Stochastic analysis of the spatial stochastic structure of precipitation in the island of Crete, Greece

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AIM OF THE RESEARCH

In the last few years, the island of Crete has been affected by extreme events. In recent decades, hydrometeorological processes in the island of Crete are monitored by an extensive network of meteorological stations.

The aim of this research is the stochastic analysis of the spatial stochastic structure of precipitation in the island by employing sophisticated statistical tools, as well as by analyzing a large database of daily precipitation records for more that 60 rainfall stations scattered in the four prefectures of Crete, for the years 1973 – 2020. In addition, for some of those stations are available monthly and annual data from the year 1909 and after, creating like this sufficient time series analysis that follows.

Descriptive statistical analysis of precipitation examines several temporal properties in the data, while correlation analysis of precipitation variability provides relations between stations and regions for spatial patterns identification. Also the precipitation variability has been investigated by employing statistical tools, such as the climacogram calculation, i.e, variance of the averaged process vs. spatial and temporal scales, to identify statistical properties, temporal dependencies, potential similarities in the dependence structure and marginal probability distribution.

THE ISLAND OF CRETE :

- Is located at the South - Eastern part of the Mediterranean and at the Southern edge of the Aegean Sea, where 3 continents meet (Europe, Asia, Africa).
- Is bounded from the Cretan Sea (North) & the Libyan Sea (South).
- Is the largest & the most populous island of Greece
- Is the fifth (5^{th}) in length of the Mediterranean.
- Has an area 8 336 km^2 (6,3 % of the country) & population of 600 000 people.
- Consist of four prefectures (Chania, Rethimno, Heraklion, Lasithi)
- Is one of the 14 Water Districts of the country.

THE CLIMATE OF CRETE :

- Dry sub-humid Mediterranean climate with long hot and dry summers and relatively humid and cold winters[1].
- Covers a wide range of bioclimatic floors with significant variations :

→ from East to West &

→ from the lowlands to the mountains

THE PRECIPITATION IN CRETE :

According to the recent Water Resources Management Plan, the historic average annual precipitation on the island of Crete is approximately 927 mm (Special Water Secretariat of Greece, 2017) [2].

Significant unequal distribution of the annual precipitation volume, both geographically and physiographically, with precipitation rating of the largest in Greece.

→ Maximum rainfall : December or January

→ Minimum rainfall : July or August (almost without rain in the lowlands)

25 % of the annual precipitation occurs during the rainiest month.

RAINFALL DATABASE OF CRETE

There are currently 58 active meteorological stations on the island of Crete, from which the daily data were obtained, starting from 2006 until today.

We have collected daily data from 60 meteorological stations of the four prefectures of Crete from the year 1973, as well as monthly and annual data from 56 stations from the year 1909 onwards, some of which are no longer in operation.

After collecting and processing them all on a monthly and annual basis, the stations with the longest time series (> 30 years) were selected for further analysis.

Map of the 58 active meteorological stations in Crete island from Meteorological and Hydrological Observatory of Crete (METEO) [3]

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METHODOLOGY

Climacogram [4]

The climacogram is a stochastic tool used to distinguish long-term obsession and correlates the variance of the average evolution with the average of the time scale κ .

The cumulative process of $\underline{x}_\tau$ for discrete time κ has been defined as

$$\underline{x}_\kappa := \underline{x}_1 + \underline{x}_2 + \ldots + \underline{x}_\kappa$$

Through this, the time average of the original process $\underline{x}_\tau$ for discrete time scale κ is defined as

$$\underline{x}_\tau^{(\kappa)} := \frac{\underline{x}_{(\tau-1)\kappa+1} + \underline{x}_{(\tau-1)\kappa+2} + \ldots + \underline{x}_{\tau\kappa}}{\kappa} = \frac{\underline{x}_{\tau\kappa} - \underline{x}_{(\tau-1)\kappa}}{\kappa}$$

