

IDŐJÁRÁS

Az Országos Meteorológiai Szolgálat folyóirata, 92. évf. 5. szám, 1988. szeptember – október
Journal of the Hungarian Meteorological Service, Vol. 92, No 5. Sep–Oct 1988, Budapest

On the concept of extreme meteorological and climatic events

E. ANTAL and T. FARAGÓ

*Hungarian Meteorological Service
H-1525 Budapest, Pf. 38.*

M. H. GLANTZ

National Center for Atmospheric Research
P. O. Box. 3000, Boulder, CO, 80307, USA*

Analysis of and coping with the extreme phenomena and occasional extreme events of the surrounding natural environment is of great importance for societies. Different aspects of the investigation of such meteorological events are dealt with from a conceptual point of view. Among others, the relative character of the occurrence of extreme values, their relation to the climatic variability, the limitations concerning the application of theoretical methods of analysis, the role of case studies and case-scenarios are considered. Because of the complexity of these problems and the potential significant socioeconomic impacts, in the authors' opinion, further interdisciplinary research is needed on extreme meteorological events in order to improve society's ability to cope with them.

*

A szélsőséges meteorológiai és éghajlati események vizsgálatának főbb szempontjai. A természeti környezet szélsőséges jelenségeinek, eseményeinek és lehetséges társadalmi hatásainak elemzése fontos feladat. E dolgozat célja e szélsőséges meteorológiai események főbb vizsgálati szempontjainak áttekintése. Ezek sorában, többek között, külön figyelmet fordítunk a szélsőértékek relatív jellegére, azoknak az éghajlati változékonysággal való kapcsolatára, az elméleti módszerek alkalmazását korlátozó egyes tényezőkre, vagy az esettanulmányok és az ún. „eset-scenáriók” jelentőségére. A problémakör bonyolultsága és a szélsőséges meteorológiai események társadalmi-gazdasági hatásainak jelentősége miatt – a szerzők véleménye szerint – az érintett tudományágak képviselőinek további kutatási együttműködése szükséges annak érdekében, hogy az említett szélsőségek negatív hatásait jelentősen csökkenthessük.

*

Climate has for a long time generally been identified by the average meteorological conditions of a region. The atmosphere, however, like other environmental elements, exhibits varying states over different time scales, and those

* The National Center for Atmospheric Research is sponsored by the National Science Foundation, USA.

variations are of great importance to ecological systems and to societies dependent on them. In searching for optimal ways of adaptation, extreme meteorological events identify some natural boundaries (i. e., thresholds), the crossing of which stimulates responses for adjustment to either established or gradually changing external conditions. Thus, climate variability in general and weather and climate extremes in particular are very important topics for scientific research in the physical and social sciences.

Extreme meteorological events refer to any kind of significant departure or deviation from normal or expected atmospheric conditions. These events often have significant ecological and socioeconomic impacts. Thus, the impacts aspects of extreme events should not be overlooked. However, "pure" meteorological extremes can also be analyzed in order to develop a more complete characterization of a region's climate. Occurrences of record or near-record values of meteorological elements gradually widen their empirical and expected ranges, but the concept of extreme is even broader. This concept encompasses all cases when certain threshold values are reached or are surpassed by particular meteorological elements. These thresholds exhibit the limits of tolerance for ecological or socioeconomic systems within which their established patterns of interactions can be maintained. It concerns elements of climate commonly viewed as "static", like temperature or precipitation on different spatial or temporal scales, their variability as well as other "dynamic" parameters such as, for example, the interdiurnal or interannual variations or even the rapidity of the changes. These are very important parameters from the point of view of environmental and societal resilience or adaptability.

The relative character of meteorological and climatic extremes

Both climatological and socioeconomic research on this topic imply the relative nature of the concept of extreme meteorological phenomena. On the one hand, the "local climate" determines what might be regarded as an "extraordinary" event; cold temperatures or droughts take on quite different meaning (and thresholds) for the Sahelian region of West Africa than for the Scandinavian peninsula. With slowly changing climates the definition of extremes and their likelihood of occurrence will also be altered. On the other hand, socioeconomic changes could be viewed in an analogous way (e. g., a society can "create" a drought situation as a result of a gradual population increase in a region in which the per capita water supply becomes increasingly insufficient (see, for example, Perkey *et al.*, 1983).

