Detection and Attribution of Climate Change in Extreme Precipitation Using Optimal Fingerprinting (Case Study: Southwestern Iran)

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1. Introduction

Determining regional vulnerability of a basin is one of the issues which have attracted scientists and researchers attentions in recent years. In discussions on climate change, the issue of extreme precipitations is significant because those extreme events are closely related to the increase in temperature of the troposphere and resulting effects of various climatic influences in form of hazards such as flood precipitations (Mondal and Mujumdar, 2015). The effect of global warming on precipitation can be explained by the Clausius-Clapeyron relationship and the associated physical evidence (Allen and Ingram 2002), Due to the fact that the relative humidity in the lower troposphere layer remains constant, the moisture capacity increases about 6 to 7 % per degree Celsius (Willett et al., 2007). Arid regions, where those values are reduced, are no exception (O'Gorman and Muller, 2010). As the Earth's temperature rises, factors such as changes in continental runoff, tropospheric water vapor, large-scale rotational patterns, ice mass balance, evaporation, and evapotranspiration can affect changes in extreme precipitations (Huntington, 2006). According to the literature, extreme precipitations have changed significantly on the global scale (Westra et al., 2013; Fischer and Knutti, 2014). These studies confirm the harmonization of temperature increase with extreme precipitations. Although these studies differ in terms of the definition of extreme events, methods of analysis, and databases, the sensitivity of extreme precipitations to the temperature rise seems not to be similar to the same in smaller spatial and temporal scales (Wasko and Sharma, 2014) because it is assumed that various dynamic and thermodynamic processes are affected by the relationship between precipitation data and atmospheric temperatures (Westra et al., 2013). Recently, extensive research has been conducted to detect changes in trends of hydroclimatic variables and to attribute changes to climate variables caused by anthropogenic forces in different parts of the planet. However, there are few studies in this area on a regional scale.

According to the definition presented by Intergovernmental Panel on Climate Change (IPCC), detection is the process of demonstrating that climate has changed in some defined statistical sense, without providing a reason for that change, while attribution of causes of climate change is the process of establishing the most likely causes for the detected change with some defined level of confidence. Hence, the process of attribution is a more complex one than detection. The reason may be due to the combination of various statistical analyses with the physical understanding (Hegerl and Zwiers, 2011).

Detection and attribution via the fingerprint method which uses modified empirical models is a formal way of understanding the relationship between global warming affected by anthropogenic forcing and observational variables such as extreme precipitation (Hegerl et al, 1996). It is currently the most common detection and attribution way (Zhang et al. 2013; Ribes and Terray, 2013). In a study done by Min et al. (2011) on extreme precipitation, the simulation signals of climate change models caused by anthropogenic forcing were investigated based on the observations of maximum daily precipitation (Rx1day) and the five-day maximum precipitation (Rx5day) of the northern hemisphere (on a semi-international scale). On a regional scale, however, these signals can be more difficult to detect because the signal-to-noise ratio decreases (Karoly and Wu, 2005; Stott et al., 2010). In addition, the extreme precipitations are rare considering their definition and the analysis of extreme precipitations in regional and basin scales is a major challenge in terms of extreme temperature and precipitation fluctuations.

In spite of the challenges of detection and attribution in small and regional scales, in the 5th assessment report of the IPCC (AR5), the approach to moving towards smaller-scale studies has been encouraged and motivated. In addition, due to the novelty of de-

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Station	Station type	Lon.	Lat.	Height (m)
Ahwaz	Synoptic	48.40° E	31.20° N	22.5
Dezful	Synoptic	48.23° E	32.24° N	143
Emamzadeh Gheis	Climatology	51.30° E	31.75° N	2285
Polzaman Khan	Climatology	50.90° E	32.50° N	1885

Table 1: Specifications of the selected stations

tection and attribution via the fingerprint method, especially in Iran (Saadi et al., 2016a,b), and also the importance of the study on extreme precipitation, the present study aims to apply the fingerprint method to external effects of climate change on extreme precipitation in southwestern Iran.

