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Extreme rainfall events in the Sinai Peninsula

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In recent times heavy rainfall resulting in flash floods affects Egypt, like in ancient times, not only in the coastal areas along the Mediterranean Sea and the Red Sea, but also in the arid and semi-arid areas such as Upper Egypt (Luxor, Aswan, and Assiut) and Sinai peninsula and their distribution has being modified by to the current climate change. These episodes, although rare, can be catastrophic in regions characterized by a very low annual total amount of precipitation, with large impacts on lives, infrastructures, properties and last but not least, to the great cultural heritage of the Country. A general overview of the Sinai current climate is presented, including a climatology of extreme rainfalls events in the last decades. In addition, few selected heavy rainfall episodes which occurred in the Sinai have been analyzed and their characteristics and links to larger scale circulation are discussed in the present paper. Results of the study provide a better understanding of the climate variability and change over Sinai, including a description of extreme rainfalls events in the recent past, which will contribute to better understand the dynamics of the extreme events, also offering the background for the next step: a detailed study of future climate scenarios in Sinai.

Data and Methodology

The climatological analysis of the current climate and its changes in the past decades has been based on the NCEP-NCAR Reanalysis provided by NOAA, and on the ERA-Interim dataset provided by the ECMWF. The study of the spatio-temporal evolution of the selected episodes of heavy rainfall is based on meteorological data from ground stations in Sinai, and on satellite images from TRMM, and HYDIS data. In addition NCEP-NCAR Reanalysis are used to highlight the atmospheric patterns during the evolution of the selected episodes in order to individuate: i) the major atmospheric patterns contributing to the evolution of the events, ii) possible driving mechanisms, iii) similarities among the events.

Climate variability and change in Sinai

The Sinai peninsula is characterized by a Mediterranean climate in the northern part of the region, while the southern part is affected by a semi-desert to desert climate. If most of the Peninsula shows hot or very hot temperature there are sub-regions, along the Mediterranean coast in the North and over the mountains, which are more temperate. Relatively lower temperatures are detected only during winter and can reach the 0°C at night on the mountains (Fig 3).

The total rainfall distribution is quite different along the Peninsula, and it decreases from the northeast towards the southwest, with a maximum in Rafah. The southern part of the Peninsula is characterized by much lower rainfall totals in coastal areas, along the Gulfs of Aqaba and Suez. Most of the precipitation is falling during the winter and then in spring and autumn, while during summer the rainfall is almost absent over Sinai (Fig 3).

The analysis performed over the period 1979 to 2015 shows a clear tendency towards decreasing total rainfall and increasing average temperatures (Fig 4 and Fig 5). The about 1°C increase in mean temperature over Sinai is even more evident in Fig 6 which shows the anomalies of air temperature at 850 hPa during the last decade, compared to the baseline period (1981-2000).

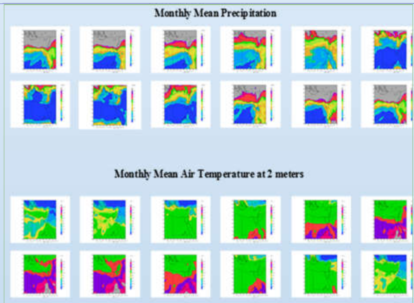

Figure 3. Climatology of the Sinai Peninsula evaluated over the period 1981-2010. Monthly mean Precipitation (in mm) and Air Temperature (in °K) at 2 meters. *(Source: ERA-Interim reanalysis)*

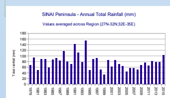

Figure 4. Annual Total Precipitation over the Sinai Peninsula *(Source: ERA-Interim reanalysis)*

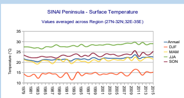

Figure 5. Annual and Seasonal Mean Air Temperature at 2m over the Sinai Peninsula *(Source: ERA-Interim reanalysis)*

