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Extreme events in the Mediterranean area: A mixed deterministic-statistical approach(*)

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Summary. — Statistical inference suffers for severe limitations when applied to extreme meteo-climatic events. A fundamental theorem proposes a constructive theory for a "universal" distribution law (the Generalized Extreme Value distribution) of extremes. Use of this theorem and of its derivations is nowadays quite common. However, when applying it, the selected events should be real extremes. In practical applications a major source of errors is the fact that there is no strict criterion for selecting extremes and, in order to "fatten" the statistical sample very "mild" selection criteria are often used. The theorem in question applies to stationary processes. When a trend is introduced, inference becomes even more problematic. Experience shows that any available *a priori* knowledge concerning the system can play a fundamental role in the analysis, in particular if it lowers the dimensionality of the parameter space to be explored. The inference procedures serve, then, the purpose of testing the reliability of inductive hypothesis, rather than proving them. Within the above general context, analysis of the hypothesis that the frequency and/or intensity of extreme weather events in the Mediterranean area may be changing is proposed. The analysis is based on a combined deterministic-statistical approach: dynamical analysis of intense perturbations is combined with statistical techniques in order to try to formulate the problem in such a way that meaningful conclusion may be achieved.

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1. – Introduction

The idea that climate([1]) variations may manifest themselves in the form of changes in higher-order moments of the probability distribution, rather than in average quantities,

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([1]) By definition the "statistics" of the climatic system.

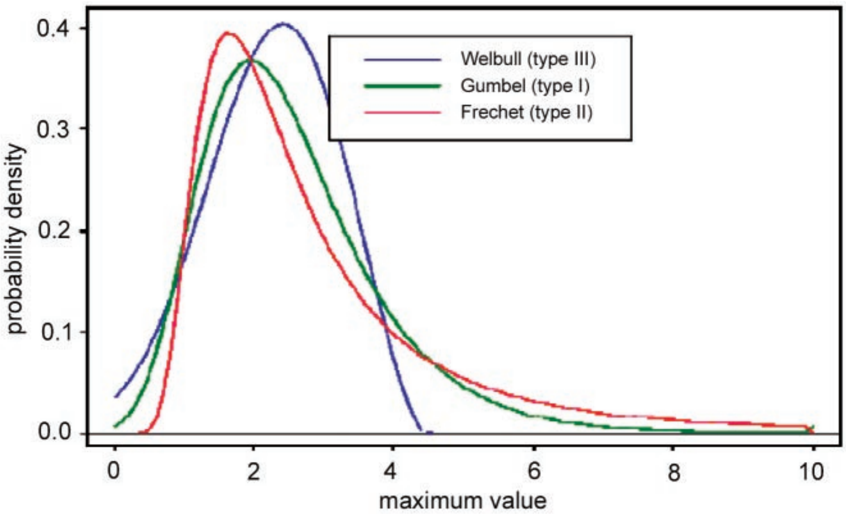

Fig. 1. – Generalized Extreme Value (GEV) distribution with the "three types": rich tail (Frechet), truncated tail (Weibull) and the separating ($\xi = 0$) Gumbel distribution.

has been rediscovered several times in the history of environmental sciences. In recent times this hypothesis has been repeatedly proposed for the frequency and/or amplitude of extratropical cyclones in connection with Global Warming.

One way of approaching this kind of problems consists in trying to estimate directly from observations the probability distribution of relevant quantities. Statistical inference, however, suffers for severe limitations when applied to extreme events. An old [1] classical theorem, in some sense similar to the central limit theorem, proposes a constructive theory for a "universal" distribution law (the Generalized Extreme Value, GEV distribution) of extremes. The functional form of this universal law (exponential of exponentials) is displayed in eq. (1), while the typical diagrams of the "three types" of distribution corresponding to different values of the "shape" parameter ξ: rich tail (Frechet), truncated tail (Weibull) and Gumbel ($\xi = 0$) are shown in fig. 1:

$$G\left(z = \frac{x-\mu}{\sigma}; \xi\right) = e^{-(1+\xi z)^{-1/\xi}} . \tag{1}$$