In addition, a weather or climate anomaly could have adverse impacts on some sectors of the economy while having beneficial effects for others. This relatively complex character of meteorological events (and especially extreme events) should be properly taken into account. Assessments of such extreme events must be undertaken with specific impacts in mind, because what is considered extreme with respect to one ecosystem or societal activity may not be considered extreme for other ecosystems or activities (such an event is characterized by Ambrózy and Faragó (1988) concerning some beneficial aspects of an extremely cold winter episode for agriculture). In other words, extreme meteorological events should be considered within the context of their location, timing, and impact on specific ecosystems as well as on economic and other societal activities.

Long-term variations in climate and its extremes

Long-term and large-scale changes have taken place in the climate of the past. Such changes are possibly going on today and will certainly occur in the future. Many of their causes and impacts are now being investigated. For example, a carbon dioxide/trace gases-induced global warming is currently predicted by many scientific researchers. Besides the estimates of changes in the averages of climatic parameters, the probable changes in their variability and the corresponding "threshold events" are also of paramount importance (Mearns *et al.*, 1984; Katz, 1988). Unfortunately, relevant credible inferences concerning the behavior of extreme phenomena cannot usually be made on the basis of scenarios generated by general circulation models because of certain limitations inherent within these models.

Extreme events as recurrent elements of climate

Besides the "normal" or the most probable events, extreme meteorological events are also fundamental elements of climate. They are recurrent (even for record events), although the timing of their onset may remain quite uncertain. Thus, they can be considered as inherently aperiodic phenomena. Because of this characteristic, the long-range (i. e., climatological) forecasting of extreme events is, for all practical purposes, rather difficult, if not impossible. Nevertheless, climatic information may be effectively used for the estimation of probabilities of occurrence of various extreme events.

Methods of analysis

The general methods of extreme value theory can be used for analyzing meteorological variables as well (Gumbel, 1958; Leadbetter *et al.*, 1983; Tabony, 1983; Triago de Oliveira, 1983; Balog *et al.*, 1984). However, a basic "physical" understanding is needed in order to properly interpret the results of such an analysis.

Theoretical results allow to find the principal probability distributions for the extremes of various meteorological elements, hence the problems of exceedances, return periods or records could be solved effectively for idealized variables. Yet, there are severe limitations concerning these approximations, the most complex of which is the availability of a satisfactory sample size (Boyack, 1985; Court, 1986).

Problems related to extreme meteorological events occasionally involve more than one parameter (Cehak, 1986). Thus, some extreme value analyses must be multidimensional. For example, in relation to severe cold episodes, a consideration of the joint distribution of temperature and wind velocity is useful. The impacts of a combination of different elements are sometimes merged into a simplified indicator as, for example, in the case of the wind-chill factor, a winter severity index or a drought index. These procedures should be reflected in the treatment of the corresponding extreme value problem. (Katz and Glantz, 1986; Skaggs, 1988; Faragó *et al.*, 1988 also consider several climatological and statistical properties of some drought incidences; similarly, for instance, severity indices might be used for the analysis of extremely cold winter episodes, as discussed by Ambrózy and Faragó, 1988.)

Problems of extreme value analysis in meteorology are frequently further complicated because of the fact that the time-series or samples of the meteorological

logical variables exhibit dependence (see, e. g., *Katz, 1977; Faragó, 1977; Leadbetter et al., 1983*).

Meteorological approaches are concerned with the causes of onset, persistence, and recurrence of extreme meteorological phenomena. Finding the relevant meteorological and statistical methods is complicated by the fact that the series of meteorological observations are sometimes disturbed by larger-scale climatic fluctuations and/or changes. Therefore, extreme meteorological events should be delineated against a slowly and perhaps significantly changing background which, among other influences, tends to distort the homogeneity of observations. Moreover, since extreme events are relatively rare in occurrence, long time series are necessary to accurately quantify their likelihood.