2. Materials and methods

In this study, two data sets of the selected stations (Tab. 1) and APHRODITE (Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation) daily gridded data (Yatagai et al., 2012) at 0.25° resolution during a period of 55 years (1951-2005) were used as precipitation data. Also the NorESM1-M model of the CMIP5 model series was employed for calculation of the region's internal climate change and to simulate climate responses to various forces. The responses addressed in this study include anthropogenic plus natural external forces (ALL), anthropogenic forces alone (ANT), natural forces alone (NAT) and the effects of greenhouse gases forces alone (GHG). In addition, 500-year-old daily precipitation simulation data before the industrial revolution, called control run (Rypdal et al., 2015), was used to simulate the regional climate change and also to provide another independent noise sample for estimating the uncertainty intervals. Figures 1 and 2 shows the methodology in this research and the study area, respectively. We compare observed changes to model simulations with a standard optimal fingerprinting method (Allen and Tett, 1999). This method assumes that the observations Y are expressed as the sum of scaled fingerprints X plus internal variability.

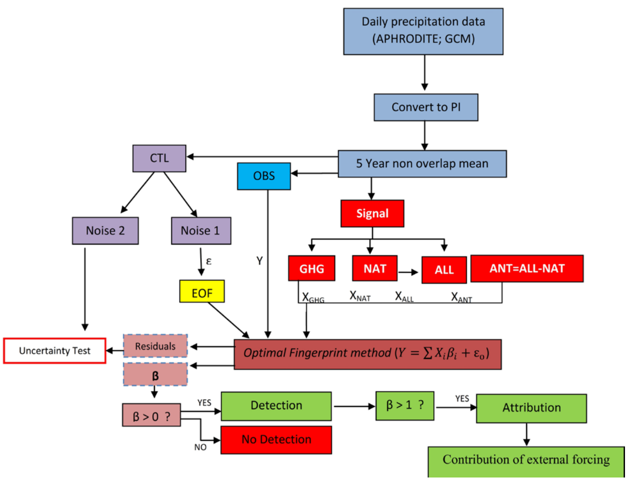

Figure 1: Flowchart of the methodology.

3. Results and discussion

The results of fingerprinting various forces on the 55-year Rx1day and Rx5day time series generated by the OLS algorithm are illustrated in Figure 3. The results obtained from fitting observation data and simulations of the NorESM1-M model show that the scaling factor associated with optimal fingerprinting, the anthropogenic plus natural external forces (ALL), greenhouse gases forcing (GHG) and the human forces alone (ANT) is significantly bigger than zero. Thus, we can say that the Rx1day of the study area during the statistical period of 55 years (1951-2005) has a significant trend and the trend change has been detected. Moreover, the confidence intervals for all detected scaling factors are also larger than one, which means that the simulated changes in the Rx1day under the above signals are consistent with changes in the maximum daily precipitation observed in the Great Karun Basin. Furthermore, the results also show that, changes in the observations can be attributed to the aforementioned forces or signals. Comparison of the results of the intervals indicates a higher uncertainty in the ANT signal fingerprint than those of the GHG and ALL. According to Figure 3a, the natural forces alone (NAT) have no significance, consistent with the change in the significant trend of maximum daily precipitation in southwestern Iran. The confidence intervals for fingerprint coefficients related to the NAT signal include negative values which are not detected. This finding reinforces the results of the effects and contribution of external factors of climate change (GHG, ANT) and confirms these results.

Optimal fingerprint analysis of the investigated forces for the Rx5day time series is similar to the results

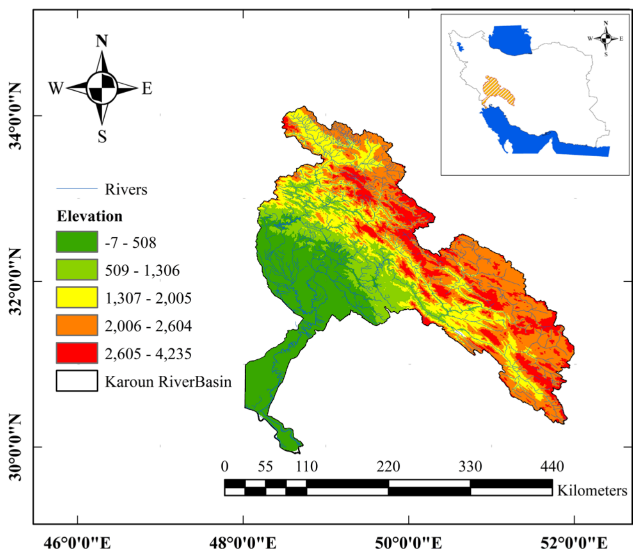

Figure 2: Study area.

