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Present and Future Climate Extreme Indices over Sinai Peninsula, Egypt

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Abstract**—**Sinai Peninsula and Suez Canal Corridor are promising and important economic regions in Egypt due to the unique location and development opportunities. Thus, the climate change impacts should be assessed over the mentioned area. Accordingly, this paper aims to assess the climate extreme indices in through the last 35 year over Sinai Peninsula and Suez Canal Corridor in addition to predict the climate extreme indices up to 2100. Present and future climate indices were analyzed with using different RCP scenarios 4.5 and 8.5 from 2010 until 2100 for Sinai Peninsula and Suez Canal Corridor. Furthermore, both CanESM and HadGEM2 global circulation models were used. The results indicate that the number of summer days is predicted to increase, on the other hand the frost days is predicted to decrease. Moreover, it is noted a slight positive trend for the percentile of wet and extremely days R95p and R99p for RCP4.5 and negative trend for RCP8.5.

Keywords**—**Climate change, extreme indices, RCP, Sinai Peninsula.

I. Introduction

SINAI Peninsula and Suez Canal Corridor will be one of the economically promising areas in Egypt due to the high availability of many natural resources, arable land and unique tourism facilities. It is therefore not surprising that the state is interested by Sinai development economically, socially and had to be attention to protecting the environment and taking into account the environmental dimension in order to preserve the integrity of the land and its inhabitants. Moreover, the Egyptian government announced of launching the Suez Canal Corridor Development Project. This project is one of the most important projects related to national security, which will contribute to solving the crises Egypt is now facing, in addition to its role in the urban and geographical re-distribution of the population through integrated urban projects aimed at reclamation and cultivation of 4 million acres.

Human-induced climate change and changes in climatic variability continue to be major global change issues not only for the present generation but also for future generations. Based on the scientific assessment of the Earth's climate system, [1] has revealed that average global surface temperature has increased by about 0.6 ± 0.2 ºC since the late 19th century. The Northern Hemisphere experienced cooling during the period from 1946 to 1975, while the Southern Hemisphere showed warming. They pointed out that the recent 1976–2000 warming was largely globally synchronous, but it was more pronounced in the Northern Hemisphere continents during winter and spring. One aspect of climate change is change in variability of weather phenomena, such as temperature and rainfall.

Climate change and related impacts may affect the development resources of Sinai Peninsula and Suez Canal Corridor, thus, the current research was initiated with the objective of assessing the climate extreme events in through the last 35 year over Sinai Peninsula and Suez Canal Corridor in addition to predict the climate extreme events up to 2100 using global climate modeling.

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II. Study Area

Sinai Peninsula is a triangular peninsula linking Africa with Asia, and occupying an area of (61,000 square km). The Sinai Desert is separated by the Gulf of Suez and the Suez Canal from the Eastern Desert of Egypt, but it continues eastward into the Negev desert. The Sinai is administratively divided into two governorates: North Sinai in the north and South Sinai in the south, [2]. Suez Canal Corridor includes Suez Canal and 3 Egyptian governorates, which are Suez, Ismailia and Port Said.

III. Data and Methodology

A. Data Source

Daily ERA-Interim reanalysis dataset from 1979 to 2014 was run by RClimDex software used to calculate climate extreme indices for eleven stations selected over Sinai Peninsula and Suez Canal Corridor (Fig. 1). To develop a full picture overall the region, average trend of climate extreme indices were calculated, relative to the period 1980-2010. Additionally, data quality was controlled and their homogeneity was tested before the index calculation. RClimDex software and users guide are available from [3].

B. Climate Extreme Indices

Extreme climate events should be closely monitored and analyzed since they can have overwhelming impact on our society and environment. Changes in temperature and precipitation extremes have been assessed for many parts of the world during the past century [4]. A main objective of constructing climate extremes indices is to use for climate change monitoring, assessment and determining the impacts of climate change on the different sectors.

