Climate variability and extreme weather events in the Mediterranean region

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1 INTRODUCTION

A large increase in greenhouse gases is a driver of climate change, leading to many other changes in the atmosphere, on land, and in the oceans. Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability. So, the change of climate can be the cause of Climate Variability, it has consequences for sea level changes, plant life, and mass extinctions; it also affects human societies.

The Mediterranean region has been identified as one of the most sensitive regions in the world to climate change (Thiébault et al, 2016). Several studies have observed changes in precipitation and temperature in the French Mediterranean, that can evolve to heavy precipitation, windstorms, heat waves and droughts.

In this study, we observe climate variability, including variation in precipitation and temperature in French Mediterranean using reanalysis ERA5 and in situ data. The goal of the study is to determine whether global warming will change climate variability of extreme events? And what trend is that change ?

1.1 Heat wave

According to the World Meteorological Organization, Heatwave is an extreme weather event with marked warming of the air over a large area that usually lasts from a few days to few weeks. The Mediterranean basin is a region where hot conditions and heatwaves are popular in the summer. The frequency of heat waves has been increasing in recent decades in Europe and specifically in the Mediterranean region due to climate change (Thiébault et al, 2016). Since the 1960s, the Mediterranean region has become warmer with the frequency, intensity and duration of heat waves has been increasing (Kuglitsch et al. 2010) and it has a lot of impact on human health, especially in areas with vulnerable populations.

1.2 Cevenol episode

On the Mediterranean rim, strong precipitation events take place during the autumn. These violent events, lasting one to several days, are accompanied by significant floods and therefore present a major hazard for the inhabitants of these regions (méteo France). These events take place when warm air masses loaded with humidity from the Mediterranean in late summer move towards the interior of the continent. These humid air masses cool rapidly as they approach the Cevenes (a small mountain range in the south of France) and condense (Fig. 1).

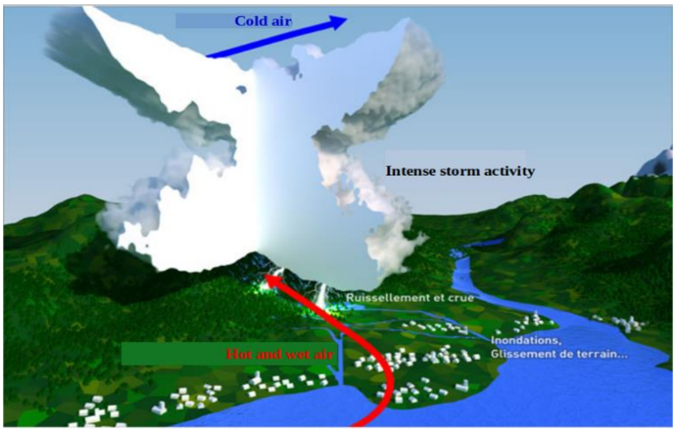


Figure 1. Operation of cevenol episode (Méteo France)

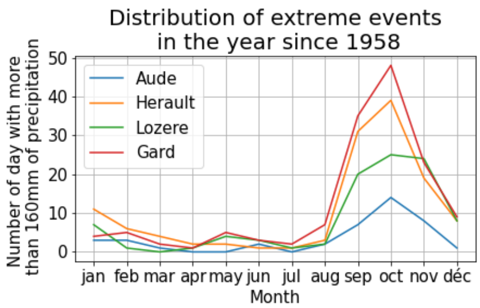


Figure 2. Annual distribution of precipitation

The large temperature difference between the continent and the sea induces a great instability which allows the appearance of a significant and very intense stormy activity (precipitation often exceeding 100mm/h). We are, therefore, going to focus on the impacts of climate change on these extreme events, in particular on the frequency of these events each year.

In the Languedoc-Roussillon region, most of bigger precipitation events occur during these episodes in autumn, as shown in figure 2 (data from Meteo France). This figure shows the number of days per month since 1958 when there was more than 160mm of precipitation. For all of the departments (in particular for Gard and Hérault) these events take place in autumn, these are Cévennes episodes.