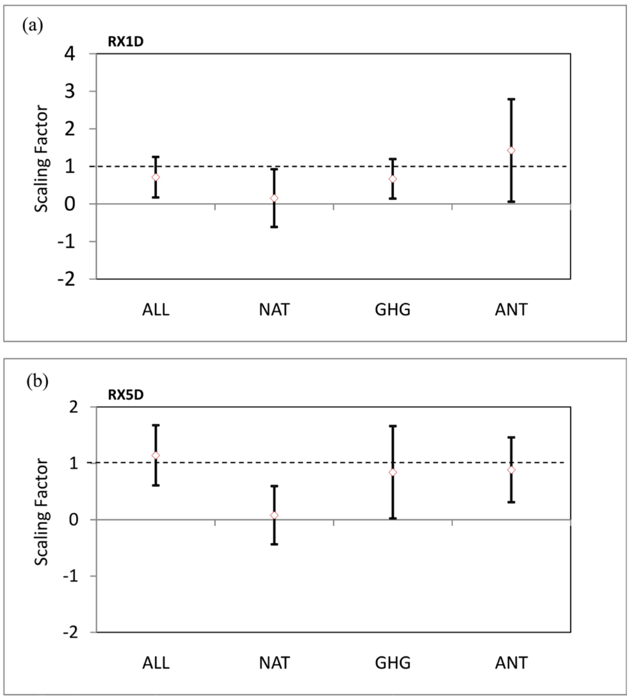

Figure 3: Optimal fingerprint analysis of various forces contributing to the (a) Rx1day and (b) Rx5day changes in southwestern Iran between 1951 and 2005.

of the maximum daily precipitation index. As shown in Figure 3b, the Rx5day changes in southwestern Iran during the study period have a significant trend and these changes can be attributed to the ALL, GHG, and ANT signals. In other words, the Rx5day simulations extracted from the NorESM-1-1 model are consistent with the five-day maximum observation time series. In addition, the NAT signals were identified to be triggered undetectable and attributable, thus changes in the trend of recent decades have been outside the range of natural fluctuations in the climate.

The results show that, after applying the optimal fingerprinting method, and determining the percentages of changes in the Probability Index (PI) and changes in the median extreme precipitation, the contribution of the effects of climate change signals including ANT and GHGs can be achieved in the study area. To this end, the average percentage of changes in the median precipitation for the whole region was first calculated via previous results. To do this separately, for the ANT and GHG signals, the average of all percentage changes in the median can be calculated and considered as the percentage changes in the basin.

The figures 4a and 4b show the comparison graphs of the mean of the total percentage changes of the Rx1day time series of the Great Karun Basin for GHG and the ANT, respectively. The figures 5a and 5b are the corresponding diagrams for the Rx5day time series. As observed in Figure 4a, the Emamzadeh Gheis Station has the lowest percentage changes in the median, and the Polzaman Khan and Dezful stations have the least estimated percentage changes. The 4x4 degree APHRODITE cell dataset depicted with the letter A and Ahwaz station have similar attributable percentage changes, with the difference that the uncertainty intervals related to the percentage changes attributable to APHRODITE datasets are smaller. The average of all of these percentage changes, each of which is a member of the entire region, is calculated and indicated in the last column of figure 4a. The average median percent change attributable to the ANT, as shown in Figure 4b, is derived