The variance of the process $\underline{x}_\tau^{(\kappa)}$ is a function of the scale κ, which is termed the climacogram of the process

$$\gamma_\kappa := var\,[\,\underline{x}_\tau^{(\kappa)}]$$

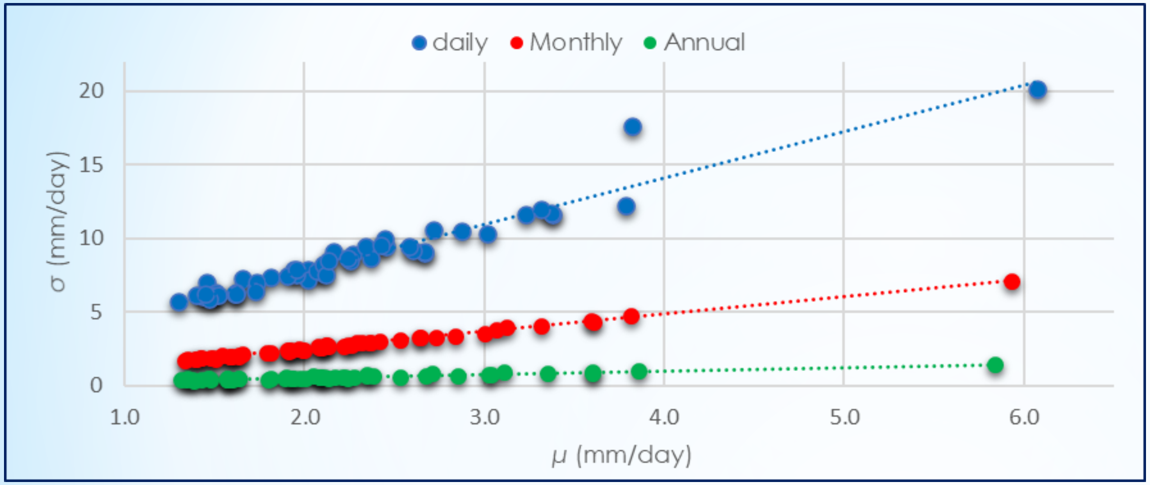
For large k, we may approximate the climacogram as : $\gamma_\kappa = \frac{\gamma_1}{\kappa^{2-2\mathrm{H}}}$

where H is termed the Hurst parameter (Hurst 1951) and implied by Kolmogorov (1940). The quantity $2-2\mathrm{H}$, is visualized as the slope of the double algorithmic plot of the climacorgam for large time – scales.

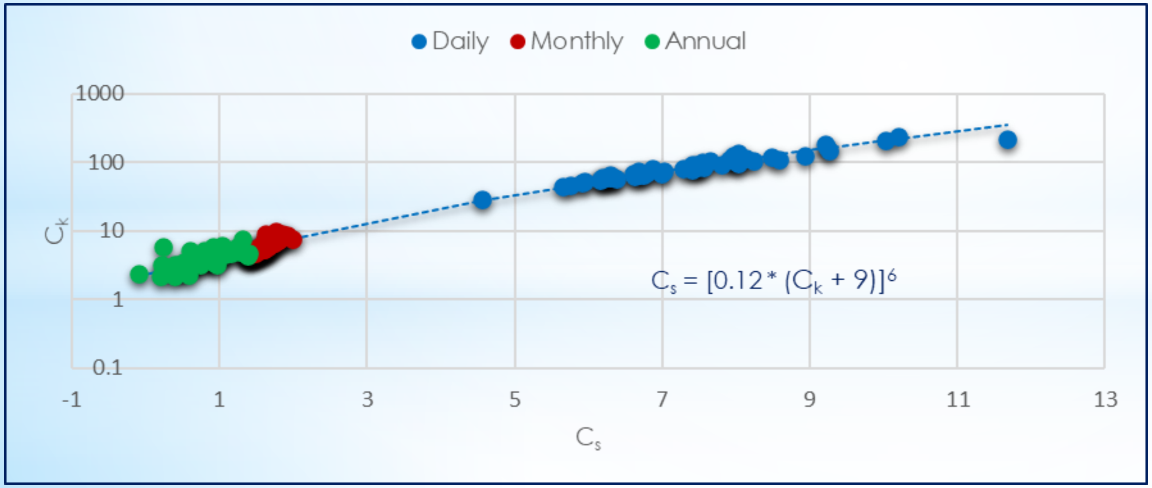
- In a random process, the Hurst parameter is expected to be approximately $H = 0.5$.
- In most natural processes : $0.5 \leq H \leq 1$ $\rightarrow H$ approaching 1 indicates enhanced presence of patterns, enhanced change and uncertainty (e.g. in future predictions).
- Low value of H, approaching 0 indicated enhanced fluctuation or antipersistence.

DATA

The following diagrams depict the mean and the 3 central moments for daily, monthly and annual rainfall for about 50 stations, with long time series from 1909 until today.



