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Highlights on Extreme Meteorological Events in Sicily

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Abstract

The aim of this paper is to analyze the reasons for which the rainfall accumulations in Sicily do not follow the downward trend observed in the period from 1921 to 2002, but, mostly in the last ten years, show a substantial increase. The analysis has been performed by applying statistical methods to a wide ensemble of collected meteorological data. The observed increase of rainfall rates has been connected both to the "global warming"(according to the National Oceanic and Atmospheric Administration, the year 2015 promises globally the warmest from the beginning of the records) and to the positive thermal anomalies of Mediterranean sea which give rise to a frequency and intensity rise of severe meteorological events. From the present study it clearly emerges that, in order to forecast such severe events with sufficient advance, it is important to classify such phenomena as well as to monitor the contest environmental conditions that generate them.

Keywords: extreme meteorological events, extreme weather, rainfall, Sicily.

Introduction

In recent years a growing attention has been addressed to environmental issues due to the significant increase registered, both in the number and intensity, of extreme weather events. The attention of stakeholders on phenomena as flash floods, strong winds and heavy seas has grown also as a result of the impact on daily life caused by landslides, damage to buildings and to agriculture and, in the most tragic circumstances, to the loss of lives. It clearly emerges, therefore, how important is the prevention of these phenomena. This can be performed only through an accurate study of the physical causes which determine such events. It clearly emerges the necessity to invest resources in the field of meteorology, to implement and improve the performance of forecasting bulletins, to broaden the detection network making it as dense as possible, to boost research in the field of weather numerical modeling, and to set up a sufficient number of operation unities connected with weather civil services.

From a general point of view, heavy rainfall events in the Mediterranean can be divided into two types: floods and flash floods. Floods are due to intense and long lasting precipitations (often of several days) caused by the decrease of atmospheric circulation on a given area. Flash floods are phenomena which consist in heavy and short precipitations (e.g. 60 mm/hour), where, even in 3 - 4 hours, pluviometric accumulations that are usually detected in an entire season can be recorded [1]. On the other hand, from the specific analysis of the extreme precipitation in Sicily, it emerges that the precipitations are nearly always connected to the action of particularly intense storm cells. These systems are usually divided into single cell storms and multicell storms [2]. The single cell is characterized by the presence of a single cumulonimbus (cloud with a pronounced vertical development), that has an average life time of 15 - 20 minutes and, therefore, has a low probability of initiation of flash floods. Furthermore, in the single cell storms, it’s easy to determine the direction of motion, characterized by a displacement which follows exactly the level guides, the wind at 500-hPa level.

The mechanism that regulates the structure of a multi-cell system is quite different and more complex; in fact, the multi-cell is characterized by a regeneration process triggered by the cold downdraft (gust front) of the mature cell. This can lead to the development of a cluster of 3 - 4 cells that, therefore, would have a mean lifetime of about 60 minutes. In this case the displacement of the system does not follow the level guide but its direction is obtained from the sum between the average wind speed at 850 - 700-500 and 300 hPa and the vector opposite to the flow at 850 hPa that with the gust front will generate new cells.

By taking into account the length of the time-window that these weather perturbations can achieve, they can become cause of storms.

Among the mesoscale convective systems which can result in flash floods, one can distinguish:

- MCS (Mesoscale Convective System), in linear form if produced by cold front or circular in the case of cold drop;
- MCC (Mesoscale Convective Complex) which is a set of MCS or a MCS very wide. This system, characterized by a temperature of the convective core less than -52 °C of at least 50,000 km^2, and by a surrounding crown with temperatures lower than -32 °C for at least 100,000 km^2 [3].