Case studies and case scenarios

Case studies can be extremely useful in attempts to assess society's ability to identify and cope with extreme meteorological events. These studies are not only useful for assessing our ability to deal with climate variability and extreme climatic events but are also of value for determining how well we are prepared to deal with potential climate changes. Case studies are based on the investigation of actual situations. They are focused on regional and local levels, so their findings can serve as inputs into national as well as local decision-making processes.

Case scenarios are slightly different and somewhat more speculative. They are attempts to determine whether other more appropriate decision pathways might have been taken with respect to responses to past events (e. g., an extreme meteorological event). Thus, the researchers attempt to re-enact societal responses to a previous climate extreme, seeking to identify more effective and efficient responses that might have been taken in the past with the purpose of seeing whether they could be taken in the future in the face of similar extreme events (see *Glantz, 1982; Glantz, 1988a*).

Case scenarios are also useful as attempts to identify how well societies are prepared to deal with future climate changes such as those that might occur as a result of a carbon dioxide/trace gases-induced global warming (*Glantz, 1988b*). Here, case scenarios can help, for example, to identify rigidities in existing systems with respect to economic and other societal responses to present-day extreme meteorological events. Once identified, such rigidities might be removed, enabling societies to make more flexible responses to an uncertain climatic future (with changes in the mean as well as in the extremes).

Extreme phenomena: the typical cases

There are many kinds of extreme meteorological events with which societies must cope. Drought, perhaps, is one that draws the most attention as it usually has an adverse impact on agricultural production. There now exist many definitions of drought (see, for example, *Wilhite and Glantz, 1985*), and these definitions are often specific to a region or to an agricultural activity. Not only a specific drought within a given year, but successive years of drought as well, can be identified as an individual extreme event (*Karl and Quayle, 1981; Karl, 1983; WMO, 1986*; see also the analysis of the recent drought episodes in Hungary by *Dunay et al., 1988*).

Other common extreme events include floods. The timing, intensity, or duration of such floods could be what makes a particular one considered to be an extreme event. Extremely cold wintertime temperatures, as occurred in the winter of 1986–87 in Hungary provide another example as discussed by *Ambrózy* and *Faragó* (1988). The unusual recurrence for a few consecutive years of such severe winter conditions can also constitute an extreme meteorological situation (*Diaz* and *Quayle*, 1980). Repeated freezes in the citrus-growing regions of central Florida in the first half of the 1980s, and repeated frosts in the wine-growing regions of Hungary in the mid-1980s are also examples of meteorological extremes (see *Glantz*, 1988a; *Csapó* and *Kozma*, 1988, respectively). While one such year might be expected to occur relatively often, a run of such years is considered quite unusual. These examples represent just a few of the extreme meteorological events that merit further research.

Another approach to classifying extreme meteorological events is to consider them from the point of view of those weather- and climate-sensitive socioeconomic activities which are heavily influenced by them. Agriculture is the most critical sector for such an analysis (see, for example, *Varga–Haszonits*, 1987). Another field of growing importance is energy management (*Bach*, 1980; some aspects of this problem are treated by *Tárkányi* and *Ambrózy*, 1984, as well as by *Ambrózy* and *Faragó*, 1988).

Continued research on the impacts of these extreme meteorological events is likely to be of benefit to societies everywhere.

Coping with extreme meteorological events

One of the basic aims of investigations of extreme meteorological events is to develop strategies to cope more effectively with these events. Changes in the environment, especially in the climate, raise the problems of vulnerability, resilience and adaptation or, in the most direct sense, the "acclimatization" of the ecosystems and societies; extreme events can be considered as the most important indicators of such changes (*Schneider*, 1977; *Czelnai*, 1980; *Faragó*, 1981; *Parry*, 1985). The results of investigations concerning extreme meteorological events and their impacts will be of some value if they are taken into account in the formation of corresponding socioeconomic decisions.

