ESF Short Visit Grant 3719
Extreme precipitation events and large scale atmospheric circulation

Dr. Andrea Toreti

1 *Purpose of the visit*

Statistical and dynamical characterization of extreme precipitation has been receiving an increasing attention by the scientific community. However, a complete and reliable characterization of these events (in terms of associated atmospheric dynamics, statistical properties, changes, etc.) has not being reached yet. Since the Mediterranean region is considered a hot-spot of climate change (Giorgi, 2006) and its exposure and vulnerability have been increasing, it is very important to achieve a good understanding of these extremes. In this context, Toreti et al. (2010) implemented a novel procedure based on a declustered Peak Over Threshold model and a 3-step classification algorithm. This procedure was applied to a set of coastal sites; besides the estimated statistical features of extreme winter precipitations, they reported anomalous atmospheric circulation patterns (in terms of geopotential height at 500 hPa, Sea Level Pressure) and relevant features of the subtropical/eddy driven jet streams during these extremes. However, the need of additional analysis was also highlighted by the authors. Furthermore, in the framework of the PREDEX (Predictability of Extreme Weather Events, http://empslocal.ex.ac.uk/people/staff/rv211/predex.html) project, Dr. Vitolo has been leading an innovative approach to extremes combining Extreme Value Theory and dynamical systems. Therefore, the main aim of the research visit of Dr. Toreti to the Exeter Climate Systems group (XCS, College of Engineering, Mathematics and Physical Sciences, University of Exeter) was to update (improving both statistical and dynamical parts) his analysis of extreme precipitations (resolving also the open issues pointed out in the aforementioned article) taking advantage of the new results obtained by Dr. Vitolo and XCS group.

2 *Description of the work carried out during the visit*

It is worth to point out that during this short visit three main aspects related to extreme precipitation were dealt with: use of dynamical systems, clustering of extremes, large scale atmospheric circulation associated with extremes.
The first days of the visit were devoted to the discussion (with Dr. Vitolo and Dr. Sterk) of dynamical systems applied to the analysis of extremes, focusing on the main research questions of the PREDEX project:

- deterministic time limits of predictability of extreme weather events;
- use of emergent dynamical patterns to enhance the predictability;
- role of spatial scale interactions in the physical processes leading to extremes.

Let $\phi\colon \mathbb{R}^n \to \mathbb{R}$ be a smooth real function describing an observable variable and $\dot{x} = f(x)$ the associated differential equation. For a trajectory $\{f^t(x), t \in \mathbb{R}\}$, extremes can be defined as points along the trajectory such that $\phi(f^t(x))$ is greater of a selected threshold (see Figure 1). The main open issue concerns the relationship between this extreme region and climate extremes, such as flooding events. Therefore, efforts should be done in the development of advanced methods to establish this link.

The clustering property of extreme precipitations was discussed together

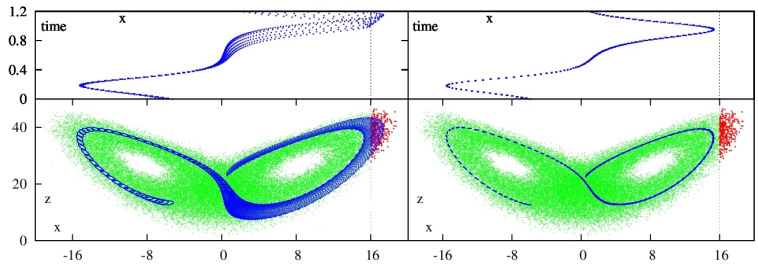

Figure 1: Definition of the extreme region (in red) for a dynamical system.

with Dr. Vitolo, Dr. Economou and Mari Jones (from the Centre for Earth Systems Engineering Research, University of Newcastle). In this context,