This diagram shows the standard deviation (σ) as a function of the mean value (μ). Naturally, the daily precipitation shows a higher standard deviation value compared to the monthly and annual ones. Interestingly, linear relationships appear between μ and σ, over all stations.



This diagram shows the kurtosis (C_k) as a function of the skewness (C_s). Usually a large skewness is accompanied by a large kurtosis. For the same reason with the previous chart, the daily rainfall is expected to show greater skewness and kurtosis compared to the monthly and annual. Interestingly, a simple power type relationship describes the skewness and kurtosis over all stations.

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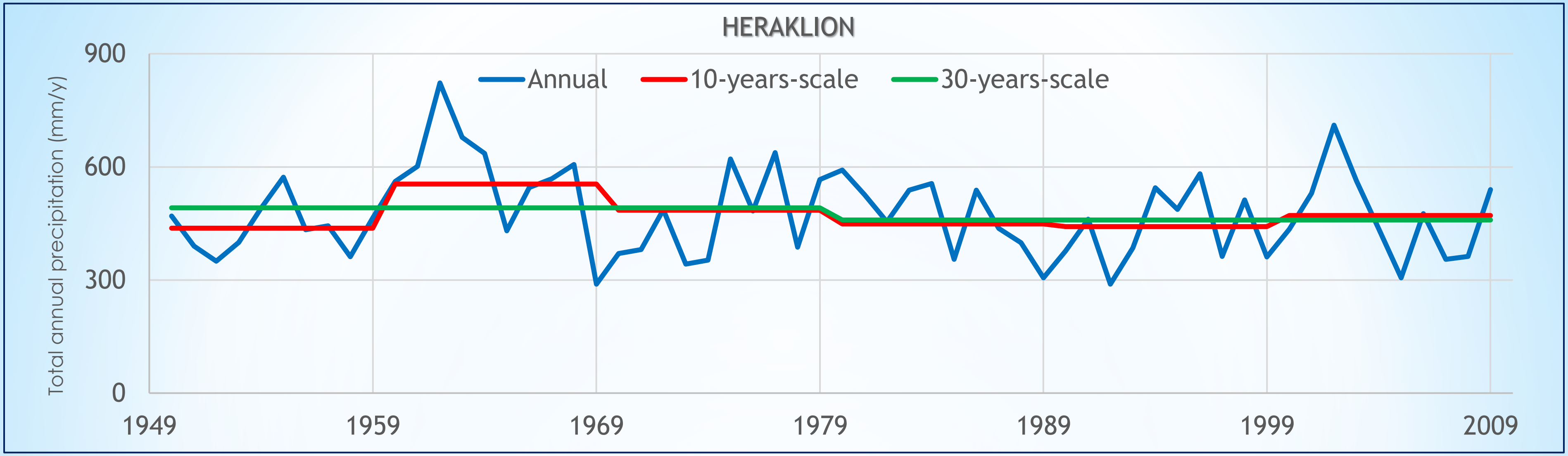
Information according to the years of operation of the stations with the longest time – series, which were used for the following diagrams is presented below :

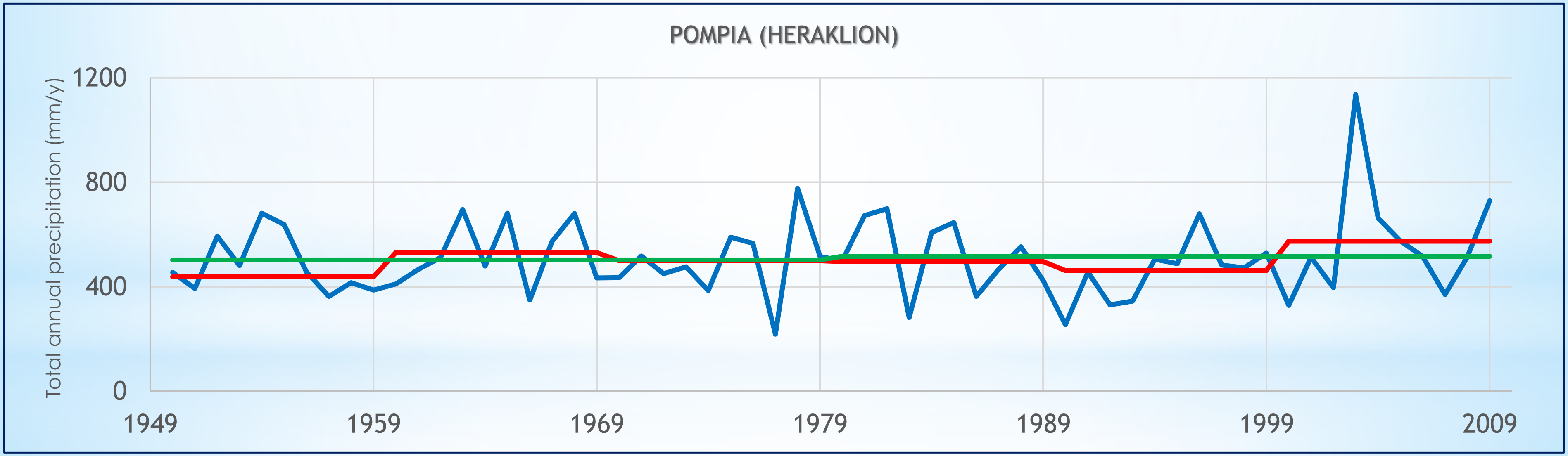
STATIONS	Hydrological years of operation	Time series length	Missing years	(%) of total length
HERAKLION	1909 - 2018	110 years	8	7.27 %
POMPIA (HERAKLION)	1946 - 2009	64 years	-	-
NEAPOLI (LASITHI)	1933 - 2012	80 years	10	12.5 %
KALO XWRIO (LASITHI)	1939 - 2010	72 years	2	2.77 %
MARWNIA (LASITHI)	1933 - 2007	75 years	9	12 %