There are different ways to cope with or prepare for the potentially adverse consequences of extreme events. As one example, these methods can be classified as follows: methods to prevent the onset of the meteorological hazard, to prevent the adverse impacts, to mitigate these impacts, or to adapt to them (*Glantz* and *Ausubel*, 1984). For example, society attempts to mitigate the impacts of drought on crop yields and crop production by adopting agricultural strategies, such as crop selection and irrigation (*Wilhite et al.*, 1986; *Wilhite* and *Hubbard*, 1988). Such actions attempt to minimize the possibility that a meteorological drought will become an agricultural one. Equipments such as heaters and wind machines are sometimes used by orchardists for protection against frost damage. In all cases, a decision should be made concerning the expected efficiency of the different actions: for instance, the probable cost-loss ratio should be assessed before using a protective equipment against frost in fruit-growing regions (*Katz et al.*, 1982). However the prediction of adverse extreme meteorological events is a complicated problem and an erroneous climate-related forecast can have con-

siderable societal implications (Glantz, 1982). Hail suppression demonstrates a method which is aimed at the prevention of the development or onset of a meteorological hazard.

Unfortunately, in many instances efforts to develop strategies and to further monitor or manage a particular severe meteorological event end immediately after the particular event and its direct impacts have seemingly ended. The best example of this would be drought. Often interest in drought is high in the midst of such an event. Once the drought ends, however, interest rapidly evaporates, even though it is known that such events can and will recur. In addition, while the physical aspects of a drought might end, its socioeconomic impacts often remain for years. Therefore, there is a need to foster multidisciplinary research on extreme meteorological events and on their direct and indirect impacts in order to improve society's ability to identify and cope with them.

REFERENCES

- Ambrózy P. and Faragó T., 1988: Recent Severe Winters in Hungary: Meteorological Approach and Some Energy Supply/Demand Aspects. *Proc. Workshop on "Identifying and coping with extreme meteorological events"*, Budapest (in print)
- Bach, W. et al. (Editors), 1980: *Interactions of Energy and Climate*. Reidel P. C., Dordrecht.
- Balog M., Gulyás O. and Szentimrey T., 1984: Meteorológiai megfigyeléssorozatok szélső értékeinek statisztikája. *Időjárás* 88, 101–108.
- Boyack, C. F., 1985: Investigation of the effect of length of record upon extreme values. *Meteor. Mag.* 114, 100–108.
- Cehak, K., 1986: Bi-variate extreme value distributions in climatology. *Third Int. Conf. on Stat. Climatology*, Vienna, 159–162.
- Court A., 1986: Misapplications of extreme value statistics. *Third Int. Conf. on Statistical Climatology*, Vienna, 218–220.
- Czelnai R., 1980: Climate and Society: Great Plain of the Danube Basin. *Proc. Workshop, IIASA Laxenburg*
- Csapó P. and Kozma F., 1988: The influence of the critical temperature, below freezing point, upon the Hungarian vineyards. *Proc. Workshop on "Identifying and coping with extreme meteorological events"*. Budapest (in print)
- Diaz, H. F. and Quayle, R. G., 1980: An analysis of the recent extreme winters in the contiguous United States. *Mon. Wea. Rev.* 108, 687–699.
- Dunay S., Faragó T., and Nemes Cs., 1988: Years of drought in Hungary, but was there a drought incidence at all? *Proc. Workshop on "Identifying and coping with extreme meteorological events"*. Budapest (in print)
- Faragó T., 1977: On the estimation of probability distribution of maximum values and the statistical analysis of a wind velocity sample. *Időjárás* 81, 27–39.
- Faragó T., 1981: Éghajlat és társadalom. *Magyar Tudomány* 26, 503–509.
- Faragó T., Kozma E., and Nemes Cs., 1988: Quantifying Droughts. *Proc. Workshop on "Identifying and coping with extreme meteorological events"*. Budapest (in print)
- Glantz, M. H., 1982: Consequences and responsibilities in drought forecasting: the case of Yakima, 1977. *Water Res.* 18, 3–13.
- Glantz, M. H., and Ausubel J. H., 1984: The Ogallala Aquifer and carbon dioxide: Comparison and Convergence. *Environmental Conservation* 11 (2), 123–131.
- Glantz, M. H., 1988a: Climate impact case studies. *Proc. Workshop on "Identifying and coping with extreme meteorological events"*. Budapest (in print)
- Glantz, M. H., 1988b: *Societal Responses to Regional Climate Change: Forecasting by Analogy*. Westview Press, Boulder, Co. USA.
- Gumbel, E. J., 1958: *Statistics of Extremes*. Columbia Univ. Press, New York.
- Karl, T. R. and Quayle, R. G., 1981: The 1980 Summer heat wave and drought in historical perspective. *Mon. Wea. Rev.* 109, 2055–2073.
- Karl, T. R., 1983: Some spatial characteristics of drought duration in the United States. *J. Clim. Appl. Meteor.* 22, 1356–1366.
- Katz, R. W., 1977: Precipitation as a chain-dependent process. *J. Appl. Meteor.* 16, 671–676.
- Katz, R. W. and Glantz, M. H., 1986: Anatomy of a rainfall index. *Mon. Wea. Rev.* 114, 77764–1.