Vitolo et al. (2009), applying a method based on a dispersion statistic ψ (defined as the deviation from unity of the ratio of variance to mean of the counts of eastward transits of cyclone tracks across meridian segments), highlighted that wintertime extra-tropical cyclones tend to occurs in clusters, especially for intense cyclones near the exit of the North Atlantic storm track. A clustering property was also pointed out for extreme winter precipitation in Mediterranean coastal sites by Toreti et al. (2010). Therefore, focusing on a specific subset of series, some tests were performed trying to understand when the clustering property is time/spatial-stationary or not. Preliminary results seems to confirm spatial differences and also changes in the occurrence and intensity of these clusters. However, a better statistical model has been discussed and is currently under investigation.
Finally, a considerable amount of time was spent in the identification and characterization of large scale atmospheric circulation associated with extreme precipitation. Together with Dr. Vitolo and Dr. Economou, new approaches to improve the results obtained by Toreti et al. (2010) were discussed. A promising step forward (recognized during the visit) is represented by considering the state of the atmosphere as a random process. In this framework, taking advantage of the method proposed by Bellone et al. (2000), the state of the atmosphere is $\{S_t\}_{t\in T}$ (where T denotes a set of times) is a nonhomogeneous Markov process, obeying:

$$P(S_t|S_1^{t-1}, X_1^t) = P(S_t|S_{t-1}, X_t) \tag{1}$$

where S_1^{t-1} denotes $(S_1, \ldots, S_{t-1})$ and X denotes the vector of atmospheric variables (e.g. geopotential heights, vorticity, etc.). Then, daily precipitation at a single station can be modelled, for instance, by using the following mixture model (Vrac and Naveau, 2007):

$$h_\beta(r) = c(\beta)[(1 - w_{m,\tau}(r)f_{\beta_0}(r) + w_{m,\tau}(r)g_{\xi,\sigma}(r)] \tag{2}$$

where $c()$ is a normalization factor, β is the parameter vector, f is a ligth-tailed density and g is a Generalized Pareto distribution, w is the mixing function providing the transition between the two densities (Vrac and Naveau, 2007). Therefore, it can be assumed that precipitation, R_t, is related to the atmospheric state by $f_{R_t|S_t}$.

3 *Description of the main results obtained*

Since the visit was short (less than two weeks), theoretical results were achieved rather than practical results connected with a specific data analysis. Indeed, an advanced method for the characterization of precipitation

(in particular extremes) and associated large scale atmospheric circulation has been identified. The weak points (to be improved) have been recognized and the statistical setting established. Moreover, clustering property of extreme precipitation has been discussed and planned to be analyzed by applying the chosen methods.

The set of series that will be analyzed is shown in Figure 2. The northern

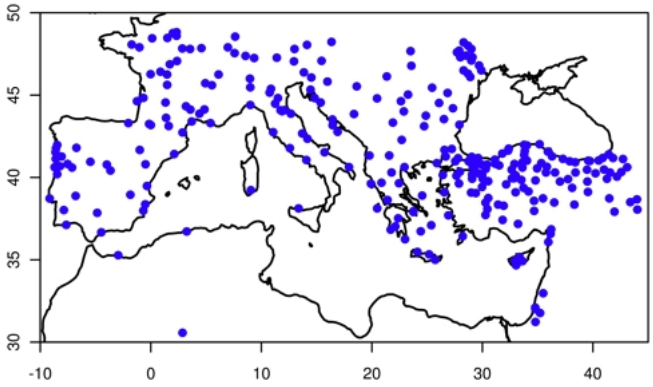

Figure 2: Map of the collected daily series in the Mediterranean area from 1950 to 2006.

part of the Mediterranean basin is well represented, whereas only few series are available over Northern Africa. A preliminary analysis, performed on a daily series of winter precipitation from a weather station in Rome (covering the period 1950-2006), is shown in Figure 3 and 4. Extreme precipitation have been characterized and return levels estimated. Figure 3 shows the precipitation field, provided by the $20th$ century reanalysis (Compo et al., 2011), before and during an observed extreme event (October 1978) with a return period greater than 5 years. The associated large scale circulation (in terms of anomalies of geopotential height at 500 hPa) is shown in Figure 4. Concerning dynamical systems, this short visit gave the invaluable opportunity to Dr. Toreti to achieve an understanding of their use in the field of extremes.