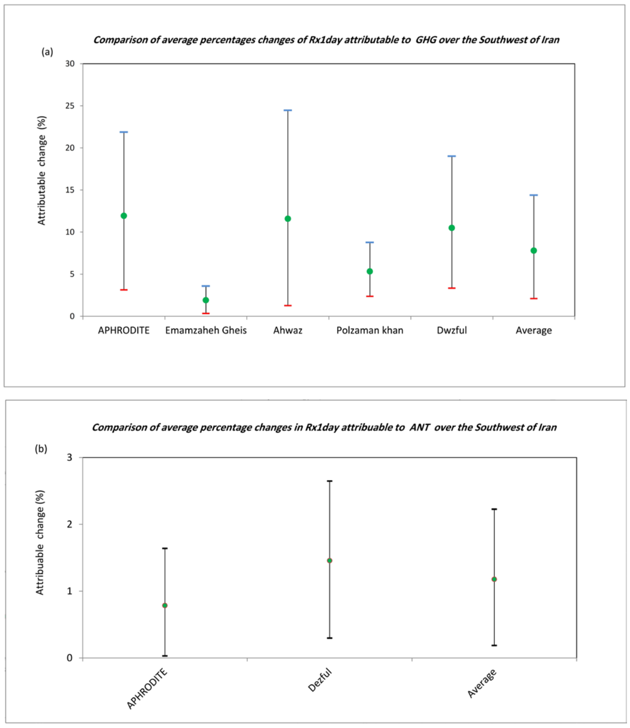

Figure 4: Comparison of the average percentages changes of maximum daily precipitation attributed to the (a) GHG and (b) ANT.

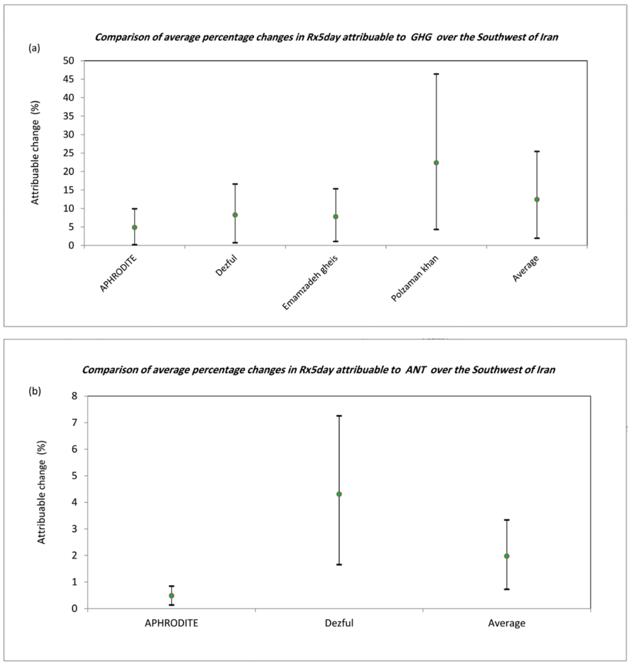

Figure 5: Comparison of the averages of the median percent changes of the Rx5day in southwestern Iran attributable to the (a) GHG and (b) ANT.