2 METHODS

2.1 Analysis of temperature variations

For evaluating variation of temperature, data of European Climate Assessment & Dataset (ECA&D) was used. We choose to restrict our study to the period 1990-2019 in order to highlight recent climatic trends, the three variables analyzed are minimum/night temperatures (Tn), maximum/day temperatures (Tx), average temperatures (Tn) for 4 stations at study area (Cepet, Montpellier, Marignane, Perpignan).

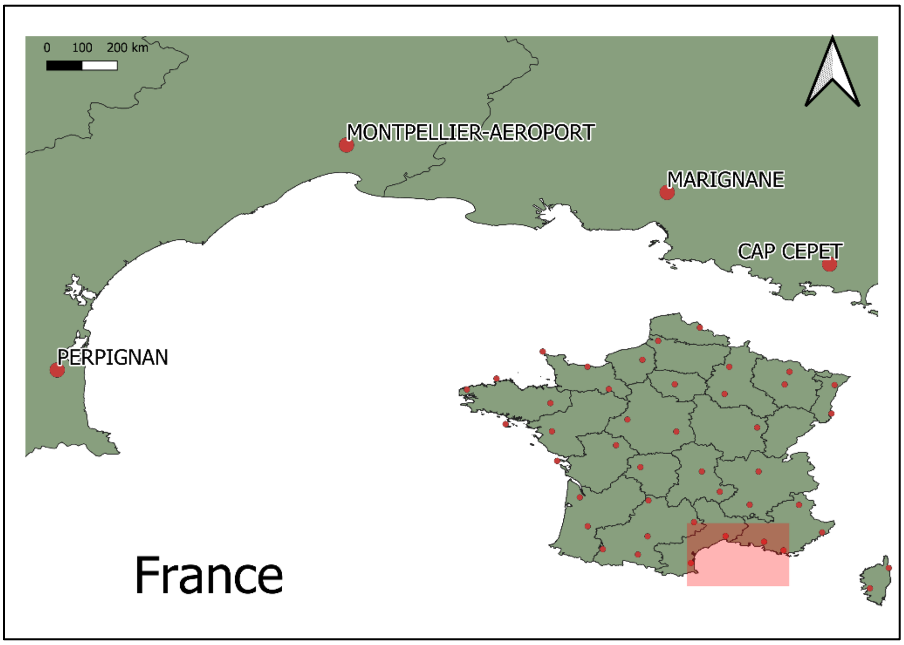


Figure 3. Study area and monitoring stations

2.1.1 Variation of annual average temperature

Basic calculations were carried out on the raw series in order to analyse the variations in temperature over time:

- Check if the data is missing in some series;
- Calculate an average annual temperature for all stations. The purpose is to observe the changes of temperature (Tn, Tx, Tg) with the time series in the study area.

2.1.2 The temperature anomaly

The temperature anomaly is the difference between the temperature measured in a place in degrees Celsius, positive or negative, compared to the normal average temperature (calculated over a period of at least 30 years) daily, seasonal or annual observed in a homogeneous geographic region. The temperature anomaly is calculated by equation below:

$$T_a(year) = T_g(year) - T_{mean}(period)$$

2.1.3 Number of heat wave events

In several studies, heatwave definitions were tested by using percentiles (e.g., from the 75th to 99th centile) of mean temperature with duration ≥2 days. In this study, we chose a threshold for the heatwave: 95th centile, lasting for 5 days. We counted the number of heatwave occurrences per year at each station to observe extreme temperatures between 1990-2019.

2.2 Cevenol episode

2.2.1 Méteo France data

Precipitation in the Languedoc-Rousillon region has been measured since 1958 by Météo France. The data used for this study are the time series of the number of days per year when precipitation exceeds a certain threshold (here 60mm / day and 160mm / day).

These data will allow us to observe the evolution since 1958 in the number of days of heavy precipitation. However, these data do not detail the measured quantity of precipitated water, only the number of days exceeding the threshold is provided.

2.2.2 ERA5 data

To obtain the precipitation values over the study area and therefore to determine which precipitation event can be considered extreme. It was necessary to have time series with good geographical coverage of the area and a daily measurement step.

For reasons of data availability, the ERA 5 reanalysis of the European Center for Medium-Term Weather Forecasts (ECMWF / ECMWF) was used. A meteorological reanalysis is a numerical method of integrating meteorological data across the globe while performing interpolations between the data using a model.

