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Stochastic investigation of the uncertainty of atmospheric processes related to renewable energy resources

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1.Introduction

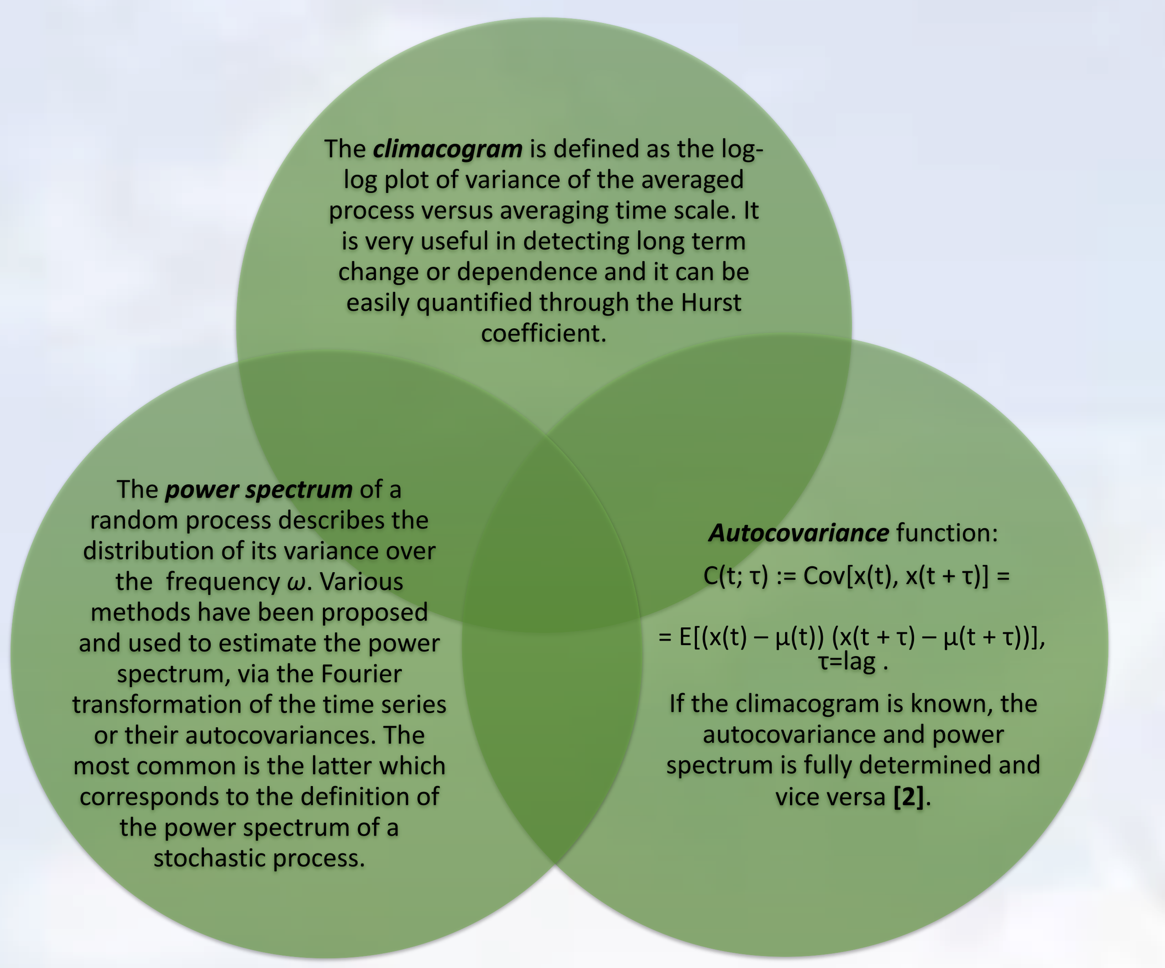
Over the past 20 years, renewable energy resources have increasingly become widely accepted. The irregular variability of the related geophysical processes introduces a great degree of uncertainty to the renewable energy resources, the most notable being ocean, wind and solar energy and thus there is limited predictability. Specifically, the more complex the process is the larger the introduced uncertainty. A simple but firm measure of the inherent uncertainty of the introduced data is the Hurst parameter. However, as the inherent uncertainty increases, so does the Hurst parameter; this phenomenon is known as the Hurst-Kolmogorov behaviour **[1]** and it has been detected in several geophysical processes.