Information on the location of the stations with the longest time – series and their central moments , which were used for the following diagrams is presented below :

STATIONS	Latitude	Longitude	Z (m)	μ	σ	C_s	C_k	C_v (%)
HERAKLION	35.31584	25.09271	85	476.32	132.45	0.1213	2.556	28%
POMPIA (HERAKLION)	35.00952	24.86237	150	504.20	145.31	1.3145	7.629	29%
NEAPOLI (LASITHI)	35.25683	25.60622	265	817.91	186.48	0.3930	3.098	23%
KALO XWRIO (LASITHI)	35.12020	25.72998	20	506.62	124.61	0.6706	3.913	25%
MARWNIA (LASITHI)	35.13478	26.08459	150	656.52	156.25	0.6108	3.098	24%

CLIMATIC EVOLUTION





Evolution of total annual precipitation in different areas of Crete island, as a climatic element [5] , seen at the annual and the climatic time scales of averaged precipitation of 10 and 30 years for the period of 1950 – 2010.

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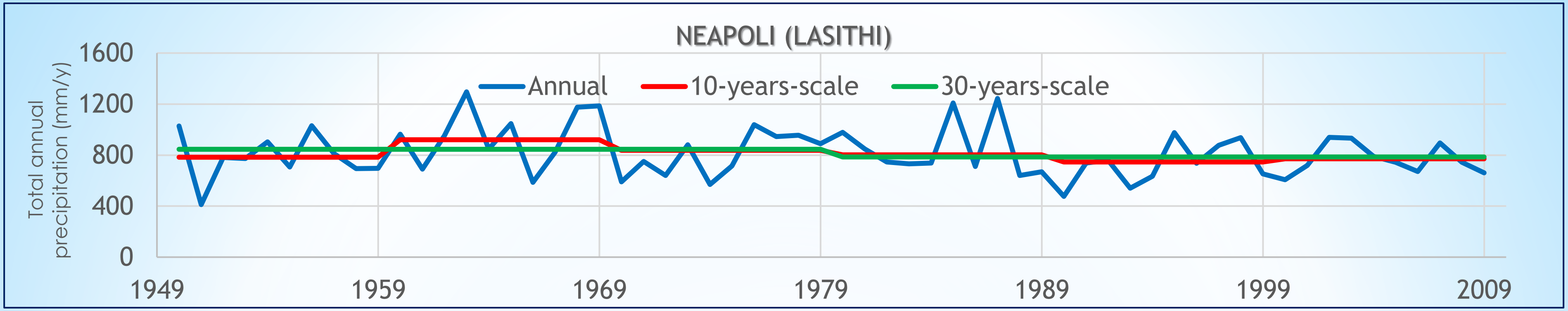