These reanalyzes have a spatial resolution of 30km and produce hourly estimates of many atmospheric and climatic variables since 1979. The ERA points used are distributed along the Mediterranean coast, as shown in figure 4.

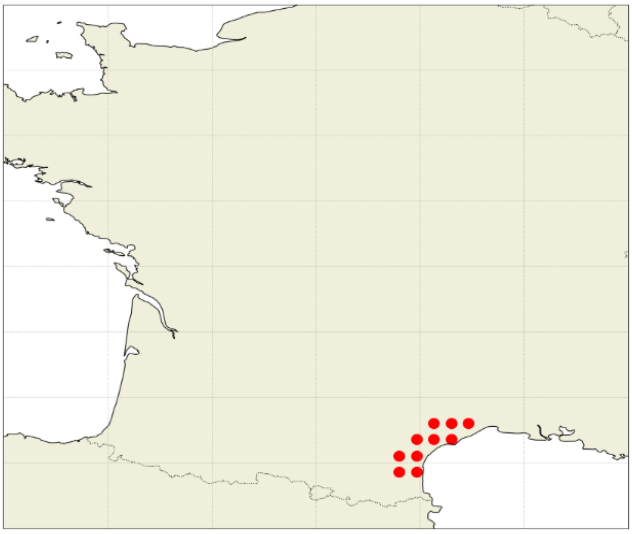


Figure 4. *ERA 5 data*

3 RESULT AND DISCUSSION

3.1 Analysis of temperature variations

3.1.1 Variation of annual average temperature

In general, there was a gradual increase in temperature during the period 1990 - 2019. The trend of the 30-year lowest, average, and highest annual temperatures are shown in Figure 5. Since 1990, the lowest temperature has increased from 11ºC to 12ºC until 2019 ($p < 0.01$). These results show the clear impact of climate change on temperature in the French Mediterranean. The lowest temperature increased continuously for 29 years, about 0.3ºC/10 years. Likewise, the annual average and highest temperature also increased gradually during the survey period, 15.5ºC - 16.3ºC and 19.7ºC - 21.2ºC respectively ($p < 0.01$).

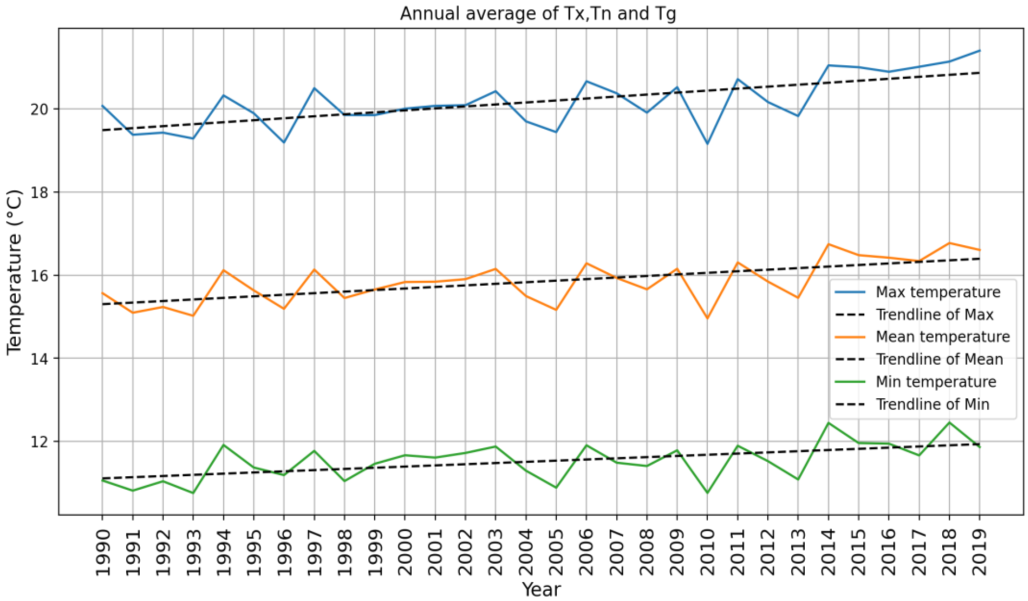


Figure 5. The annual lowest temperature (Tn), mean temperature (Tn), highest temperature (Tx) in French Mediterranean from 1990 to 2019. The dash lines are trend lines, obtained by linear regression.