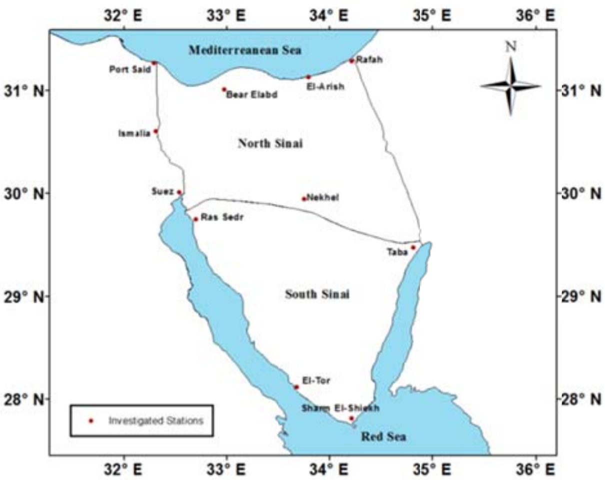

Fig. 1 Investigated stations in Sinai Peninsula and Suez Canal Corridor

Climate extreme indices over 11 stations distributed over Sinai Peninsula and Suez Canal Corridor were calculated by RClimDex program. It was developed and maintained by Zhang and Yang, 2004, [5] at the Climate Research Branch of Meteorological Service of Canada. Its initial development was funded by the Canadian International Development Agency through the Canada China Climate Change Cooperation (C5) Project.

RClimDex (1.0) was designed to provide a user friendly interface to compute indices of climate extremes. It computes all 27 core indices recommended by the CCl/CLIVAR Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI) as well as some other temperature and precipitation indices with user defined thresholds. These core indices include almost all the indices calculated by RClimDex (Version 1.3).

Climate indices can be defined as a calculated value that can be used to describe the state and the changes in the climate system. Climate indices allow a statistical study of variations of the dependent climatological aspects, such as analysis and comparisons of times series, means, extremes and trends. Total of 27 indices were considered to be core indices. They are based on daily temperature values or daily precipitation amount. Table I contains the climate extreme indices which calculated for selected eleven stations over North Sinai, South Sinai and Suez Canal Corridor.

C. Future Climate Scenarios and Climate Extreme Indices

According to the development plan of Sinai and Suez Canal Corridor, future climate extreme indices were analyzed. In this regards, output data of two RCP scenario's (RCP4.5 and RCP8.5) for two global models (CanESM model and HadGEM2 model) were used for the period (2010– 2100) to study the future trend of the climate extreme indices.

Representative Concentration Pathways (RCPs) are new scenarios developed by The Intergovernmental Panel on Climate Change (IPCC) in Fifth Assessment Report (AR5). There are four pathways: RCP8.5, RCP6, RCP4.5 and RCP2.6, [6]. The term pathway is meant to emphasize that it is not only a specific long-term concentration or radiative forcing outcome, such as a stabilization level that is of interest but also the trajectory that is taken over time to reach that outcome. They are representative in that they are one of several different scenarios that have similar radiative forcing and emissions characteristics [7]. In this paper, two scenarios were used (RCP4.5 and RCP8.5).

TABLE I
CALCULATED CLIMATE EXTREME INDICES FOR THE STUDY AREA

	ID	Indicator name	Definitions	Unit
Temperature	SU25	Summer days	Annual count when TX(daily maximum)>25ºC	Days
	TR20	Tropical nights	Annual count when TN(daily minimum)>20ºC	Days
	TXx	Max Tmax	Monthly maximum value of daily maximum temperature	ºC
	TNx	Max Tmin	Monthly maximum value of daily minimum temperature	ºC
	TXn	Min Tmax	Monthly minimum value of daily maximum temperature	ºC
	TNn	Min Tmin Monthly	minimum value of daily minimum temperature	ºC
Precipitation	RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
	RX5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
	PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR>=1mm)	mm

RCP 4.5 is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshooting the long-run radiative forcing target level [8]–[10]. RCP 8.5 is characterized by increasing greenhouse gas emissions over time, representative of scenarios in the literature that lead to high greenhouse gas concentration levels [11].