Use of this theorem (and its derivations) is nowadays quite common and relatively easy (free software is readily available). However, when applying it, it should be always kept in mind that: the selected events should be real extremes; the theorem, strictly speaking, applies to stationary processes; the GEV distribution is determined by three real parameters. In practical applications the major source of errors is, probably, the violation of the caution proposed in the firs point: there is no *a priori*, "objective" criterion for selecting extremes and, usually in order to "fatten" the statistical sample, very "mild" selection criteria are quite often used. When also a trend is considered(2), inference becomes even more problematic. In general, we do not dispose of a sufficient number of

(2) Note that Gnedenko's theorem holds only for stationary processes.

TABLE I. – *Correlations among the mean values of SLP pattern produced extreme events as defined in the text (Atlantic Cyclones).*

	NW	NES	NEN	SO	CE
NW	1	0.8347	0.9070	0.5115	0.9213
NES	0.8347	1	0.6685	0.6190	0.8163
NEN	0.9070	0.6685	1	0.2013	0.9499
SO	0.5115	0.6190	0.2013	1	0.3290
CE	0.9213	0.8163	0.9499	0.3290	1

non-correlated events for reliable estimates and, anyhow, since "trend functions" (linear, quadratic, and so on) are not orthogonal among them we can, at most, show that a specific, hypothesized trend function is consistent with available observations, but not exclude that this is also true for other possible trend functions. This is because, due to the lack of orthogonality, the variance of the analyzed signal simultaneously projects onto the different trend functions. In fact, experience shows that a purely "objective" inference approach is not the best and use of any available *a priori* knowledge concerning the system can play a fundamental role in the analysis itself, in particular if it helps in lowering the dimensionality of the parameter space to be explored. The inference procedures serve, then, the purpose of *testing* the reliability of inductive hypothesis, rather then *finding* them.

2. – Characterization of atmospheric circulations leading to Italian intense precipitation events in the years 1951-2000

With the above concepts in mind, we (a joint Camerino University-CNR ISAC Bologna team) are currently facing the problem of studying the statistics of weather events associated with intense precipitation over Italy [2]. The precipitation dataset is the same of Brunetti *et al.* [3]. Data coming from a variety of sources were homogenised and missing data filled. Thus Italy was divided in according with Brunetti *et al.* [3] in five regions, Northwest (NW), Northeast-North (NEN), Northeast-South (NES), Central (CE) and South (SO). In the first, preliminary analysis, we consider an event "intense" when the precipitation amount exceeds the 99 percentile threshold for at least two stations within the same region and in the same day. Our purpose is to analyse the weather

TABLE II. – *Mean of correlations of SLP pattern for each region in which Italy was divided (Atlantic Cyclones).*

Regions	Number of events	Correlation
NW	14	0.3220
NEN	38	0.3439
NES	17	0.1864
CE	19	0.2156
SO	7	0.1743