However, the thunderstorm system potentially dangerous for the Mediterranean, and in particular on Sicily, is the so called "V Shaped" storm. Analyzing the causes that lead to its formation is equivalent to predict, in advance, favorable conditions to the manifestation of extreme events, such as those that occurred in eastern Sicily. For example:

- on October 1st, 2009 in Giampilieri (ME), rainfall exceeding 300 mm were recorded in a few hours;
- on November 22nd, 2011 in Castroreale (ME) we have recorded precipitation amounts of 382 mm in 4 h;
- on October 10th, 2015 in Acireale (CT) we have recorded precipitation amounts over 400 mm in 24 h;

These rainfall amounts, according to the evaluated climatological averages, are recorded in almost a year in some parts of the provinces of Agrigento and Caltanissetta [4].

The origin that give rise to the formation of very intense storms are to be linked to the presence of "deep instability" conditions that are to be found in the temperature and humidity profiles in the air column of the arrival mass and in the existing site as well as the interaction between air masses of different nature thermo-hygrometer [5]. In the analyzed cases very often at the same time were observed:

- high amount of water vapor provided by the "warm conveyor belt" (a kind of river of warm and humid air flowing in the lower level troposphere in correspondence with the warm sector, namely between the rear of a warm front and the front of the cold front which follows) estimated by ThetaE (equivalent potential temperature or pseudopotential, namely the final temperature of a particle flow rate from a reference dimension, in this case 850 hPa, the conventional 1000 hPa) values that quantify the contribution of moist air;

- extensive resources of thermal energy (latent and sensible heat supplied from the sea) for strengthening updraft (hot running upward) [6];

- diffluence of jet stream flowing between the isobaric surfaces of 500 hPa and 300 hPa or - alternatively - jet streak (jet “core”, which is the maximum speed of the jet stream) transit;

- diffluence in the high troposphere level (the rate of the change of the direction of the flow in the direction transverse to the motion); convergence lines to low level (often for the presence of a minimum baric secondary), nuclei of positive vorticity;(2ω, with ω the fluid angular velocity, it is positive in case of counterclockwise rotation (cyclonic));

- stronge vertical wind shear (evidenced by the presence of a sub-tropical jet stream at 300-hPa level ;

- strong veereing of the wind with height, with southeasterly low flow underlying southwesterly flow aloft;

- high values of Convective Available Potential Energy: CAPE

- high thermodynamic indices such as LI, K, TT, PWAT, SREH;

- orographic forcing that can generate dynamic feedback to persistent thunderstorms produced by the self-regenerating convective cell along the coast (cold air, after the precipitation, slides down the slope can generate a mini cold front (gust-front) on marine waters overlooking the mountain range, triggering a new convective activity)

- in some cases "dry intrusion", i.e. the intervention of a corridor of very dry air at the isobar of 500 hPasurface (the cold and dry air is heavier than warm and moist, therefore, if present at high altitude, is destined to sink to the ground which allows to trigger, animate, or possibly, intensify the convection)

Although a thorough analysis of these conditions can help estimate the likelihood of an extreme phenomenon and its location, it is appropriate to careful monitoring and forecasting very short-term (nowcasting through satellite and radar) after the formation of the same, in order to identify the trajectory and, therefore, the areas that will be invested, in addition to his stage of development (next attenuation or intensification, evaluated on the basis on the energy of the system) [7].

In order to evaluate the probability of the genesis of storms it has been calculated the thermodynamic index CAPE [8], which measures the energy gained from the floating air mass until, during the ascent, remains warmer environment air. In other words, the CAPE measure the work done by the buoyancy and its unit of measurement is J / kg. For example, the CAPE of 1500 J / kg implies that a package of air of 1 kg has received, during the rise, a total energy of 1500 J. Under certain conditions and in the absence of interactions with the external environment and / or turbulence, (assuming that the parcel ascends without mixing with the environment) this potential energy is converted entirely into kinetic energy, going to animate intense updrafts. It's precisely the maximum kinetic energy available to convective systems which determines the intensity of the vertical speeds of the air mass and, hence, in the case of values of relative humidity near to 100%, the precipitation.

