop and turn into kinetic energy, especially via convection. A third experience is that in a warmer world the average lapse rate is higher, which in turn also support the formation of convective systems.

Other considerations, however, may cause less intensive extremes. E.g., the experience that the high-latitudes and the continents warm faster than the lower latitudes and the oceans, leads to smaller horizontal temperature- and, hence, pressure gradients generally become weaker in the process of global warming-up.

4.2 Data quality, free oscillations, conceptual problems

Establishing trends in extremities is difficult due to at least three problems. They are the uneven quality of observations (data problems), a conceptual problem, since scientists often search the trends in function of time, sometimes mixing the glob ally warming, stagnating and cooling periods and the existence of long-term free oscillations which make it difficult to detect the appearance of extreme events.

The data problem. Near-surface temperatures are generally influenced by various local disturbances (developing cities, vegetation), modifications in the observation technology (changes of time, instrumentation or shading devices) or simply relocation of the weather (climate) station. In some other cases, e.g. for the tropical cyclone records, the completeness of observations is rather heterogeneous due to changing observation technology and reporting protocols.

A conceptual problem. The third problem, making empirical trend analyses very difficult, is the mechanistic computation of statistical trends for any long period of time. Very often, these periods join globally warming periods, together with no change, or even with cooling periods. One may assume that a given behaviour of the extremities in a warming period should not be the same as in a stagnating or cooling period. Hence, any meaningful trend estimation should consider monotonously warming, or cooling periods, otherwise nothing can be told about possibilities of their extrapolation. (In principle, the extrapolation is never sure, but it is more likely if established in a similarly warming period, expected for the future.)

The free oscillations problem. Climate also fluctuates randomly, with relatively long, but irregular cycles. *Fig. 4* presents such fluctuations at the high latitudes of Northern Hemisphere. The three periods of 12, 7 and 6 years of duration indicate very different distribution of temperature anomalies. These natural fluctuations make the detection and attribution of changes in the extremities very difficult.

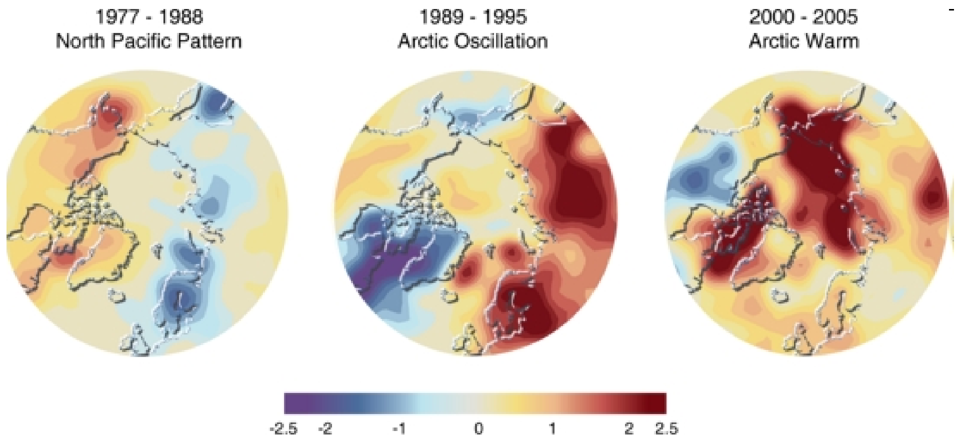


Figure 4 Arctic temperature anomaly patterns as examples of strong inter-annual variability within a monotonously warming period at the global scale. Data from NOAA/ESRL, http://www.cdc.noaa.gov/cgi-bin/Composites/ printpage.pl. Positive anomalies are found over Canada (1977-1988), Eurasia (1989-1995) and over the majority of the Polar region except the cooler than average mid-Canada (2000-2005). Negative anomalies are fould in wide areas of Eurasia (1977-1988), ocean areas attached to Northern Canada (1989-1995).