There are various methods to estimate the Hurst parameter, such as the climacogram, the power spectrum and the autocovariance. Nevertheless, it has been noticed that the former is the most valid one. The climacogram has a low estimation uncertainty compared to the autocovariance and power spectrum and it is also useful for detecting long term changes of a process. Once we have gathered all data needed, we applied the climacogram method to timeseries from different processes related to renewable energy systems and compared the results among them in order to provide real-word examples of renewable energy systems management and to demonstrate the technical significance of the outcome of this research

Research objective

The purpose of this analysis is to investigate whether it is possible to determine the degree of the uncertainty and predictability across different timescales, by applying the climacogram method to timeseries from processes related to renewable energy systems. Emphasis is given to processes related with marine energy, and we also present summary results for other processes.

2.Climacogram vs Autocovariance and Power Spectrum



- ❑ The estimation of power spectrum or autocovariance from data, may distort the true behavior of the process and thus, may lead to wrong or unnecessarily complicated interpretation.
- ❑ The climacogram has larger bias and the smallest estimation error compared to the other two methods (with the power spectrum presenting the largest one).
- ❑ As far as the autocovariance is concerned, even for an infinite sample size besides its large bias, it is also prone to discretization errors as its value can never be equal with the true value in continuous time and so does the power spectrum.
- ❑ The power spectrum has a complicated definition (based on the Fourier transform of the autocovariance), which also involves complicated and high computational cost calculations for the discrete time and expected values

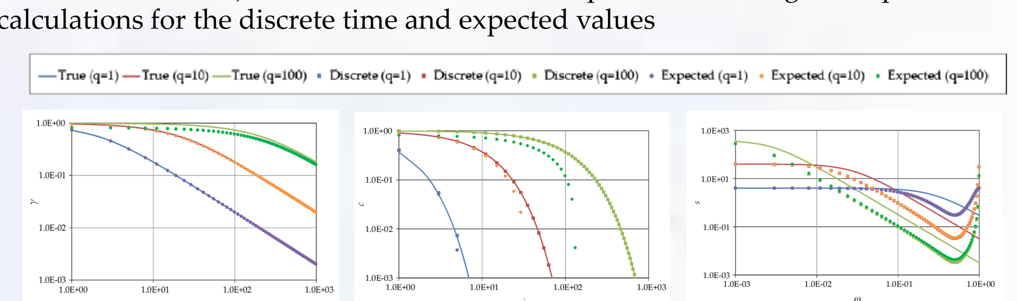


Figure 1.True values in continuous and discrete time and expected values of the climacogram (left), autocovariance (center) and power spectrum (right)

Uncertainty

The term "Renewable Energy Sources" (RES) is directly related to natural elements and weather phenomena that are governed by strong uncertainty, and thus unpredictability. The latter can be quantified by applying the climacogram (i.e. the variance of the time-averaged process over averaging time-scale) and estimate the corresponding Hurst parameter. We remark that the uncertainty of predictions increases with time scale, while the autocorrelation factor deteriorates.

The inherent uncertainty of the stochastic processes related with RES strongly affects both the cost and capacity of investments. Thus, optimization should be applied in the design and management of renewable sources, since they are all destined to be reclaimed in systems related with energy production. Determining the level of uncertainty might lead to more efficient investments and add greater reliability while as a consequence firm energy could be produced.

Determinism vs Unpredictability

The common sense which prevails that unpredictability is a component of predictability, suggesting that there is a "virus of randomness" infecting only specific phenomena, is inaccurate. Natural systems may instill both randomness and determinism in their processes. Recent studies **[3]** indicate that determinism and unpredictability actually coexist; however, the latter has a wider time-window than the former, in which predictability dominates unpredictability.

3. Climacogram of Marine energy parameters

An innovative form of renewable energy is the marine energy, which components can be classified into two categories; the first category includes tides, waves and currents which are generated by gravitational forces and the second one is expressed through the temperature or salinity differences, which are derived from the chemical processes. Although it is a very promising energy source, it has limited application; this also justifies the limited research made so far on the uncertainty of the associated processes. Nevertheless, the marine energy is expected to have a significant contribution in the near future, with a theoretical potential energy production estimated at 7500 EJ/year.