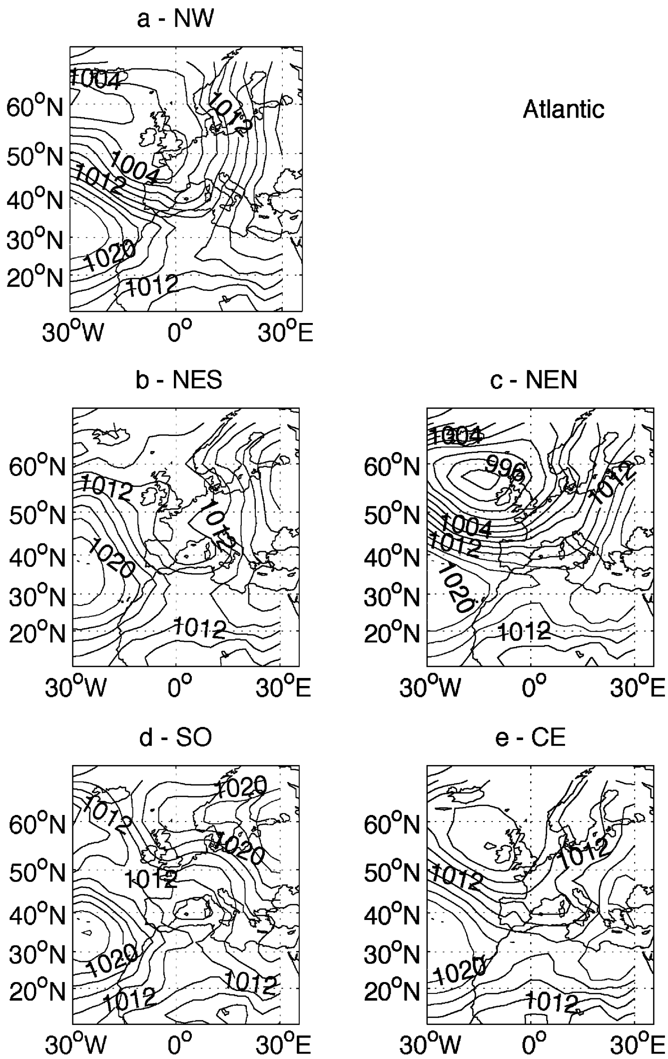

Fig. 2. – Contours of the Sea Level Pressure computed averaging fields produced extreme events as defined in the text. The five panels are for any region in which Italy was divided. The selected cases concern only Atlantic Cyclones.

associated with such events in order to formulate reasonable *a priori* hypotheses that can help in statistical inference. An objective procedure has been used to track the depression systems. The procedure divides the pressure field into local depressions. The pressure in each grid point is compared with the value at its nearest-neighbour grid points to find a steepest descent path leading to a sea level pressure (SLP) minimum. A depression trajectory is obtained by following the centre of the depression over time.

Cyclones that produced such events were classified as Atlantic, Mediterranean and African depending on the region where cyclogenesis occurred. When the SLP is averaged on the events, correlations among patterns characterizing the different regions are very

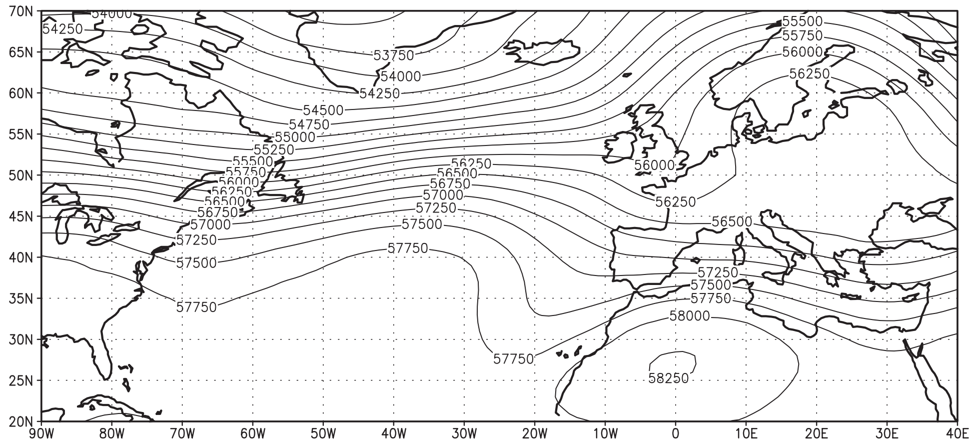

Fig. 3. – Contours of monthly mean geopotential for August 2002.

high. For example, table I shows the correlation among the SLP patterns obtained averaging the SLP of the Atlantic cyclones that caused extreme events over the five different regions (fig. 2). Actually these high values of correlation should not come as a surprise since performing an averaging operation is really a smoothing operation; as a consequence, differences among the different events are levelled. Table II shows the mean of correlations of SLP patterns for each region. It is possible to note that correlation computed on the same region is actually lower than the case described earlier. It has to be remarked that with the latter procedure results are really expected, knowing that in the atmosphere having two analogues is very difficult or impossible [5].