In Sicily, more precisely in the eastern side, there is a particular risk of generation of extreme weather events. For geographical reasons, due to the wide stretch of sea located between the Libyan coast and the Sicilian, and to the presence of mountains slope rather pronounced, areas that lend themselves to the development of extreme weather events are the provinces of Messina, especially the Ionian coast, and Catania, especially the Etna sector. This occurs in the presence of a flow of current south-eastern to the ground quite extensive which allows the air mass coming in to acquire significant amounts of thermal energy, in the form of latent heat and / or sensitive from surface waters; it loads of water vapor, going to impact against the barrier orographic offered from Peloritans and, above all, from Etna, under appropriate conditions already given, it is able to generate particularly intense and insistent precipitation with self-healing temporal displacement (in the case of current south-western portion) to the coastal areas [9]. It' s clear that a lowering of return times for this type of phenomenon can influence the course and distribution of rainfall. It's expected, in fact, a growing trend of rainfall, namely a rate of rainfall higher than climatic averages.

Results and Discussion

A study conducted by SIAS (Servizio Informativo Agrometeorologico Siciliano) in 2010 showed that rainfall accumulations of the Sicilian Region, in the period from 1921 to 2001, showed a downward trend average of about 19mm / decade.

But this trend appears to be confirmed? The increasing of the extreme weather events should not lead to a significant increasing of rainfall?

In the Table 1 the values of annual precipitation observed at 107 agrometeorological stations of SIAS located throughout the region Sicily, are reported. The source data has been provided by SIAS and the meteorological parameter investigated is the "daily precipitation total - monthly total" (in mm). The row "Sicilian average" was calculated by averaging arithmetic value precipitation of the individual years of nine Sicilian provinces: Trapani (TP), Palermo (PA), Messina (ME), Caltanissetta (CL), Agrigento (AG), Catania (CT), Enna(EN), Ragusa (RG), Siracusa (SR).

Province	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Climate
AG	360,09	639,87	703,07	650,80	533,22	549,91	424,80	739,11	659,04	602,76	596,53	734,11	558,78	556
CL	335,51	626,94	477,48	648,97	516,97	457,23	445,20	694,66	614,71	583,03	503,57	605,00	483,54	468
CT	534,25	1002,29	710,00	770,62	846,18	825,65	652,20	867,85	799,30	935,25	688,32	640,88	667,85	650
EN	426,57	895,20	706,87	808,80	503,00	611,53	664,23	744,37	644,93	662,57	593,87	674,47	564,73	566
ME	836,15	1028,47	918,37	901,06	799,35	1051,66	864,81	1305,16	1028,98	959,97	729,01	885,86	901,59	843
PA	597,55	785,18	719,69	761,63	553,68	717,92	530,73	1002,72	741,65	628,21	623,80	810,60	699,71	679
RG	303,03	707,43	683,46	571,69	648,40	618,91	430,80	598,60	717,60	836,03	576,23	611,91	432,94	476
SR	272,51	813,40	677,66	711,26	742,06	727,91	475,20	625,86	661,46	927,31	633,83	542,89	503,31	575
TP	499,15	774,80	888,73	752,33	571,91	765,87	447,64	951,11	702,60	610,51	561,10	776,38	611,14	535
Sicilian Average	462,76	808,18	720,59	730,79	634,98	702,95	548,40	836,60	730,03	749,51	611,81	698,01	602,62	594,22

Table 1: Values of annual precipitation collected by agrometeorological Sias stations. NB: Red cells highlight the data below the average temperatures expected. The column " Climate " is the average value of the rainfall of the last thirty years.

The table has been realized as follows:

1. After having cataloged stations for provinces of belonging, it is calculated for each station the "sum of annual precipitation values" registered a monthly basis;

2. It has been estimated the average annual rainfall of the stations belonging to each province, resulting in the "average annual rainfall provincial" in the table.