The purpose of this section is to document changes in indices that are calculated in a very consistent manner as simulated within the Coupled Model Intercomparison Project Phase 5 (CMIP5) multimodel ensembles for various emission situations. As referenced [12], the radiative forcing prescribed within the RCP situations is result in totally different average temperature responses, and expect that this can even be evident in seasonal and annual temperature and precipitation extremes. Through the study, associate ETCCDI indices for the CMIP5 ensembles were created and were obtainable from Canadian Centre for Climate Modelling and Analysis, [13]. The challenges concerned in such associate analysis, given the temporal and spatial resolution of GCMs further because the convenience of appropriate empirical knowledge sets also was mentioned. Moreover, Climate simulations of the 21st century performed by models participating in CMIP5 were analyzed. The CMIP5 model output is available from the data archives of the Program for Climate Model Diagnosis and Inter-comparison [14] and the Earth System Grid data distribution portal [15]. Two CMIP5 models, CanESM model and HadGEM2, were analyzed for output of two RCP scenarios (RCP4.5 and 8.5). The spatial resolution of both used models (CanESM model and HadGEM2) are 128 × 64L35(T63) and 192 × 145L40, respectively.

IV. Result and Discussion

A. Historical Climate Extreme Indices

TABLES II-IV list the obtained results for the rates of change (%) of climate extreme indices calculated for North Sinai, South Sinai and Suez Canal Corridor for the period 1979 to 2014. The highlighted cells in the tables by yellow are the statistical significant results at 95 % level.

TABLE II
Rate of Change (%) of Climate Extreme Indices for North Sinai

Station	El-Arish	Bear El-Abd	Nekhel	Rafah
SU25	0.81	0.8	0.68	0.73
TR20	1.17	1.14	1.96	1.31
TXx	0.05	0.06	0.01	0.04
TNx	0.07	0.08	0.05	0.05
TXn	0.01	0.02	0.05	0.02
TNn	0.001	0.02	0.04	0.02
RX1day	-0.04	-0.01	-0.04	-0.05
Rx5day	-0.034	-0.013	-0.05	-0.04
PRCPTOT	-0.15	-0.04	-0.06	-0.17

TABLE III
Rate of Change (%) of Climate Extreme Indices for South Sinai

Station	Taba	El-Tor	Sharm El-Shiekh	Ras Sedr
SU25	0.55	0.6	0.89	0.68
TR20	1.7	0.6	0.6	1.37
TXx	0.04	0.05	0.06	0.01
TNx	0.06	0.06	0.07	0.08
TXn	0.05	0.05	0.03	0.04
TNn	0.03	0.04	0.02	0.06
RX1day	-0.06	-0.02	-0.04	-0.02
Rx5day	-0.07	-0.02	-0.04	-0.03
PRCPTOT	-0.1	-0.02	-0.04	-0.04

TABLE IV
Rate of Change (%) of Climate Extreme Indices for Suez Canal Corridor

Station	Suez	Port Said	Ismailia
SU25	0.61	1.1	0.38
TR20	1.2	0.67	0.97
TXx	0.02	0.05	-0.003
TNx	0.07	0.06	0.03
TXn	0.01	0.01	0.01
TNn	0.04	-0.03	0.06
RX1day	-0.004	-0.003	-0.01
Rx5day	-0.01	-0.02	-0.02
PRCPTOT	-0.02	-0.07	-0.02

From Tables II-IV, a statistical significant increase at 95 % level in No. of summer days over all stations was observed for all stations. For Port Said, it has a trend value of 1.1 as a highest value of increasing in No. of summer days. It means that there is an increase by 1.1 % of warm days every year. All stations record an increasing in No. of summer days which it ranges between 1.1 to 0.38 % per year. In addition, the results state that all of stations show a statistical significant increase in the No. of tropical nights (TR20) except El-Tor and Suez stations. The highest value of TR20 trend is found in Nekhel (1.96%) flowed by Taba (1.7%), on the contrary the lowest value of the trend found is found in Sharm El-Shiekh is (0.6%) per year.

The results refer that the change in monthly maximum value of daily maximum temperature (TXx) is small and significant only in stations Bear El-Abd (0.06%), Taba (0.04%), El-Tor (0.05%) and Sharm EL-Shiekh (0.06%). Furthermore, the change in monthly minimum value of daily maximum temperature (TXn) is limited for all investigated stations.

