Extreme rainfall analysis based on precipitation events classification In Northern Italy

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Introduction

Extreme rainfall statistical analysis is constituted by a consolidated family of techniques that allows to study the frequency and the statistical properties of the high-intensity meteorological events. This kind of techniques is well established and comprehends standards approaches like the GEV (Generalized Extreme Value) or TCEV (Two Components Extreme Value) probability distribution fit of the data recorded in a given raingauge on a given location. Regionalization techniques, that are aimed to spatialize the analysis on medium-large regions are also well established and operationally used. In this work a novel procedure is proposed in order to statistically characterize the rainfall extremes in a given region, basing on a "event-based" approach. Given a temporal sequence of continuous rain maps, an "event" is defined as an aggregate, continuous in time and space, of cells whose rainfall height value is above a certain threshold. Basing on this definition it is possible to classify, on a given region and for a given period, a population of events and characterize them with a number of statistics, such as their total volume, maximum spatial extension, duration, average intensity, etc. Thus, the population of events so obtained constitutes the input of a novel extreme values characterization technique: given a certain spatial scale, a mobile window analysis is performed and all the events that fall in the window are analyzed from an extreme value point of view. For each window, the extreme annual events are considered: maximum total volume, maximum spatial extension, maximum intensity, maximum duration are all considered for an extreme analysis and the corresponding probability distributions are fitted. The analysis allows in this way to statistically characterize the most intense events and, at the same time, to spatialize these rain characteristics exploring their variability in space. This methodology was employed on rainfall fields obtained by interpolation of the raingauges observation in northern Italy for the period 2003-2015.

Methodology

Let $\mathbf{P}=P_{i,j,t}$ be a three-dimensional precipitation field (temporal sequence of two-dimensional maps on a regular grid), $i=1,...,N_i$, $j=1,...,N_j$, $t=1,...,N_t$, and let Dx be the horizontal dimension of the single cell and Dt the time step.

The procedure is based on the analysis of the populations of single "rainfall events" E_k, defined as aggregates of cells with rainfall height above a certain threshold P, continuous in space and time (with P possibly equal to 0).

Two cells are considered to be part of the same event if they are in contact with a face, edge or vertex, in space or in time:

$$E_k=\{P_{i,j,t}\}: \quad \forall P_{i,j,t} \in E_k \quad \exists\ P_{i',j',t'}>P,\ P_{i',j',t'} \in E_k: \quad (|i-i'|<=1 \cup |j-j'|<=1 \cup |t-t'|<=1)$$