The results of the average temperature anomalies in French Mediterranean between 1990 and 2019 were divided into two phases (Figure 6). Negative anomalies frequently existed between 1990 and 2013, while positive anomalies only existed from 2014 to 2019. In addition, in the first phase there existed positive anomalies in some years, notably 1994, 1997, 2003, 2006, 2009 and 2011. In contrast, in the second phase, there were only positive anomalies. This result shows that temperature anomalies (increase trend) occurred strongly in recent years (since 2014).

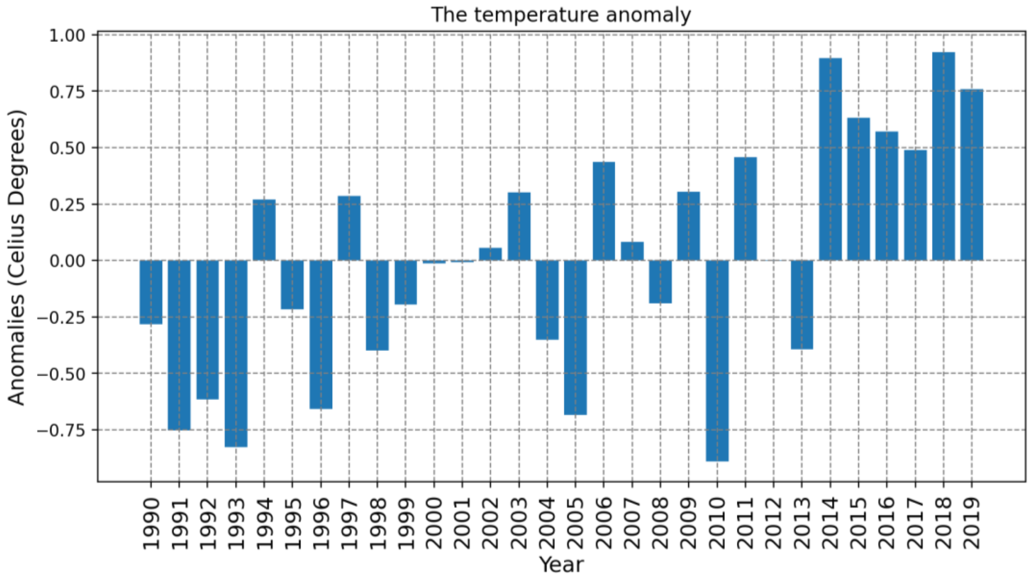


Figure 6. Average temperature anomalies in French Mediterranean in period 1990 – 2019

Figure 7 depicts the number of heatwave events in four stations from 1990 - 2019. The annual number of heatwaves at the stations had strong fluctuations, but most were less than 5 events per year except for Cepet station. Cepet station was the station with the most heatwave events in recent years, more than 20 events per year. Merignane and Perpignan stations had only one year with the number of events more than 20 times while Montpellier station had only a maximum of 13 events in 2003. In addition, the results also showed that 2003 was the year with the most heatwave events. This result is consistent with the observation of the number of people affected by prolonged high temperature in France in 2003.

Besides, in recent years (from 2015), the number of events at stations has also tended to increase by more than 5 events per year at Marignane and Cepet stations.