3. – The wet summer of 2002

Surface pressure is not the best field to consider in view of dynamical interpretation and sometime the same geopotential at 500 hPa is not. A better variable might be the relative vorticity. Figures 3 and 4 show the monthly mean of geopotential (fig. 3) and relative vorticity (fig. 4) from an analysis of the outstanding (extreme precipitation over Europe) August of 2002 [4]. That summer was characterized by floods in several European countries, ended by the so-called century flood that interested the cities of Dresden and Prague. The geopotential map shows a zonal flow that never occurred that summer, whereas the relative vorticity map the monthly conditions are clearer, as the anti-cyclonic circulation remained confined over the regions of North Europe, North Africa and North Atlantic indicated by negative values of relative vorticity, whereas positive values denote cyclonic circulation. In fact, the lack of the usual anticyclone, characterizing a classic Mediterranean summer season, was the main feature of that summer. The absence of anticyclone over the Mediterranean region permitted the passage of several cyclones through European countries. Many of them moved from higher Atlantic latitudes to the Mediterranean latitudes. When they approached the Mediterranean area, they slowed down and grew more intense causing heavy precipitation. The three areas where positive vorticity values are high, close to England, over the western Mediterranean and over Atlantic, near the African coast, gave also an idea about the real cyclonic tracking. In fact, cyclones moved by higher latitude areas passing over England, where they

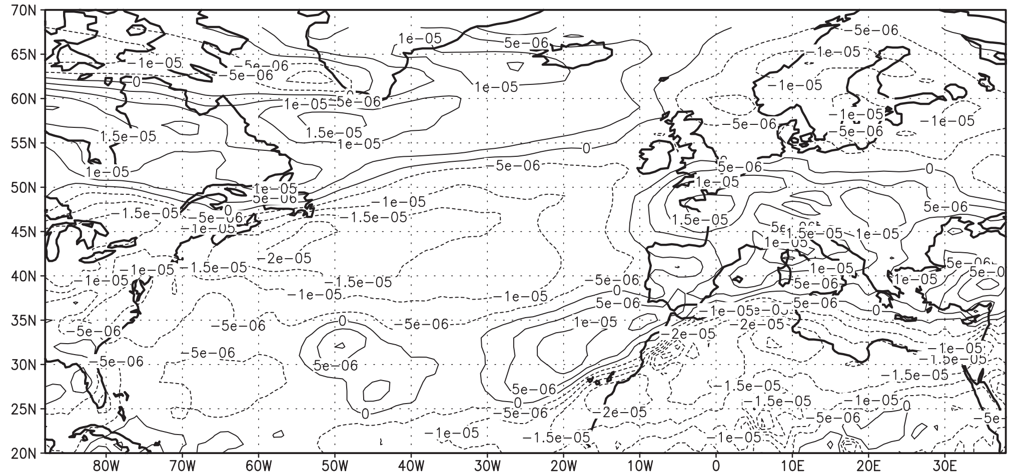

Fig. 4. – Contours of monthly mean relative vorticity for August 2002. From −30° W eastward three important maxima are present. Each maximum characterizes a region of strong cyclonic activity.