Tides Florida			
STATIONS	ρ_1	γ_1	H
1	0.20	27985.29	0.65
2	0.45	160049.35	0.61
3	0.69	0.65	0.74
4	0.31	123823.90	0.52
5	0.22	108507.59	0.74
6	0.97	3493975.97	0.64
7	0.30	69854.52	0.70
8	0.51	108267.13	0.50
9	0.33	127685.69	0.85
10	0.44	159126.52	0.87
11	0.59	108330.70	0.63
12	0.25	50892.07	0.51
13	0.31	83330.25	0.58
14	0.41	276594.09	0.50
15	0.42	116525.10	0.50
16	0.23	54094.09	0.67
17	0.33	91602.58	0.60
18	0.44	100272.99	0.50
19	0.12	27645.12	0.50
20	0.40	134585.52	0.64
21	0.45	221647.49	0.50
22	0.39	171980.39	0.66

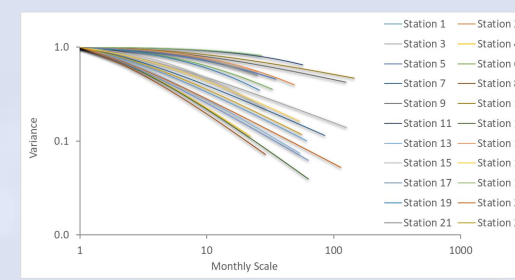


Figure 2. Climacogram for tides in Florida

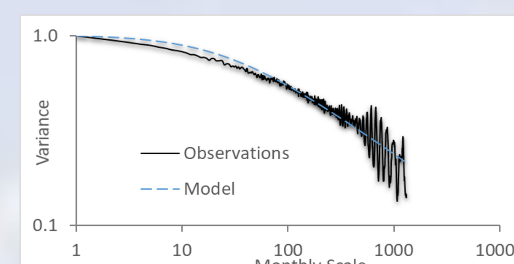


Figure 3. Climacogram for current transport in Florida

Currents	ρ_1	γ_1	H
Transport(SV)	0.93	10.73	0.80

Methodology

- **Step 1**: collection of data from different regions across the world needed to compile different timeseries (monthly, daily, hourly and semi-hourly time scale).
- **Step 2**: Climacogram estimation (the variance of the time-averaged process over averaging time-scale) for each timeseries.
- **Step 3**: Standardization of the climacogram trend through a model that uses the Hurst and q parameters.

$$\text{Model}=\frac{\gamma 1\left(1+\frac{1}{q}\right)}{\left(1+\frac{k}{q}\right)^{(2-2H)}}$$

- **Step 4:** Calculation of the Hurst parameter (a measure of uncertainty) in order to define the degree of predictability for each parameter associated with marine energy.

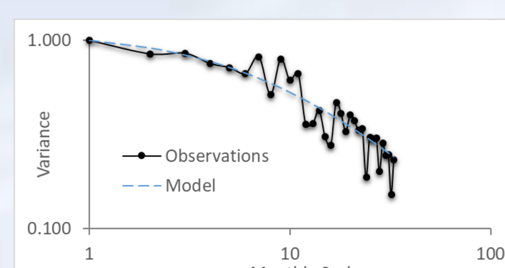


Figure 4. Climacogram for salinity in Florida (SSW28")

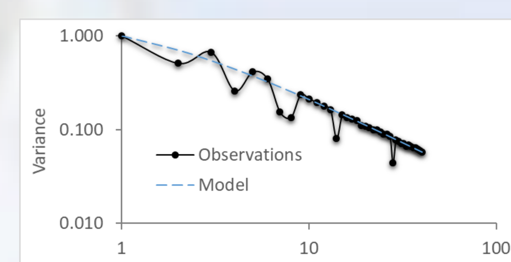


Figure 6. Climacogram for salinity in Florida (DSW40")