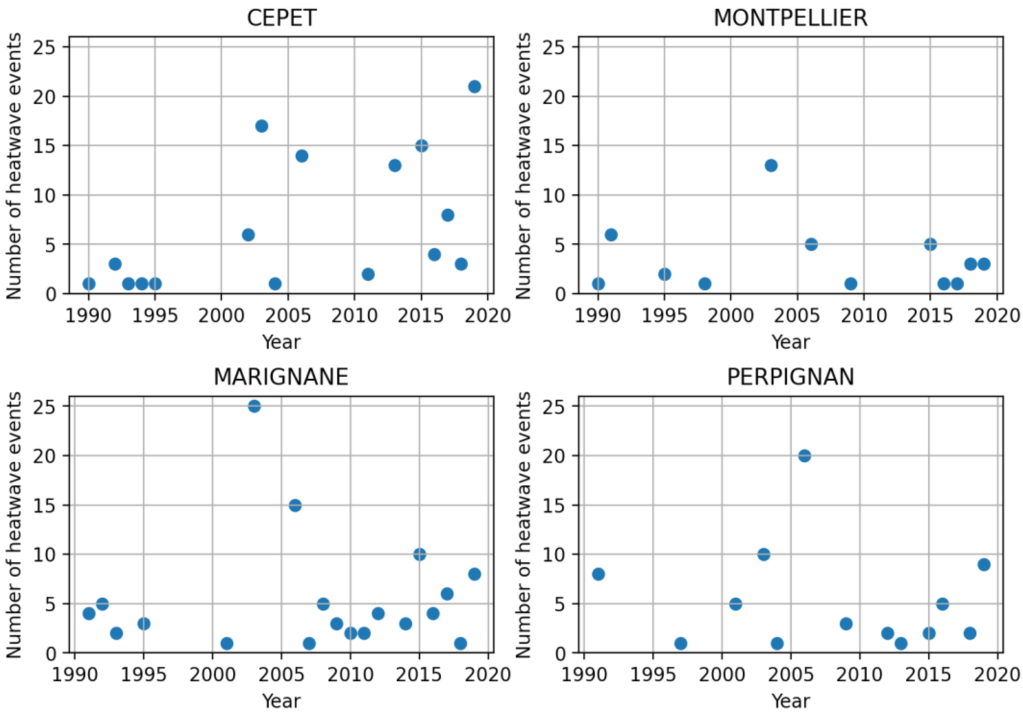


Figure 7. Number of heatwave events in Cepet, Montpellier, Marignane and Perpignan stations from 1990 – 2019.

3.2 Extreme precipitation

3.2.1 Evolution of major events since 1958

Using Meteo France data, we can determine the evolution of the number of days exceeding a precipitation threshold for each year since 1958 (figure 8). The basic statistical data of these two series are summarized in table 1.

Table 1. The basic statistical data

Threshold	Mean	Std	Min	Max
60mm/day	58.89 day/year	18.67 day/year	21 day/year	112 day/year
160mm/day	6.58 day/year	4.39 day/year	0 day/year	22 day/year

We notice a high variability in these data and the absence of a general trend (the rolling 20-year average remains close to the 62-year average).

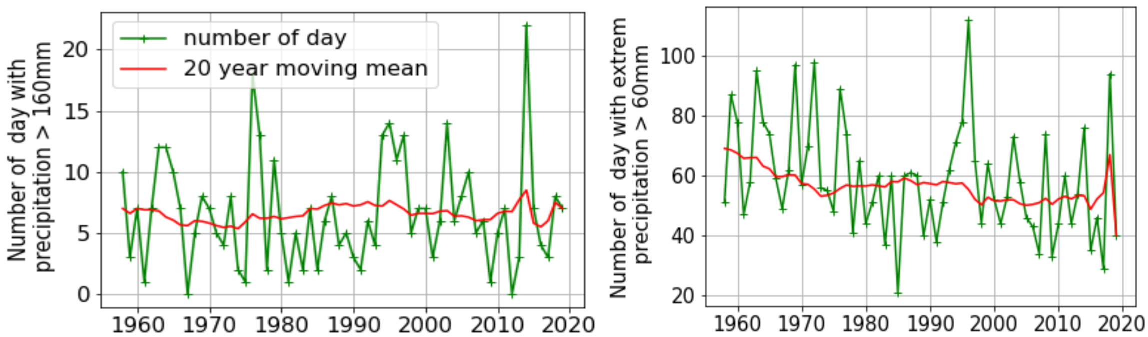


Figure 8. Evolution of extreme events, Météo France

These two graphs do not allow us to conclude on the impact of climate change on major precipitation events in the study area. However, we are limited by Meteo France data which only shows the number of days and not the amount of precipitation. Therefore, we cannot determine if the threshold of 60mm/day corresponds to the precipitation threshold that described the limit between extreme and normal events.

So, we used the ERA5 data to answer this question. By plotting the histograms and cumulative histograms for each of the ERA5 points (Appendix 1), we can determine the value of the threshold limit which is defined as the amount of precipitation that only 0.5% (5 percentile) of events exceed.