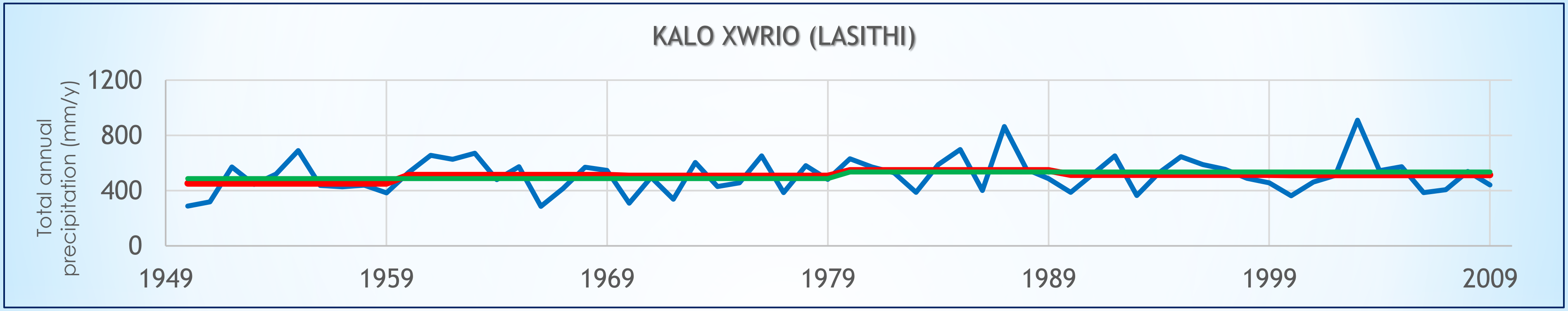

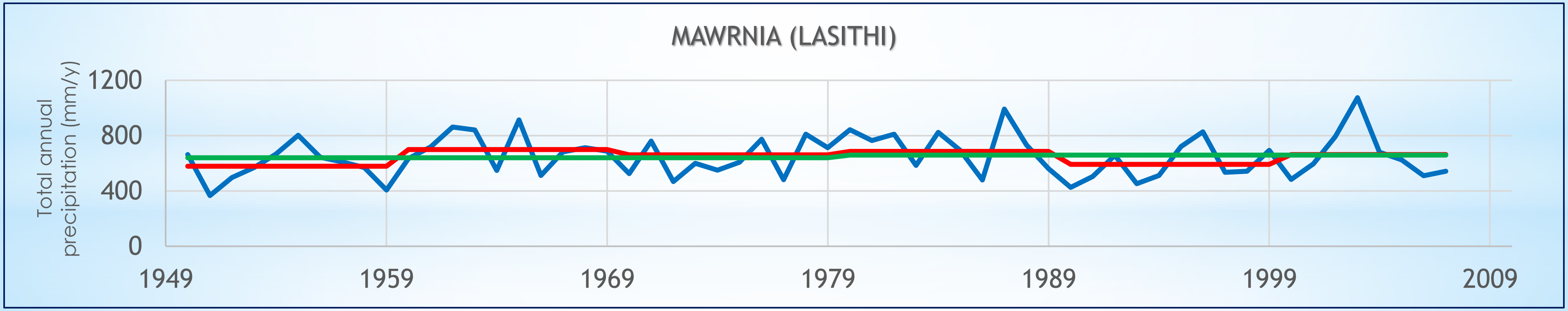

From the diagrams above, it can be seen that the rainfall variability decreases, as the time – scale increases and these variations of rainfall seem insignificant over time.