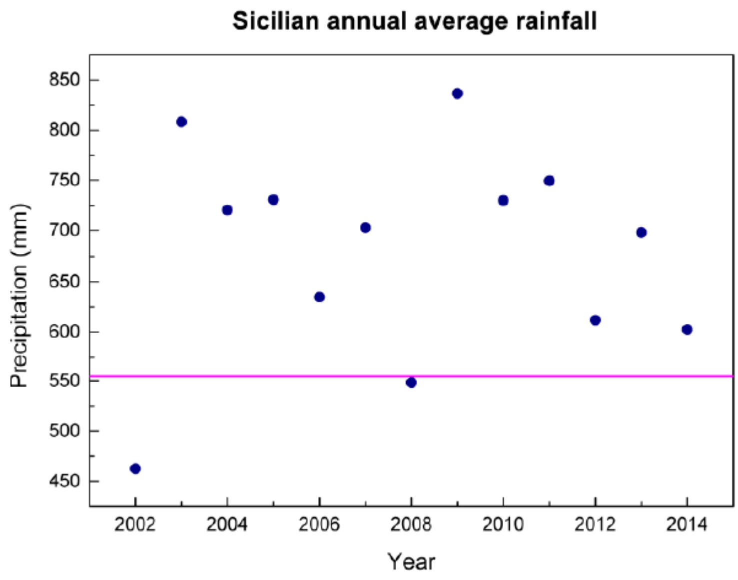

Fig. 1: Sicilian annual average rainfall obtained through provinces average. Blue dots: values of annual average precipitation in Sicily; magenta continuous line: Sicilian climate average of the last thirty years.