4.3 What is seen from the research?

Tab. 1 displays the major extreme events, indicating the 20th century tendencies and likelihood of the future trends. It indicates „warmer and fewer cold days and nights”, as well, as „warmer and more frequent hot days and nights”, detected over most land areas. Both statements are assessed “very likely” with over 90 % of probability concerning their 20th century trends. For the future, the continuation of the trends is virtually certain (99 %). Heavy precipitation events at the temperate latitudes and increase of drought affected area are likely in many regions since 1970s. Continuation of the increasing area in the 21st century is “likely”.

Recently, the IPCC SREX Report (2011) mainly approved these statements. E.g,, changes in return periods of the 20 years thresholds in diurnal maximum temperatures and in daily precipitation are displayed in Figs SPM 4A and 4B, for 26 continental regions between two future periods and 1981-2000. For Central Europe they indicate 4-6 times more frequent occurrence in the thermal and ca. 1,5x in the precipitation extreme by 2045-2065, depending on the assumed emission scenario.

Since, it is very likely (IPCC, 2007) that in the recent five decades, mankind significantly contributed to global warming, these decades are fair natural experiments with similar causes of warming to those likely driving the following decades. Nevertheless, one cannot be sure that all trends found in the past decades will be valid for the future. This question can only be assessed by combining modelling and statistics in the attribution studies that tackle the extremes (Min et al., 2011).

Table 1.Recent trends, and projections of extreme weather events. (IPCC, 2007: Tab. SPM-2. Statements on human origin are ommited.)

Phenomenon and direction of trend	Likelihood that trend occurred in late 20th century	Likelihood of trends projected for 21st century)
Warmer and fewer cold days and nights over most land areas	*Very likely*	*Virtually certain*
Warmer and more frequent hot days and nights over most land areas	*Very likely*	*Virtually certain*
Warm spells/heat waves. Frequency increases over most land areas	*Likely*	*Very likely*
Heavy precipitation events. Frequency mostly increases	*Likely*	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis)	*Likely*	*Likely*

4.4 Inter-model variability proving uncertainty of the mezo-scale models

Series of the maps shown by the IPCC (2007) Report demonstrate big inter-model differences in most climate variables. Hence, (i) no single GCM output can be applied for adaptation-related consequences, and (ii) the embedded regional climate models aimed to overcome the differences between the GCM-resolution and the significant scales, are strongly influenced by the boundary conditions. This means that though coupling the GCMs to regional models (Christensen et al., 2007; Halenka and Jacob, 2008) is a popular way to improve the resolution, ensuring adequateness of climate modelling, we should remember uncertainty of the GCMs.

This is clearly demonstrated in *Fig. 5*, where two different mainframe models (Hadley Centre of the British MetOffice and Max Planck Institute for Meteorology) led to different responses in the same regional model. The projected changes in the precipitation are more expressed in the upper combination of the models than in the lower one. The zero line is also shifted northwards in the first combination. These differences lead to stronger decrease for the Carpathian region by the first line of the Figure. The same difference between the two model-combinations is valid for the scalar changes of wind-speed, as well.