- Katz, R. W., 1988: Statistics and decision-making for extreme meteorological events. *Proc. Workshop on "Identifying and coping with extreme meteorological events"*. Budapest (in print)
- Katz, R. W., Murphy, A. H. and Winkler, R. L., 1982: Assessing the value of frost forecasts to orchardists: a dynamic decision-making approach. *J. Appl. Meteor.* 21, 518-530.
- Leadbetter, M. R., Lindgren, G., and Rootzén H., 1983: *Extremes and related properties of random sequences and processes*. Springer, N. Y.
- Mearns, L. O., Katz, R. W. and Schneider, S. H., 1984: Extreme High-Temperature Events: Changes in their Probabilities with Changes in Mean Temperature. *J. Clim. Appl. Meteor.*, 23, 1601-1613.
- Parry, M. L. (Editor), 1985: *The Sensitivity of Natural Ecosystems and Agriculture to Climatic Change*. IIASA, RR-85-1
- Perkey, D. J., Young, K. N. and Kreitzberg, C. W., 1983: The 1980-81 drought in Eastern Pennsylvania. *Bull. Amer. Meteor. Soc.* 64, 140-147.
- Schneider, S. H., 1977: Climate change and the world predicament. *Clim. Change* 1, 21-43.
- Skaggs, R. H., 1988: Drought in the North Central United States. *Proc. Workshop on "Identifying and coping with extreme meteorological events"*. Budapest (in print)
- Tabony, R. C., 1983: Extreme value analysis in meteorology. *Meteor. Mag.* 112, 77-98.
- Tárkányi Zs. és Ambrózy P., 1984. A légköri erőforrások szerepe az energiagazdálkodásban. *A légköri erőforrások hasznosítása az energiagazdálkodásban Magyarországon*. OMSZ. Hiv. Kiadv. LVII, Budapest, 43-54.
- Tiago de Oliveira, J., 1983: Extreme Values and Meteorology. *Second Int. Conf. on Statistical Climatology*, Lisbon. 10. 1. 1-10. 1. 8.
- Varga-Haszonits Z., 1987: *Agrometeorológiai információk és hasznosításuk*. Mezőgazdasági Kiadó Budapest.
- Wilhite, D. A. and Glantz, M. H., 1985: Understanding the drought phenomenon: The role of definitions. *Water International*, 10, 111-120.
- Wilhite, D. A., Rosenberg, N. J. and Glantz M. H., 1986: Improving federal response to drought. *J. Clim. Appl. Meteor.* 25, 332-342.
- Wilhite, D. A., and Hubbard, K. G., 1988: Drought management: The role of near-real time weather data. *Proc. Workshop on "Identifying and coping with extreme meteorological events"*. Budapest (in print)
- WMO, 1986: *Report on Drought and Countries Affected by Drought during 1974-1985*. WCP-118.