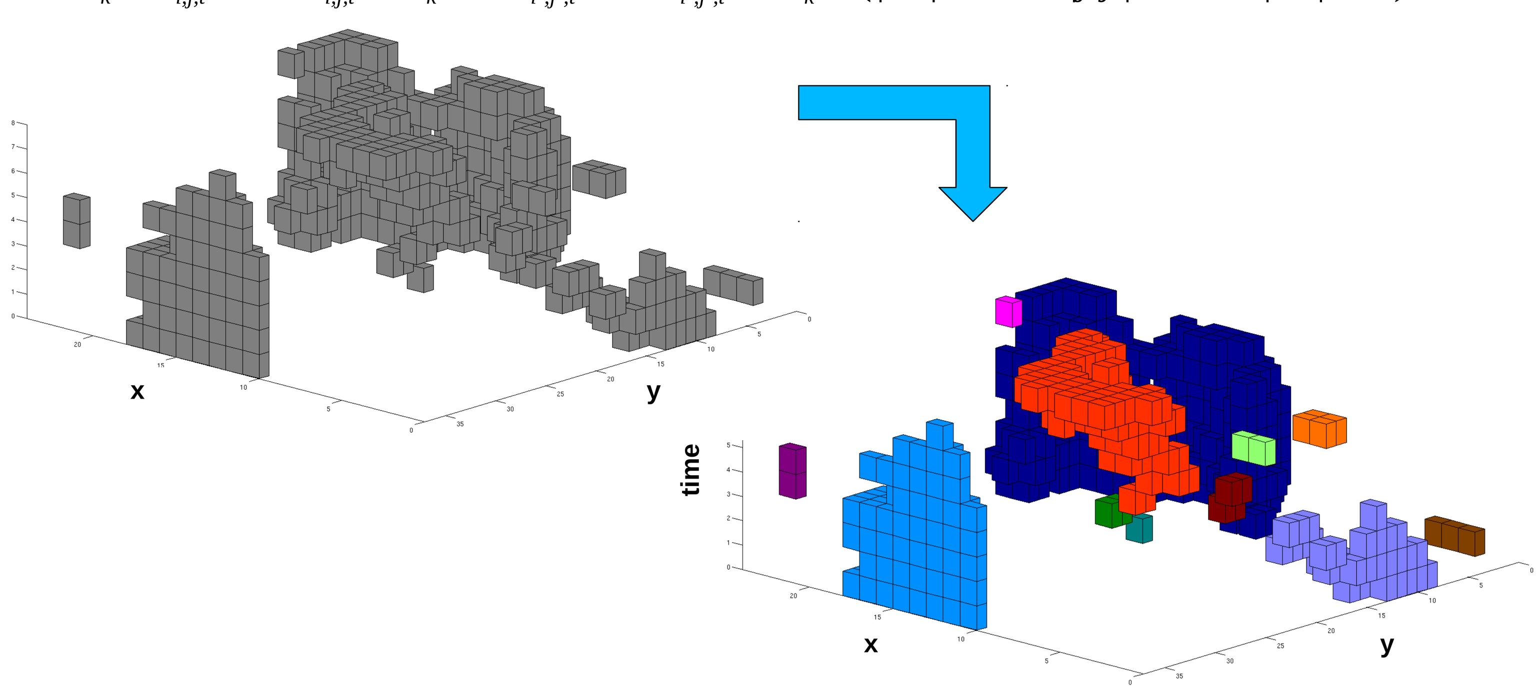

Figure 1. Definition of "rainfall events" as continuos aggregates in space-time, considering a time sequence of 2D rainfall height maps. Each color represents a different event.

Given a population of events E_k $(k=1,...,N)$ defined with the above criteria, the precipitation field is characterized in terms of statistics and probability distribution of several parameters:

$V_k=\#E_k$	*(event "volume" [-])*
$P_k=\sum_{i,j,t \in Ek} P_{i,j,t} Dx^2$	*(total rainfall volume [m^3])*
$I_k=P_k/V_k$	*(average intensity [mm/h])*
$t_{min,k}=\min_{Ek} t\ ,\ t_{max,k}=\max_{Ek} t$	*(initial and final instant [h])*
$D_k=t_{max}-t_{min}+1$	*(total duration [h])*
$B_k=(i_k,j_k,t_k)=(\sum_{i,j,t \in Ek}(i,j,k)\cdot P_{i,j,t}/\sum_{i,j,t \in Ek}P_{i,j,t})\cdot Dx$	*(center of gravity [m,m,m])*
$E_{k,t}=\{P_{i,j,t}\}\vert_{t=cost}$ $B_{k,t}=(i_k,j_k,t)=(\sum_{i,j \in Ek,t}(i,j)\cdot P_{i,j,t}/\sum_{i,j \in Ek,t}P_{i,j,t})\cdot Dx$ $T_k=\{B_{k,t}\},\ t\in[tmin,tmax]$	*(trajectory of the istantaneous center of gravity [m,m,m])*

The characterization of the extremes was performed on these indexes basing on a moving spatial window approach.
Given a spatial size of the window (50 km), all the yearly maximum events (defined on the aforementioned indexes: volume, intensity, etc,) which centers of gravity fall inside the windows are considered and used to estimate the extreme probability distributions.

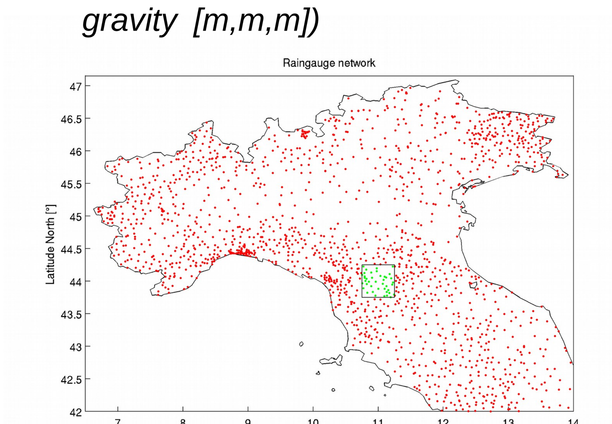

Figure 2. Raingauge network and mobile window.