The tables list that all stations, expect Nekhel and Ismailia, have positive significant trend for Monthly maximum value of daily minimum temperature (TNx). It is noted that the results of TXx and TNx (warm temperature indices) show a positive trend which follow the increase of the number of summer days and tropical nights over the study area. Only a significant slight increase is observed in five stations (Nekhel, El-Tor, Ras Sedr, Suez and Ismailia) for TNn.

B. Future temperature indices

Summer days (SU), frost days (FD) and tropical nights (TR) count the days when maximum temperature (TX) is above 25°C and minimum temperature (TN) is below 0°C or above 20°C, respectively. These indices are often useful for climate impact studies. Changes in frost days, for instance, can be relevant for agricultural practice and engineering applications [16]. Tropical nights usually occur in combination with extended periods of heat (particularly in extra-tropical regions) and have been suggested to be problematic for human health [17].

The thresholds are obtained from a 5 day window centered on each calendar day over the reference period 1961-1990. The results (Fig. 2) are referenced to a significant increase by a hot day every year until the end of the century for the used RCP scenarios. The increase in tropical nights (TR) is more noted than summer day (SU) by about 1.5 days per year in RCP8.5 and by one day per year in RCP4.5. For frost days (FD), it has negative trends for used RCP scenarios for Sinai Peninsula and Suez Canal Corridor. The number of FD is predicted to be zero at the last quartile of the century and only CanESM RCP4.5 has a pronounced variation. It is appear that HadGEM2 model RCP4.5 has a positive increase of number of frost day reach to 5 days at the end of the century.

Projected changes in the percentile indices are shown in absolute terms, and not as differences relative to the reference period as for the other temperature indices. Generally, the percentile indices represent exceedance rates relative to the 1961–1990 base period. There is a consistent decrease in cold nights (TN10) and cold days (TX10) from 2010 to 2100 in all RCP scenarios (Fig. 3). In RCP4.5, TN10 decreases from about 3.5°C in 2010 to about 0.5°C by the end of the 21st century for CanESM model and decrease by about 5°C to

1.2°C for HadGEM2 model.