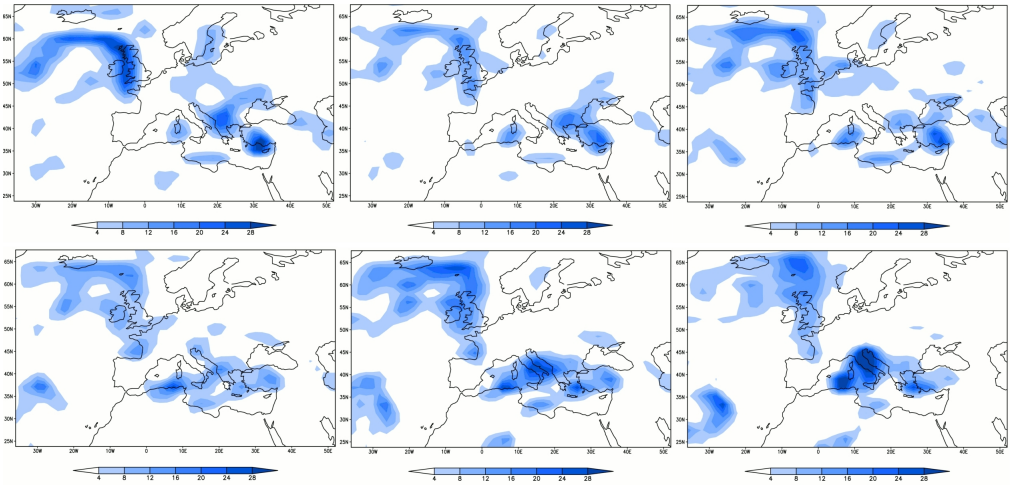

Figure 3: Precipitation field from 20*th* century reanalysis (Compo et al., 2011), 4 days before and during an extreme precipitation event observed in Rome (Italy).

4 *Future Collaboration and projected publications*

The next step of the collaboration concerns the implementation of the theoretical results obtained during the short visit, in order to be applied to a set of daily precipitation series from Mediterranean coastal sites. The complete results (methods plus application to precipitation data in the Mediterranean) are planned to be published in the Journal of Geophysical Research within this year (acknowledging the support received from ESF-MedCLIVAR). Since the topic is very interesting, both from a theoretical and practical point of view, the collaboration with the XCS group will continue.

5 *Other Comments*

It is worth to highlight that Dr. Toreti participated, during his short visit, to the activities of the XCS group, such as meetings, seminars (e.g. on health and climate) discussions with Ph.D. students, etc. In addition to the activities mentioned in the previous sections, he also had specific meeting on dynamical factors contributing to extreme precipitations with Prof. Stephenson and Prof. Ferro.

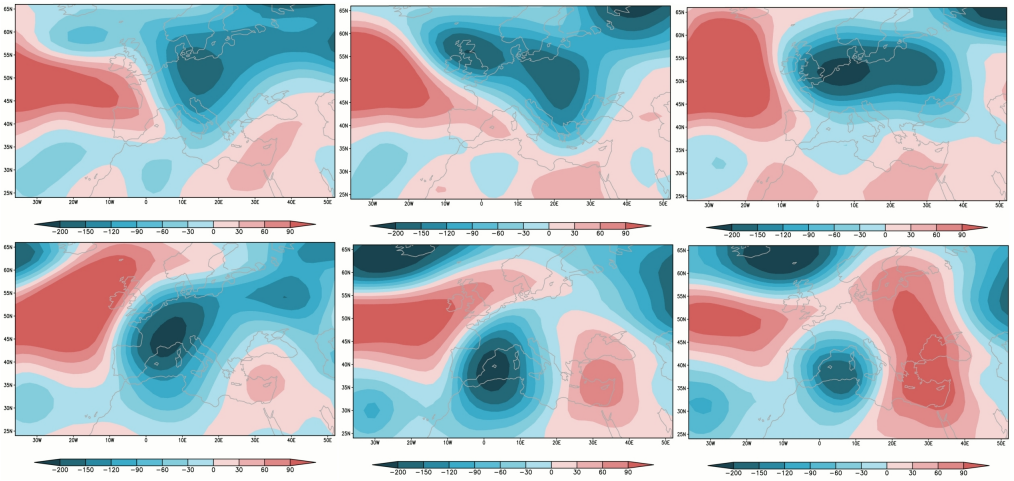

Figure 4: Anomalies of geopotential height at 500 hPa from 20*th* century reanalysis (Compo et al., 2011),4 days before and during an extreme precipitation event observed in Rome (Italy).

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