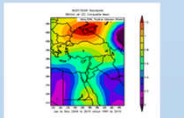

Figure 6. Mean air Temperature at 850hPa: anomaly over the period 2006-2015 relative to the base period 1981-2010 *(Source: NCEP-NCAR reanalysis)*

Major storms affected Egypt in the past

Heavy but sporadic rainstorms in the desert are usually of the thunderstorm type and are apt to cause large floods in the otherwise dry wadis, and these floods may be experienced many miles from the scene of the actual storm.
Moreover since the thunderstorms occur more commonly in the evening than at any other time of day, it is at night that the floods are most frequent and for these reasons they are a great danger to people and flocks which happen to be in their path at the time. On many occasions when rain has fallen over a large area and in a few minutes has transformed a dry wadi into a raging torrent, men and flocks have been drowned in the sudden onrush of water.

Source: Sutton (1950) The Climate of Egypt. Weather, 59-63

In ancient Egypt, people liked the flood along the Nile River because it brought rich soil for farming.
Flash flood is an event that occurs **WITHIN few hours** following the end of the causative event which result in fatalities, injuries, and/or significant damage to property.
Flash flooding events **develop rapidly** and can occur anywhere water collects, especially areas of steep terrain, and water runoffs. Flash floods rarely last more than 12 hours.

Major storms which affected Egypt in recent years

2016

According to WMO figures, 51 mm of rain fell in 24 hours between 27 and 28 October 2016 in Hurghada, capital of Red Sea Governorate.

Major storms which affected Sinai

The number of events since year 2000 is quite remarkable.
They usually are very short but intense episodes.

In recent decades Sinai has been affected by measurable changes in the climate with drier and hottest conditions relative to the baseline period (Fig 4, 5, and 6), and with more intense storms with associated short, but intense rainfall.
This trend caused severe and long dry periods suddenly interrupted by high and rainfall difficult to forecast specially because of their large variability in space and time.
If this tendency continues, the impacts on the natural environment and resources, including renewable water, as well on population, infrastructures and properties can be severe. A list of major recent storms which affected Sinai is presented in the following table showing how the number of events since year 2000 is quite remarkable.
They usually are very short but intense episodes.

Flash Floods Records – South Sinai

Ras Sedr	Ras Sedr (ELMELHA)	Saint Katherin	Newaiba
02/03/1997	07/12/2000	22/03/1991	17/01/2010
07/02/1999	04/12/2001	17/10/1993	27/01/2013
07/12/2000	06/01/2003	20/10/1993	09/03/2014
10/01/2002	14/12/2003	31/01/1994	09/05/2014
16/12/2003	22/01/2004	18/01/2010	12/09/2015
14/01/2004	05/02/2004	09/01/2013	29/10/2015
04/02/2004	04/04/2011	25/01/2013	
18/01/2010	31/12/2013	27/01/2013	
25/02/2010	09/03/2014	09/03/2014	
09/01/2013		09/05/2014	
01/02/2013		12/09/2015	
09/03/2014		29/10/2015	
07/09/14			

Flash Floods Records – North Sinai

Gedirat	Maghara
22/03/1991	27/10/2005
05/01/2001	21/11/2007
29/01/2004	18/01/2010
17/04/2006	09/01/2013
19/12/2009	09/05/2014
17/01/2010	29/10/2015
09/03/2014	
09/05/2014	
29/10/2015	
29/10/15	

A case study: March 2014

The 2014 event lasted over Egypt three days: 7-9 March, and affected all Sinai with a maximum daily rainfall 30mm measured at Dahab station.
Table 3 summarizes the total amount of precipitation occurred in the Upper Egypt, Red Sea and Sinai peninsula during the storm (7-9 March 2014), while on the 10th it moved rapidly towards East.
The evolution of the 2014 storm as captured by TRMM satellite images is shown in Fig 7, where it is clear how the storm, which started to form in the Upper Egypt on 07-03, then rapidly moved toward North-East, strongly affecting the Sinai peninsula in the next days (8-9 March).