We obtain an average threshold value of 41.79 ± 9.22 mm/day (1σ). This threshold value allows us to determine the number of days per year corresponding to an extreme event. As shown in figure 8b (number of days with extreme event per month since 1979), the events selected by this method correspond for the most part to fall precipitation, which we will assume to be Cévennes episodes.

3.2.2 The evolution of the number of extreme events determined with the ERA5

Figure 9a shows the evolution of the number of extreme events determined with the ERA5 data. The number of days per year is quite variable (as for France weather data) but a very slight trend can be seen from these data.

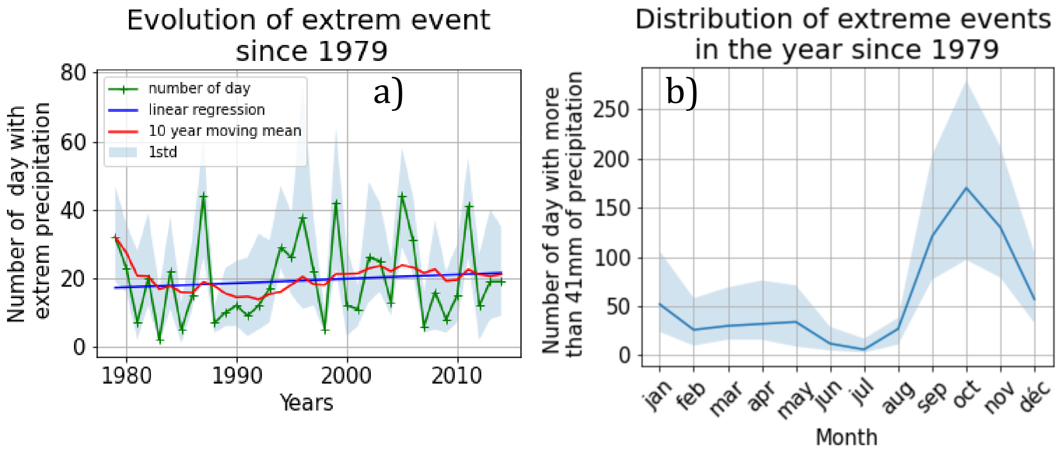


Figure 9. Evolution of extreme events, Météo France

The linear regression on the time series shows us that every 10 years the number of extreme events increases by 1.5. However, the p-value of the regression being equal to 0.42 (there is a 42% chance of being wrong in accepting this regression), it is difficult to conclude on the existence of this trend.

4 CONCLUSION

4.1 Heat wave

After analyzing the temperature data of 4 stations in the French Mediterranean in the period 1990 - 2019, the results show that the temperature in this area has increased. Since 2014, temperature anomalies tend to be 0.5 - 0.9^{0}C higher than the average temperature of the period, much higher in 2003 (the year with the historically high temperature in France). Heatwave events in 2015 also showed signs of increase compared to previous years, especially at Cepet station. It can be concluded that the temperature in French Mediterranean has changed and tends to increase in the future.

4.2 Cevenol episode

Using weather data from France and ERA5, we were able to observe that the occurrence of a Cevennol episode has not changed since the 1950s. To confirm this result, it would be necessary to use long times series of measurements of precipitation.

Indeed, ERA5 data only cover the period with satellite observations (since 1979) and only allow us to observe the absence of a trend over the last 35 years. Appendix 2 also shows that the annual precipitation averages of these events have been relatively constant since 1979, so there is no change in the violence of the event either. Another element was not taken into account in this study: the duration of these events, which could also vary in a context of climate change.