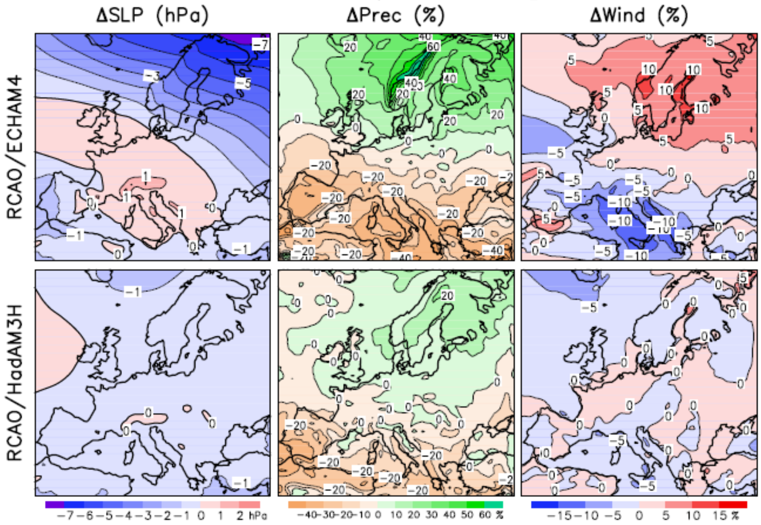


Figure 5 Simulated changes in annual mean sea-level pressure (ΔSLP), precipitation (ΔPrec) and wind speed (ΔWind) for 2071-2100 compared to 1961-1990, according to the A2 emission scenario. The results are obtained by regional atmosphere-ocean model of the Rossby Centre, Stockholm in both cases. The boundary conditions were provided by the ECHAM4/OPYC3 mainframe model (upper line) and HadAM3H model (lower line). The corresponding changes considerably differ from each other. (IPCC, 2007: Fig. 11.6)

5. Discussion

The Special Report on extremes (IPCC SREX, 2011) forwards statements which coincide with those in Table 1 from the IPCC (2007) Report. The recent report also satates “There is *low confidence* in projections of small spatial-scale phenomena such as tornadoes and hail because competing physical processes may affect future trends and because current climate models do not simulate such phenomena.”

REFERENCES

1. Beniston, M. (2009), *Trends in joint quantiles of temperature and precipitation in Europe since 1901 and projected for 2100. Geophys. Research Letters,***36**, L07707.
2. Burt C.C., 2007: Extreme Weather. Norton and Comp., New York, N.Y., 304 p.
3. Christensen, J.H., Carter T.R., Rummukainen, M. and Amanatidis, G. (2007), *Predicting of regional scenarios and uncertainties for defining European climate change risks and effects:ThePRUDENCE Project.*ClimaticChange 81:Suppl. 1,1-371
4. Della-Marta, P.M., H. Mathis, C. Frei, M.A. Liniger, J. Kleinn, and C. Appenzeller (2009), *The return period of wind storms over Europe. International Journal of Climatology,* **29(3)**, 437-459.
5. Eitzinger, J., and 15 co-authors (2008), *Agroclimatic indices and simulation models. In: Survey of Agrometeorological Practices and Applications in Europe Regarding Climate Change Impacts.* (P. Nejedlik and S. Orlandini, eds.), Ch. 6,246-278
6. EEA (2010), *Mapping the impacts of natural hazards and technologi-cal accidents in Europe. An overview of the last decade.* EEA Technical Report, No 13/2010.
7. Halenka, T. and Jacob, D., (eds.) (2008), Workshop on Regional Climate Modeling. Időjárás, vol. 112, No. 3–4,
8. Hoeppe P., 2006: *Trends of Natural Disasters – the Role of Global Warming.* Geo Risks Research, Munich Reinsurance Company, 1-17 pp.
9. IPCC, (2007), *Climate Change (2007), The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the IPCC, 2007 (Solomon, S., D. et al., eds.) Cambridge University Press, Cambridge UK & New York NY, USA.
10. IPCC SREX (2011), *Changes in Climate Extremes and their Impacts on the Natural Physical Environment.* IPCC Special Report. Summary for Policy Makers 1-29
11. Matzarakis, A.; Mayer, H. and Iziomon, M. G. (1999), *Applications of a universal thermal index: physiological equivalent temperature.* Int. J. Biometeor. 43: 76-84.
12. Min, S.-K., X. Zhang, F. W. Zwiers, and G. C. Hegerl (2011), *Human contribution to more intense precipitation extremes.* Nature, **470,** 378-381.
13. Oke, T. R. (1979), *Boundary Layer Climates.* John Wiley and Sons, 372 pp.
14. van Engelen, A., A. Klein Tank, G. van de Schrier and L. Klok (2008), *Towards an operational system for assessing observed changes in climate extremes*. European Climate Assessment and Dataset (ECA&D) Report, KNMI, Netherland, 70 p.
15. WMO, (2006): *WMO an example of International Cooperation.* Presentation by M. Jarraud, Secretary-General of the WMO in Budapest, Hungary March, 6, 2006.