caused no damage, towards the Mediterranean region. Only when they approached the Mediterranean region the precipitation was very intense. It is worth noting that heavy precipitation occurred over the Austrian alpine regions, where many tributaries confluence in the rivers that flooded the German and Czech Republic areas. The other cyclogenetic area was the Atlantic one, near the coast of Africa, but such cyclones that moved towards northeast, lost their force before approaching to European coasts and never interested the Mediterranean area. Moreover, a couple of cyclones formed over the Mediterranean area during that summer. Any single event was not really "extreme". The "exceptionality" of that summer was due to the number of events, some of them may be classified as intense events, which interested the Europe, mainly Austria, Italy, Germany, Czech Republic and so on; a dozen of cyclones hit the Europe in 60 days. Thus, every event did wetter the soil, reducing the capacity of absorbing water in the next event. Thus the definition of extreme, associated with a single event, in Meteorology might be reductive. A weather lasting many days (persistent) may cause even more damage that a single intense event. Thus, complete analysis of the event shows that local persistence of the perturbations, associated with their low mobility, is a key factor. Reconstruction of the hydrological cycle demonstrates the important role of preconditioning (pre-existing atmospheric water), water advection from the boundaries and local evaporation.

4. – Processes in controllable models

Phenomenological studies can help in formulating reasonable hypothesis, but the only convincing way of interpreting observations is in terms of well understood processes. In fact, a considerable part of our research is devoted to analyzing the dependence of the statistical properties of extratropical cyclones on climatic conditions in controllable models. Controllable means that, besides having a deterministic knowledge of the processes operating in the model atmosphere, we have also the possibility of achieving very high reliabilities (usually by means of long integrations in time). A system of intensive study

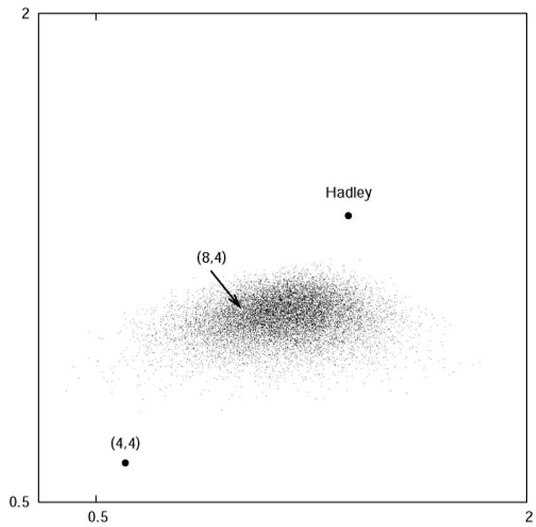

Fig. 5. – Scatter diagram of zonal wind speed (abscissa) versus average baroclinicity (ordinate) of a 192 component model of the middle latitude jet [6]. Also shown are the symmetric circulation (Hadley circulation) and the circulations corresponding to different low-order truncations (4,4 and 8,4) of the model.

for us is a model of the middle latitude tropospheric jet in terms of 192 components already used for studies of the middle-latitude circulation [6]. Figure 5 shows a projection in the phase-space of the system. By means of very long integrations (thousands of years), we generate different statistics (including different trends) and study the way the different processes (basically, barotropic equilibration of baroclinic instability) operate in determining the statistics of extremes. Preliminary results show that all the parameters of the GEV (average, variance, shape) vary simultaneously and regularly as functions of the solar heating. Moreover, with this kind of models, systematic checks of the statistical behavior in controllable numerical experiments can be performed pretty much the way this is done in Monte Carlo simulations of the type proposed, for example, in [7]. Preliminary results confirm the difficulty of assessing trends in the distribution of extremes when disposing of limited sampling as in the case of standard climatic analysis.

5. – Conclusions

Besides the obvious practical interest, statistics of extreme proposes elements of great potential relevance in our basic understanding of meteo-climatic processes. In fact, the existence of a universal distribution opens the way to many possible statistical developments. On the other hand, extremes are rare and working with a limited sample causes problems that are well known to everybody in statistics. Real progress will come from studies that simultaneously exploit the strengths and minimize the weaknesses described above. For what concerns our specific applicative problem—the statistics of meteo-climatic extremes in the Mediterranean area, it appears that the definition of such events in a dynamically meaningful way is problematic and recourse to advanced diagnostic shall be done.

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