Results

The above-described analysis was applied to a set of interpolated rainfall maps (from ground raingauges measures) on a domain that covers Northern Italy. The interpolation was performed with the Inverse Distance Weight (IDW) method (exponent $p=2$) on hourly basis in the period 1/1/2003 – 12/31/2015 , at a spatial resolution of 6 km.

$$V_i=\frac{\sum_{j=1}^{n}\frac{1}{d_{ij}^{\,p}}V_j}{\sum_{j=1}^{n}\frac{1}{d_{ij}^{\,p}}}$$

The maps obtained with this interpolation method were then masked assuming a threshold of null value equal to 1 mm (i.e. it is assumed that rainfall height below 1 mm is null). In this way the rainfall-no rainfall structure was maintained on the territory avoiding excessive interpolation artifacts far from the non null rainfall observations.

Figure 3. Domain of the study.

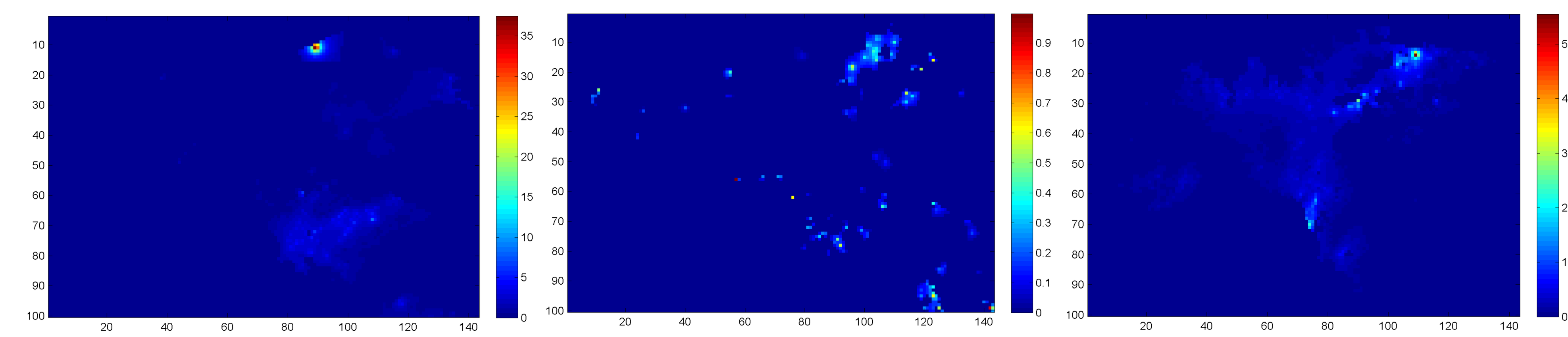

Figure 4. Examples of rainfall height intepolated maps (values in mm).

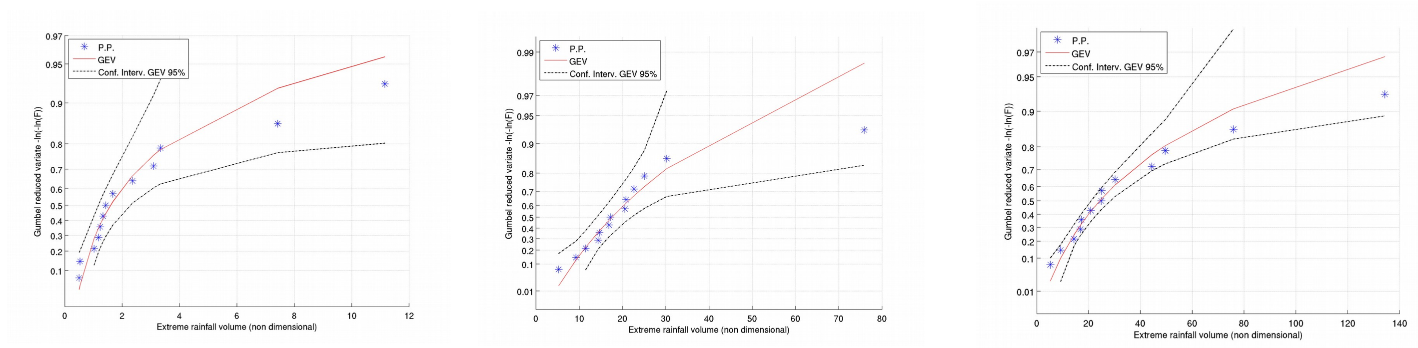

Figure 5. Examples of fit of GEV on extreme rainfall volume events in 3 different locations.

$$F(x)=\exp\left(\left[1+\left(\frac{x-\mu}{\sigma}\right)\xi\right]^{-1/\xi}\right)$$