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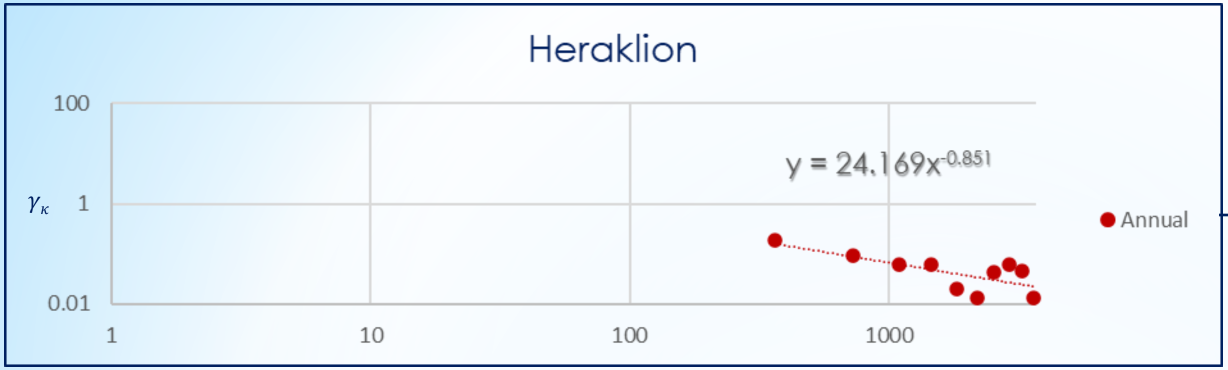
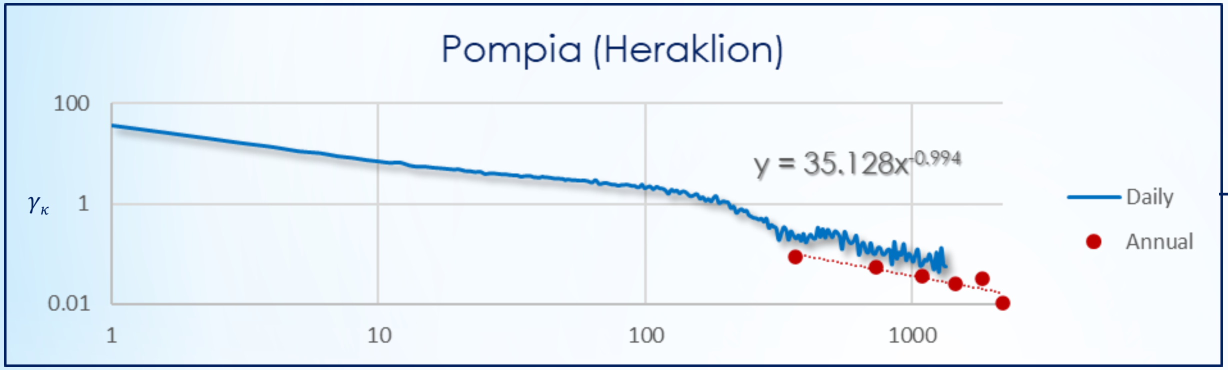
CLIMACOGRAMS