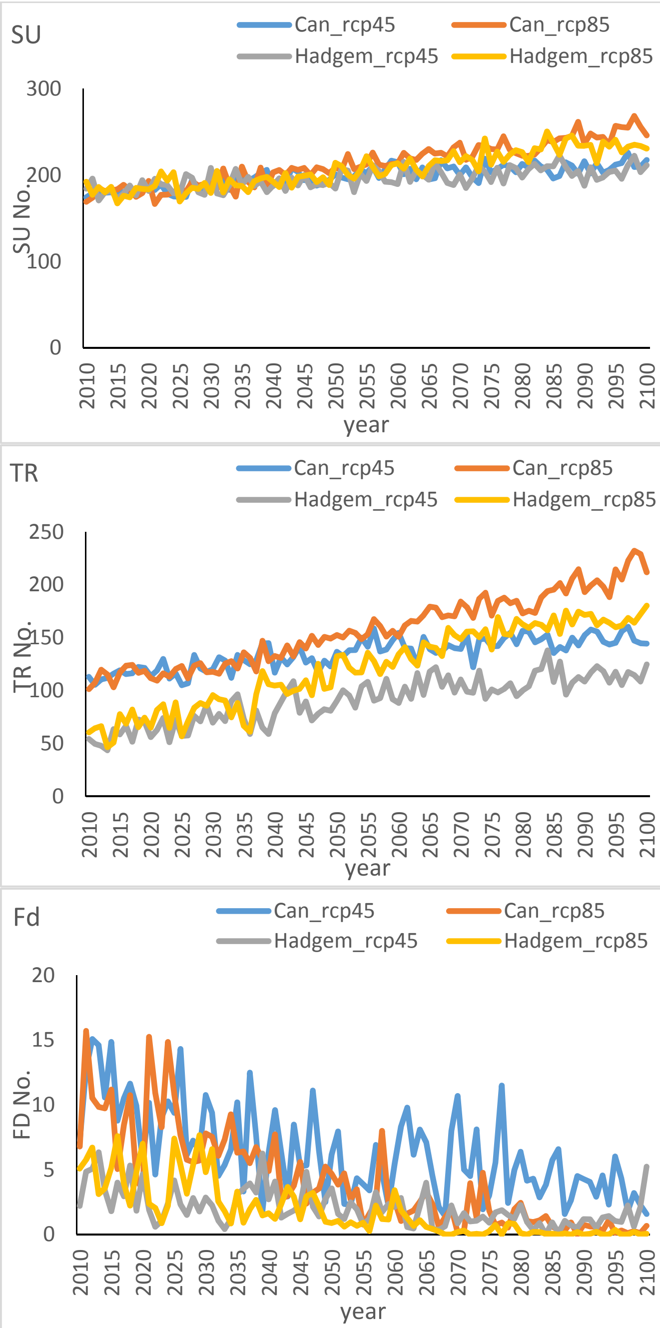

Fig. 2 Summer days, tropical nights and frost days for Sinai Peninsula

Time series of TN10 from 2010 to 2050 has a clear variation with different RCP scenarios and for each model. Highest values of TN10 appear in HadGEM2 RCP8.5 at years 2016, 2020, 2025, 2035 and 2047, then the value of TN10 reach to zero from 2060 until 2100. Although these previous years are the highest value of TN10 for HadGEM2 RCP8.5, years 2012, 2015 and 2024 give the highest values of TN10 for CanESM RCP8.5.

RCP4.5 for CanESM and HadGEM2 has the same variation of TN10 except for 2028 which TN10 is 0.34 for CanESM and 1.5 for HadGEM2; furthermore TN10 for year 2034 is 0.03 and 0.8 for CanESM and HadGEM2 respectively. For cold days percentile (TX10), it has high variation for RCP4.5 for both models, Fig. 3. For example for year 2016, TX10 is 1.02 for CanESM and it is 4.2 for HadGEM2, also at 2039; TX10 is 0.51 for CanESM and 2.5 for HadGEM2. At near future, a clear difference is found in RCP8.5 which TX10 is 1.3 for CanESM and 4.7 for HadGEM2 at 2016 year.

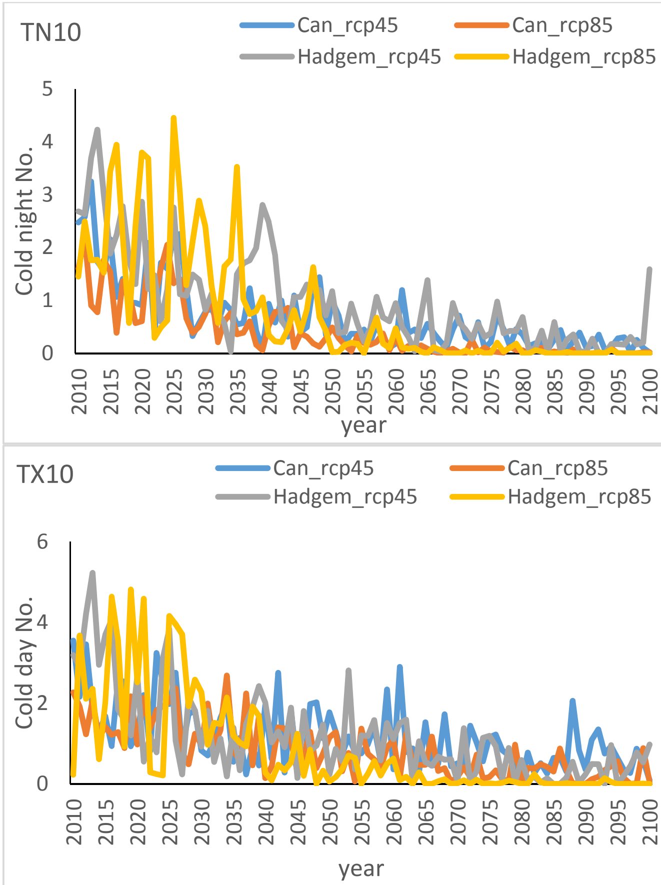

Fig. 3 Cold nights (TN10) and clod days (TX10) for Sinai Peninsula

Warm nights and days (TN90 and TX90, respectively) show a general increase in the exceedance rate toward the end of the 21st century (Fig. 4). The increase is pronounced for TN90p than for TX90p. Significant positive trend is noted in the used RCPs and in HadGEM2 model than CanESM model for Sinai Peninsula and Suez Canal Corridor.