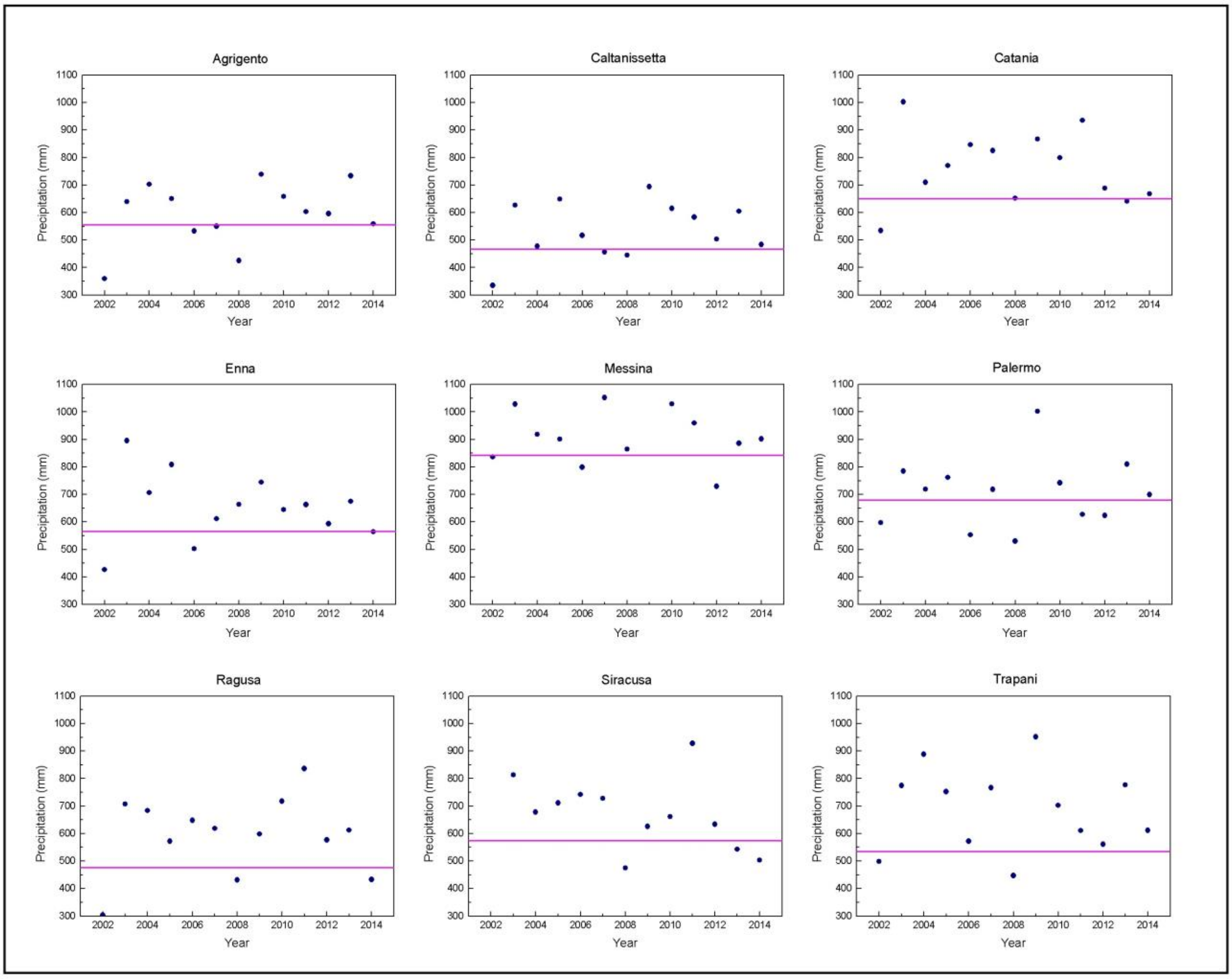

Fig. 2: Province annual average rainfall. Blue dots: values of annual average precipitation in each Sicilian province; magenta continuous line: climate average of the last thirty years of each Sicilian province.

By the analysis performed in this work, it emerges that, as shown in the Fig. 1, for the year 2002 an average Sicilian below the climatic averages has been registered; from 2003 to 2014, except the year 2008, it emerges a substantial increase in average rainfall in Sicily. In Trapani, Messina, Catania, Ragusa and Siracusa have been registered the largest increases, as reported in the Fig. 2.

The increase in global temperature and the surface of seas raises the probability of generation of extreme weather events such as heavy rainfall: this leads to the reversal of the trend of rainfall which is therefore growing [10-12].

Conclusions

As was stated above, the intensity of the convective systems can be increased by high resources of thermal energy in the lower layers.

In the last 150 years the average temperature on earth has been a gradual increase; the Global Warming has reported a sudden acceleration since 1980. Nowadays a great debate about the causes, whether natural and/or man-made, which have led to an increase in the average temperature of the Earth, of about 0.8 °C in the last thirty years, is in progress. It is clear that the two hypotheses should not be in close antithesis since the effects of the two causes may overlap. Increased concentrations of greenhouse gases, caused by the action of human activities (CO_2 in the atmosphere up to 386ppm against the value of 270 of the pre-industrial period), would have resulted in a substantial overheating. Such gas, in fact, is retained in atmosphere: soil heating by radiation shortwave, cooling for reintroduction long-wave (infrared) inhibited by the presence of gas called - precisely - "greenhouse".

Another hypothesis invoked to justify the rising temperatures in our planet, formulated by researchers of the Earth Institute at Columbia University (http://earth.columbia.edu/news/2003/story03-20-03.html) deals with a significant variation in solar activity, that has been gradually increasing in recent years.

Beyond the actual cause of Global Warming, the significant increase of the planetary temperature, has led to an increase in the resources of thermal energy available for convective phenomena, and, hence to an increase of the evaporative potential of seas and, consequently, to a rise in the frequency of extreme events.

The increasing of the global temperature and of the surface of our seas determines raises probability of generation of severe weather events such as heavy rainfall: this leads to the reversal of the trend of rainfall which is therefore growing.

This, in theory, would favor an increasing of the rainfall. The analyzed data confirm this trend: in Sicily, from 2003 to 2014, with the exception of 2008, there were accumulations rainfall higher than average weather.

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