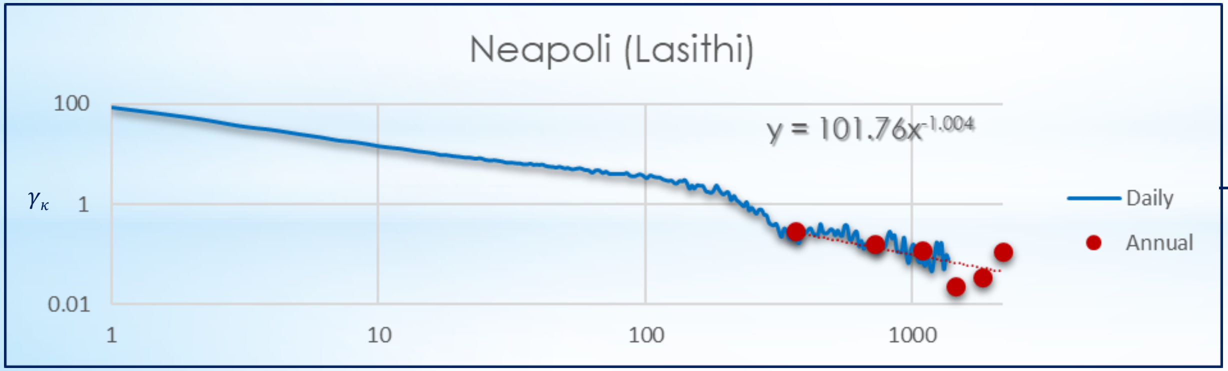
** Only Annual Data



H = 0.57



H = 0.50



H = 0.50

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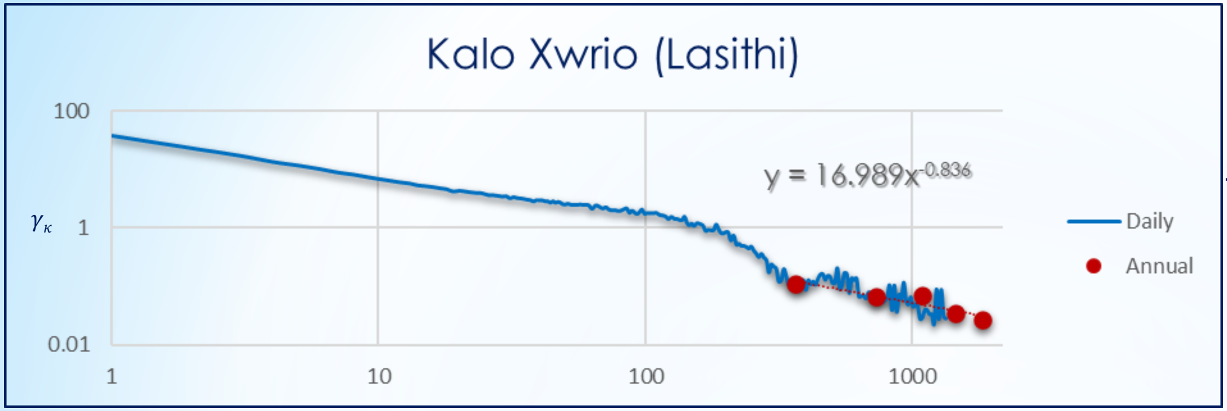
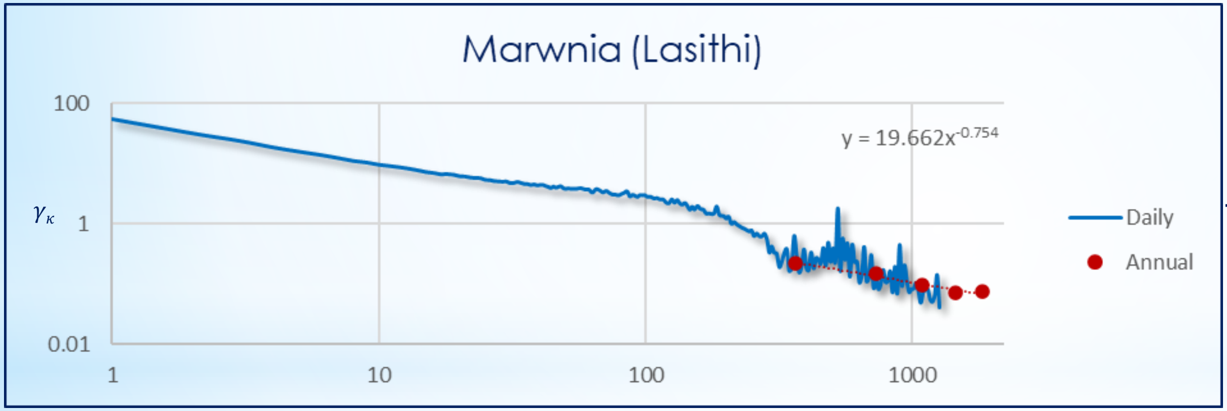
CLIMACOGRAMS



H = 0.58



H = 0.62

As expected, for precipitation, as for the most natural processes, the Hurst parameter ranges between 0.5 and 1. For the annual rainfall data of the 5 stations for which there is the most data (> 60 years), the H occurs between these values. The results show that over time, rainfall on the one hand is based on randomness, nevertheless show that there is the presence of patterns but also increased uncertainty as the parameter grows. It should be also noted, that the 2 rainfall stations that seem to show H = 0.5, are those with comparatively less data or large gaps in the data over the years and thus perhaps more unreliable results.