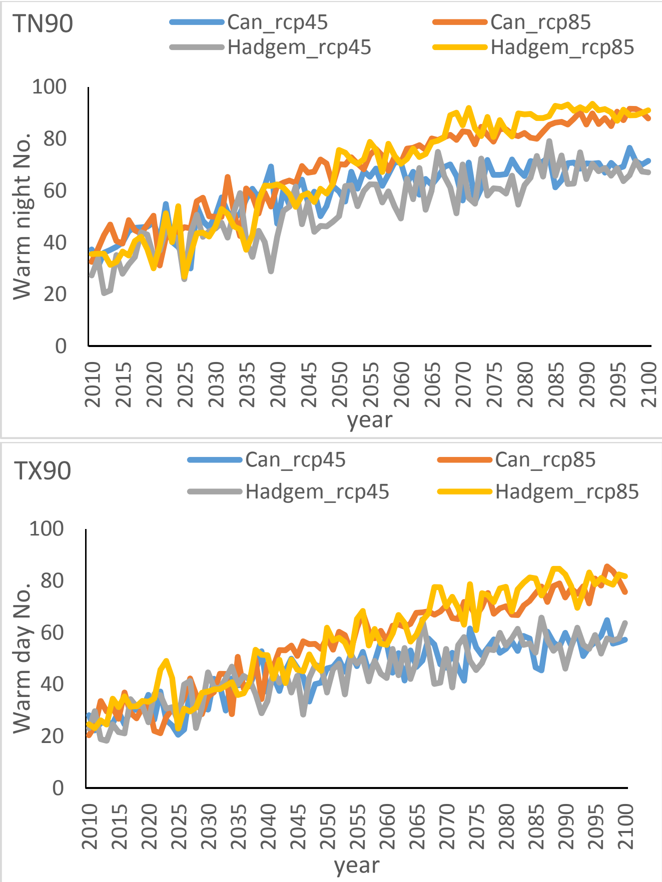

Fig. 4 Warm nights (TN90) and warm days (TX90) for Sinai Peninsula

C. Future Precipitation Indices

Very wet days (R95p) describe the annual precipitation amount (in mm) accumulated on days when daily precipitation is greater than the 95th percentile threshold of the wet day precipitation (PR > 1 mm) distribution derived from the base period (1961-1990). Moreover, R99p is the extremely wet day rainfall which is the total rainfall when daily rainfall rate is greater than the 99th percentile of the base period. RCP4.5 for both models has a positive trend of R95p with about 0.1 mm/year, on the contrary a negative trend is shown for RCP8.5 of CanESM and HadGEM2 models for Sinai Peninsula and Suez Canal Corridor. Furthermore, R99p show a slightly positive trend for both CanESM RCPs and HadGEM2 RCP4.5 while a negative trend appear in HadGEM2 RCP8.5 only. Both the 95th percentile rainfall (R95p) and the 99th percentile rainfall (R99p) show more intense rainfall for shorter time period in the future, Fig. 5.

V. Summary and Concluding Remarks

This paper presents the trends of daily and extreme temperature and precipitation indices for the Sinai Peninsula and Suez Canal Corridor from 1979 to 2014. Data was carefully examined for quality and homogeneity by RClimDex program and a consistent methodology was applied for the preparation and investigation of the temperature and precipitation indices. This study provides an analysis of the climate trends and extremes using many long-term land stations of the region.