Generalized Extreme Value (GEV) Cumulate Distribution Function

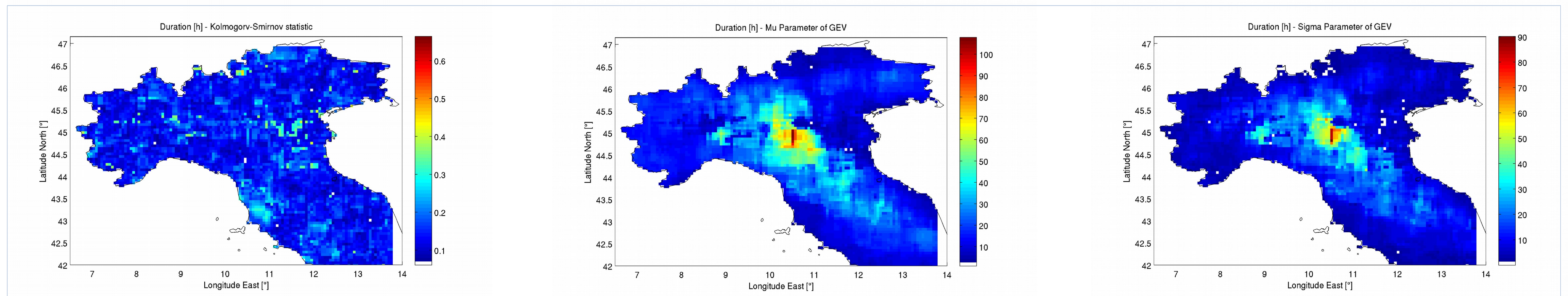

Figure 6. Spatial patterns of the 3 parameters (Csi, Sigma, Mu) of the GEV fitted for each pixel. The extreme variable considered is the duration of the events [hours].

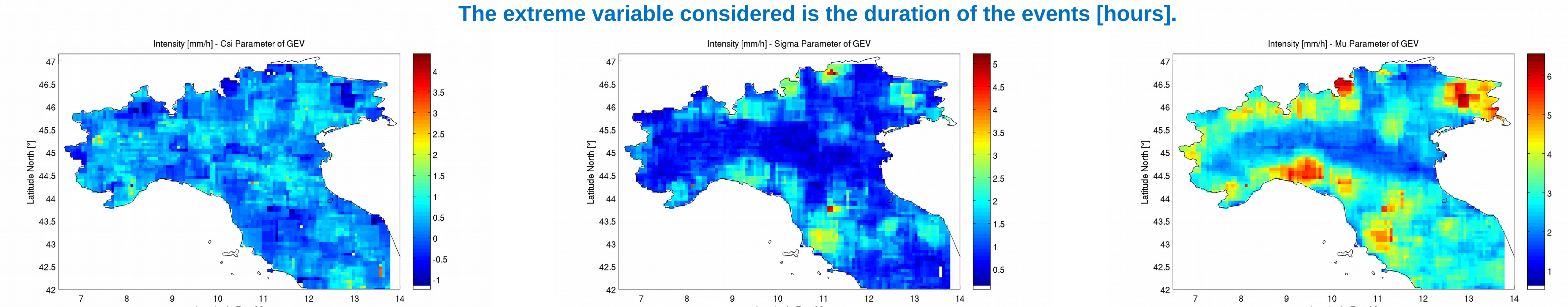

Figure 7. Spatial patterns of the 3 parameters (Csi, Sigma, Mu) of the GEV fitted for each pixel. The extreme variable considered is the average intensity of the events [mm/h].