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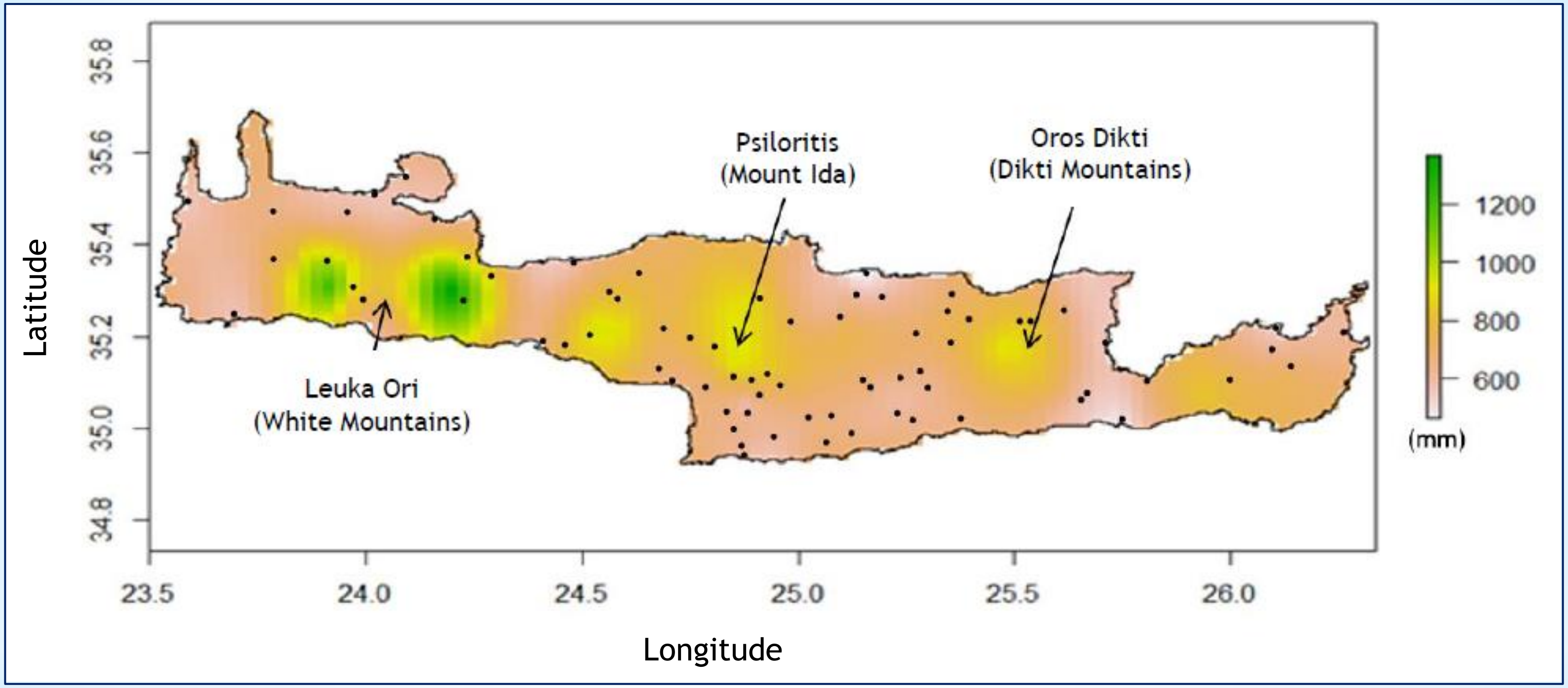
SPATIAL DISTRIBUTION OF PRECIPITATION

The average spatial distribution of the rainfall on the island of Crete using annual data, is presented below in terms of Regression Kriging.



- The variation of the rainfall is not so clear from east to west, although in the western part of the island there is an increase in the amount of rainfall through the color display, the variation in rainfall is clear depending on the altitude.
- Certain areas, with significant rainfall, are observed to be areas at high altitudes. More specifically, in the western part of the island, where the White Mountains are located, the highest level of rainfall is observed. Also, similar behavior is found in the central part of the island where Mount Idi or Psiloritis is located, as well as in the eastern part of the island where Mount Dikti is located.

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RESULTS

- The rainfall variability decreases, as the time scale increases with the climatic variation of rainfall appearing insignificant over time.

- The temporal dependence structure of precipitation in the island of Crete exhibits a Hurst – Kolmogorov behavior with $H \approx 0.6$, as expected for the natural processes.

- The annual precipitation of Crete shows a spectacular areal distribution, increasing :
  - → from east to west
  - → from lowland to mountainous areas.

- High altitude rainfall stations receive up to three times the amount of precipitation compared to low altitude stations.

REFERENCES

1. E.A. Varouchakis, D.T. Hristopulos, G.P. Karatzas, G.A.C. Perez , V.D. Crossmark, Spatiotemporal geostatistical analysis of precipitation combining ground and satellite observations, *Hydrology Research*, *doi.org/10.2166/nh.2021.160*, *2021*.

2. Special Water Secretariat of Greece, Integrated Management Plans of the Greek Watersheds. *Ministry of Environment & Energy, Athens, 2017*.

3. Meteorological and Hydrological Observatory of Crete (METEO), meteo.gr

4. D. Koutsoyiannis, and Z. W. Kundzewicz, Atmospheric temperature and CO_2: Hen-or-egg causality?, *Sci, 2 (4), 83, doi:10.3390/sci2040083, 2020.*

4. D. Koutsoyiannis, Rethinking climate, climate change, and their relationship with water, *Water, 13 (6), 849, doi:10.3390/w13060849, 2021*

5. O.Akoumianaki, Space-time analysis of rain data of Crete using statistical methods, *Diploma Work, School of Environmental Engineering, Technical University of Crete, Chania, Greece, doi.org/10.26233/heallink.tuc.83550, 2019*