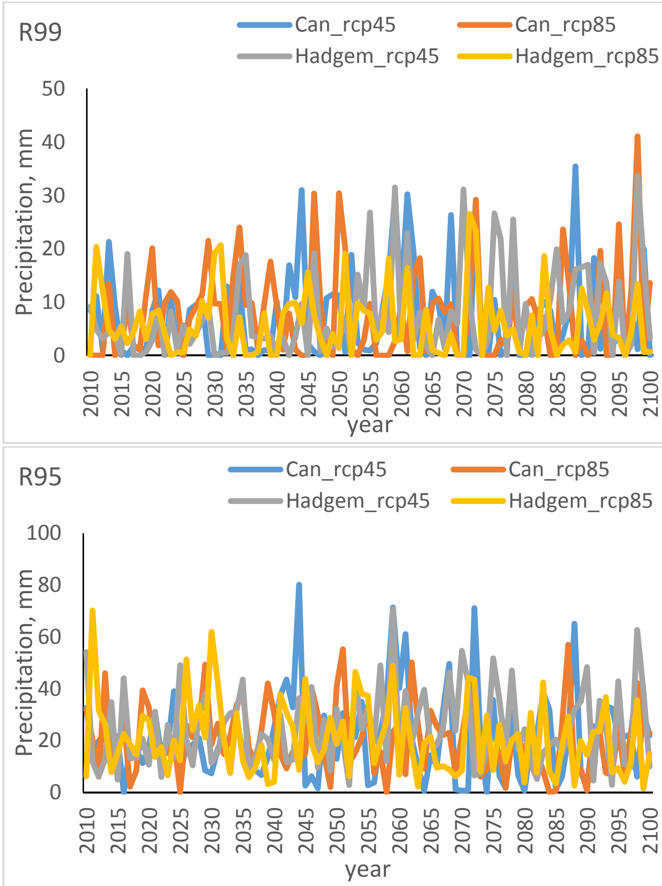

Fig. 5 Precipitation percentile R95 and R99 for Sinai Peninsula

The results show warming of the surface air temperature at the investigated area. The annual mean of daily maximum and minimum temperature (TXMean and TNMean) have increased for the past 36 years, leading to no discernable change in the diurnal temperature range. In addition, summer days and tropical nights have become more frequent. Overall, warm extremes have changed more than cold extremes and this remark was also recorded in the highest and lowest temperatures of the year.

Precipitation indices show less evidence of coherent changes. Regionally, only the annual total precipitation (PRCPTOT) has indicated a significant change, with a decrease of 0.15% per decade through 1979 – 2014. It was observed an indication of more consecutive dry days (CDD), especially in Taba, and a small change in consecutive wet days (CWD). Although no significant change was detected regionally for the extremes, many days above 10 and 20 mm (R10mm, R20mm) was observed, and a decrease in the annual highest daily amount (RX1day) and highest 5 consecutive days (RX5day) of precipitation were recorded at Taba station.

Future results generally indicate an intensification with increasing radiative forcing of patterns of change in temperature and precipitation based indices that have already been found in observations [18] - [20]. The asymmetry in the warming of minimum and maximum temperatures as observed in the historical record [21] continues and intensifies with increasing radiative forcing in the future climate projections. In particular, projected changes in indices based on TN (warm and cold nights, frost days and tropical nights) are more pronounced than in indices based on TX. Note however that detection and attribution studies based on TN and TX tend to show that models warm TN less than observed and that they warm TX more than observed over the latter half of the 20th century [22]. This means, while the contrast in changes between TN and TX in the models corresponds qualitatively with observations, the observed contrast tends to be even larger than simulated by models.

Changes in very wet days (R95p) indicate that extreme precipitation (flash floods) frequency will generally increases in most regions, but although there is a positive increase in R95p, some areas will be under water stress. Projected changes in temperature and precipitation extremes are generally more pronounced in RCP4.5 than in RCP8.5 simulations, although both have similar amounts of radiative forcing by year 2100 due to rapid increase in anthropogenic emission. Furthermore, to get a better idea of the changes in extremes in relation to the amount of radiative forcing, other factors (such as aerosol concentrations) that affect climate response would also need to be assessed using satellite data.

Finally , future changes in temperature and precipitation extremes need to be assessed carefully as they are significant parameters concerning food security and sustainable development in the target area in relation to changes expected in circulation patterns [23], [24] and other feedback mechanisms such as snow, soil moisture, and vegetation [25]-[28]. The results presented in this study give a first impression of what we can expect from the CMIP5 multimodel, more further studies on the changes in climate and extremes should be directed to this area using regional circulation climate models and to facilitate impact studies and the development of adaptation strategies by providing the necessary physical basis.

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