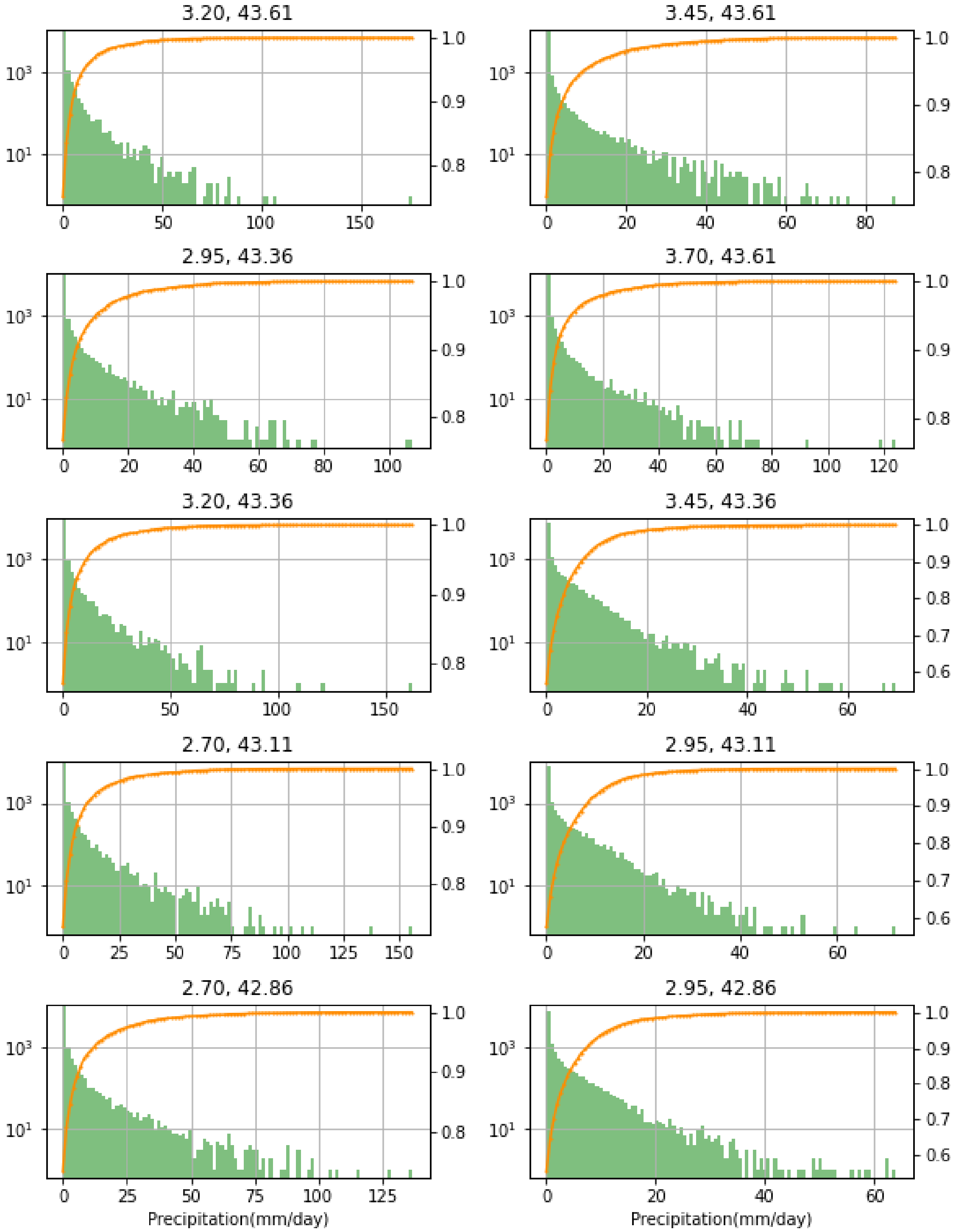
5 REFERENCE

[1] Thiébault, Stéphanie & Moatti, Jean-Paul & Eds, & Ducrocq, V. & Gaume, Eric & Dulac, François & Hamonou, E. & Shin, Yunne-Jai & Joel, Guiot & Boulet, Gilles & Guégan, Jean-François & Barouki, Robert & Annesi-Mae, Isabella & Marty, Pascal & Torquebiau, Emmanuel & Sou, Jean-François & Aumeeruddy-Thomas, Yildiz & Chotte, Jean-Luc & Lacroix, Denis. (2016). The Mediterranean Region Under Climate Change. A Scientific Update.

[2]. Kuglitsch, F. G., Toreti, A., Xoplaki, E., Della-Marta, P. M., Zerefos, C. S., Türkeş, M., & Luterbacher, J. (2010). Heat wave changes in the eastern Mediterranean since 1960. Geophysical Research Letters, 37(4).

6 APPENDIX

Appendix 1: Histogramme and cumulative histogramme of ERA5 precipitation



Appendix 2: Evolution of precipitation since 1979