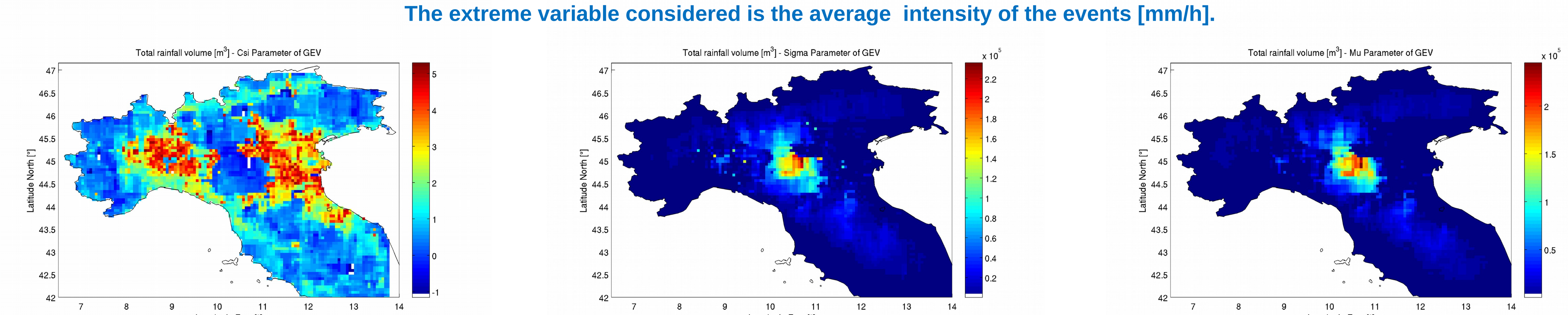

Figure 8. Spatial patterns of the 3 parameters (Csi, Sigma, Mu) of the GEV fitted for each pixel. The extreme variable considered is the total rainfall volume of the events [mm].

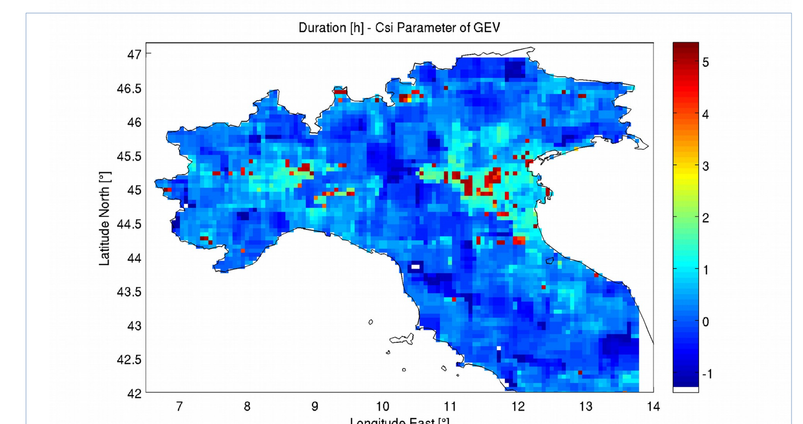

Figure 9a. Kolmogorov-Smirnov statistic of the fit for extreme durations.

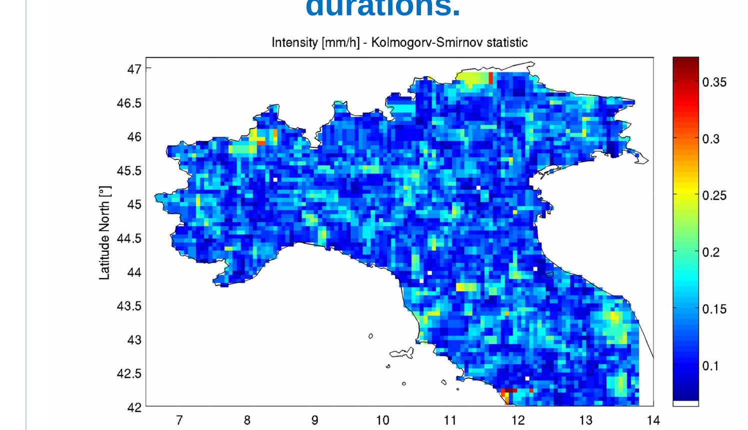

Figure 9b. Kolmogorov-Smirnov statistic of the fit for extreme intensities.

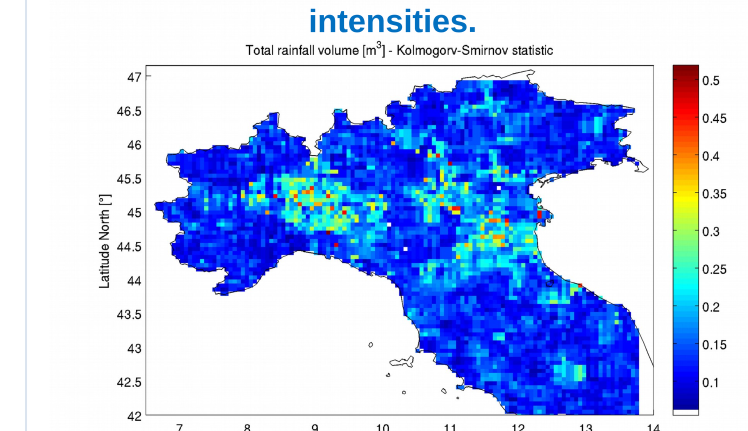

Figure 9c. Kolmogorov-Smirnov statistic of the fit for extreme rainfall volumes.