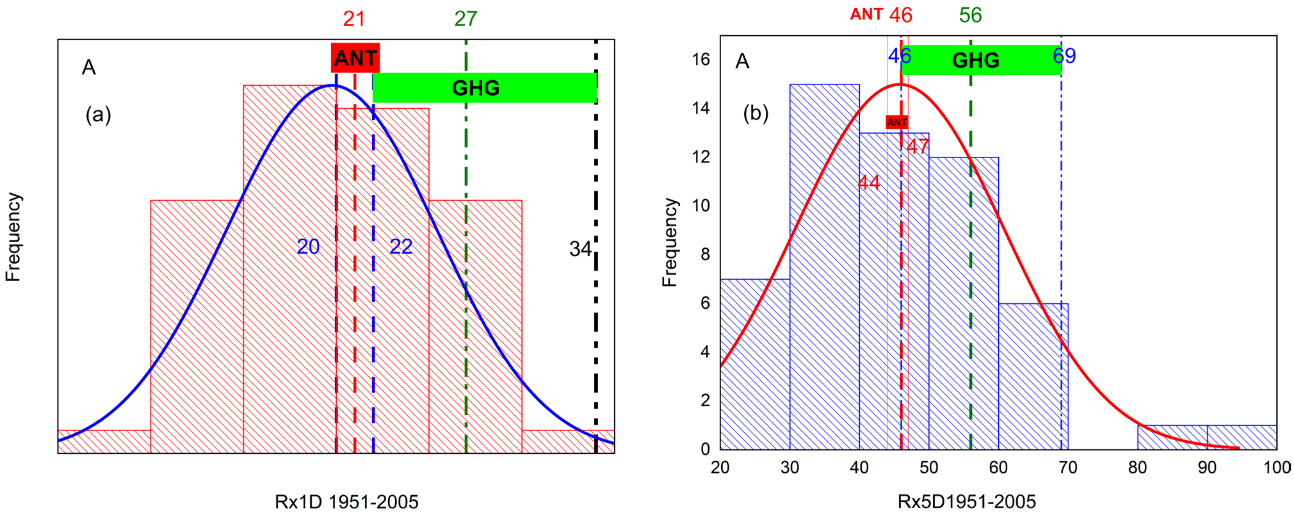

Figure 6: The range of the GHG and ANT effects on the frequency of (a) Rx1day and (b) Rx5day in the frequency histogram between 1951 and 2005.

from averaging two Dezful stations and the APHRODITE datasets. The median percent change at the Dezful station is bigger than that of the APHRODITE dataset.

According to the basin averages which are taken as the percentage change in the basin, the extreme precipitation rate attributed to the GHG and ANT were calculated for all datasets including the APHRODITE data and the four sample stations. Figure 6a illustrates the range of the GHG and ANT forces on the histogram of the maximum daily precipitation rate during 1951 to 2005. As observed, the average daily precipitation has values about 21 mm and higher on a scale, and in other part of area A (averaged APHODITE), it was detected by the ANT. The uncertainty range related to the contribution of the ANT to the maximum daily precipitation is very small including one millimeter difference on both sides and values 20 and 22 mm of maximum daily precipitation. The contributions of GHG are colored with green in the figure including 27 mm maximum daily precipitation and more. In terms of uncertainty in the results of the GHG signal, this value is 22 mm in the lower limit (that is, it corresponds to the high limit of the ANT uncertainty) and 34 mm in the upper limit. The contribution of climate change effects on the Rx5day in southwestern Iran, as indicated in the Figure 6b, shows that in all the results the ANT is close to the median and is about 44 mm average regional precipitation of the Rx5day, and its contribution is confirmed to be larger than the median. Furthermore, the GHG is about 46 mm of Rx5day (area average) immediately after the uncertainty boundary of the upper limit of the ANT, i.e. about in the threshold and its uncertainty intervals are bigger than the uncertainties of the ANT. Although the above values are calculated on the basis of certain mathematical equations, it should be kept in mind that given the available uncertainties and including data especially from global models, it cannot be expected to specify certain values for sharing of climate change. It can be concluded from the results that the GHG effects are within the range of extreme precipitation, while other components of the ANT have had a less severe effect on values close to median. In addition, the starting point of the range attributable to the ANT are much shorter and the uncertainty of the results is low, while the uncertainty range of results related to the GHG is very long and covers the range close to the extreme precipitation up to the most extreme precipitation values.

4. Conclusions

The present research aimed to examine various forces which affect Earth's climate system including human forces at the regional scale. Therefore, the standard fingerprint method was employed and the effects of different forces on the Rx1day and Rx5day for the statistical period of 1951-2005 in southwestern Iran were investigated. According to the results, the extreme precipitation of the study area during 1951-2005 had a significant rise. These findings are consistent with previous studies (for example, Zhang et al., 2013) and with the general model derived from global scales. This is confirmed by the relevant mechanism between global warming and increase in relative humidity of the atmosphere and increase in the probability of extreme precipitation by average global temperature rise. The NorESM1-M model reacted significantly to the ALL, and the simulation of the signal was compatible with the observed changes in the studied indices. In other words, the changes of the significant trend of extreme precipitation of the study area was attributed to the ALL signal. The contribution of ANT and GHG have been confirmed as forces of the climate change phenomenon on regional extreme precipitation changes in past periods. The NAT including the effects of solar radiation and volcanic eruptions did not interfere with the changes in the precipitation trend in southwestern Iran. These results reinforce the existence of non-natural factors in past change and increase the probability of regional climate vulnerability to the effects of climate change. The GHG forces include extreme precipitation to some extent, while other components of the NAT have affected values close to the median and with lower intensity. Moreover, the starting point of the range attributable to the ANT are much shorter, and the uncertainty of the results is low, while the uncertainty range of the results is associated to the GHG, and covers the range close to the median of the maximum precipitation up to the biggest values of extreme precipitation.

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