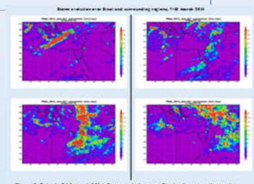

Figure 7. Episode 7-10 march 2014. Storm evolution over Sinai and surrounding region. *(Source: TRMM satellite data)*

Table 3. Amount of precipitation observed in the Upper Egypt, Red Sea and Sinai peninsula - 7-9 March 2014

	Station	Precipitation mm
Upper Egypt	ASSWAN	29
	LUXOR	29
	ASYAT	9
Red Sea	HURGADA	21
Sinai	SHARM EL-SHEIKH	27
	DAHAB	30
	SAINT CATHRENE	29
	EL TOR	17
	NUWAIBAA	8
	NEKHEL	5

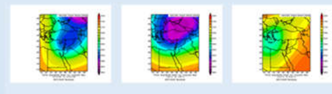

Figure 8. Geopotential height at 700hPa for the three selected episodes 27th December 2006, 8th January 2013, 9th March 2014. *(Source: NCEP-NCAR reanalysis)*

Discussion

Results of the analysis of the large scale configuration during extreme episodes show some similarities, with heavy rainfall usually resulting from mesoscale convective systems embedded in synoptic-scale disturbances interacting with the complex terrain of the Peninsula. The evolution of the storm is similar in most of the cases (as an example, Fig 8 show the spatial distribution of the geopotential at 700 hPa during three different episodes), and a correlation is also noticed with the atmospheric circulation over the Arabic Peninsula and with low pressure systems over the Eastern Mediterranean. In addition, the distribution of the rainfall between the Northern and Southern parts of the Peninsula is strongly dependent on the complexity of the terrain and by the mountain ranges of the peninsula.
The mechanism leading to such storms with torrential rainfall, thunders, lightning has been studied by some Authors which emphasize the very limited spatial and temporal extent of the phenomena. Although this part of the study is not yet fully completed, some general remarks can be delineated here.
Climatically the whole Levant is under the influence of the westerly winds, and the weather is usually determined by the presence of a Red Sea Through (RST) generated and supported by a thermal forcing and by the presence of the local complex topography, and it usually brings dry and hot conditions.
The size of storms travelling in the eastern Mediterranean basin is of the order of few km, with a life time of few days. Many storms in the East Mediterranean originate in the region around Cyprus and travel eastwards, without hitting Egypt. However, given favorable conditions in the Red Sea, the storms can be diverted southeastwards, reach Egypt, and, given their life time, they can hit North and Central Egypt. These storms are usually associated to the presence of an Active Red Sea Trough which is a RST accompanied by upper trough, bringing severe weather, heavy precipitation and flash.
In a very simplified scheme, several factors can contribute to transform an RST in an Active Read Sea, and these factors enhances the tropospheric instability driving the storms. At the beginning, the systems are very similar to Mesoscale Convective Systems (MCS), with rainfall particularly intense during the first stage when the convection was dominant. After the first stage, the intensity of rain, as well the role of convection, diminishes considerably while the storms keep moving east.

Conclusions

Results of the first phase of ASRT-CNR, an Egypt-Italy joint project have been discussed and main results highlighted.
Climatological data analysis show unequivocal climate change signals in the Sinai Peninsula, and, at larger extent, over Egypt and the Eastern Mediterranean:

- Temperature has increased over the last decades
- Precipitation has decreased
- Heavy rainfall episodes increased in number and intensity

The presented results are a step forward for the evaluation of the impacts of current and future climate on the sequence and severity of flash floods, which will be the subject of the next phase of the project.
A further deeper analysis of extreme rainfall episodes will help to better understand the driving mechanisms, the generation and evolution of these short-lived and patchy storms and their future evolution under future climate change scenarios.
The overall results of the project will also:

- give some indication for an improvement of the weather forecast systems in the Region;
- provide some basic information for future water harvesting in the Region;
- help decision makers to decide between future protection works and/or water harvesting structures.

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