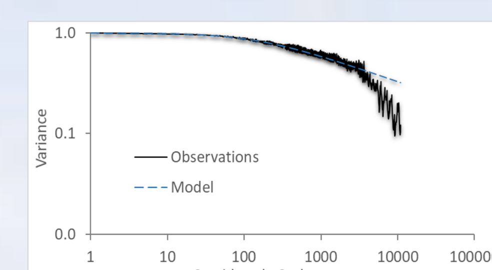


Figure 8. Climacogram for wave heights in Hilo, Hawaii

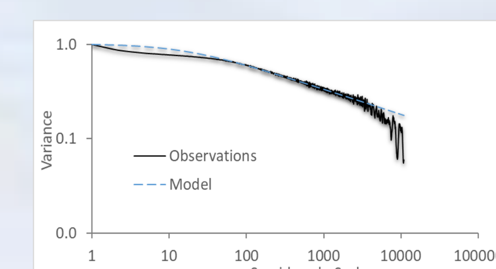


Figure 10. Climacogram for wave direction in Hilo, Hawaii

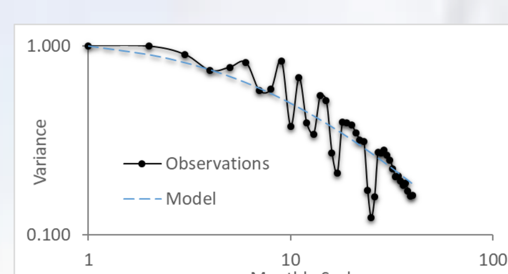


Figure 5. Climacogram for water temperature in Florida (SSW28")

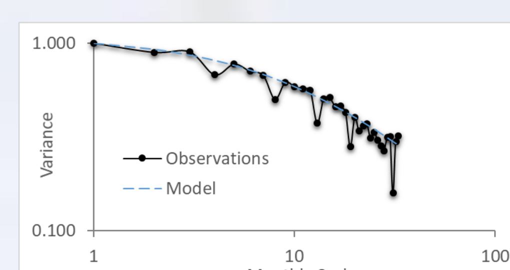


Figure 7. Climacogram for water temperature in Florida (DSW40")

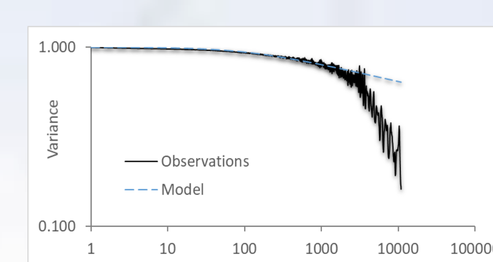


Figure 9. Climacogram for waves' mean period in Hilo, Hawaii

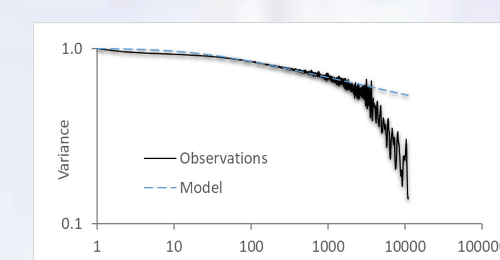


Figure 11. Climacogram for waves peak period in Hilo, Hawaii

SSW28"	ρ_1	γ_1	H
Salinity	0.71	0.07	0.50
Temperature	0.74	1.20	0.50

DSW40"	ρ_1	γ_1	H
Salinity	0.80	0.02	0.50
Temperature	0.80	0.02	0.50

Hilo,Hawaii	ρ_1	γ_1	H
Wave Height	0.98	0.51	0.87
Direction	0.72	10107.57	0.87
Peak Period	0.82	5.18	0.95
Mean Period	0.98	1.31	0.97

5.Hybrid energy system in Astypalaia

The Greek island of Astypalaia, which is located in the southern part of the Aegean sea, is currently providing energy by using fossil fuel power plants. After an extensive investigation **[8]**, it has been proved that a hybrid system, including all four renewable energy sources (solar, marine, hydropower and wind), in combination with the fuel oil could cover efficiently the energy demand of the island. However, taking into consideration that none of the aforementioned energy sources has a constant and adequate reservoir, another alternative solution could be applied. The addition of a geothermal and biomass system to the energy balance could cover all energy requirements effectively. The latter energy system would be easily controlled by operators and provide energy in all timescales.

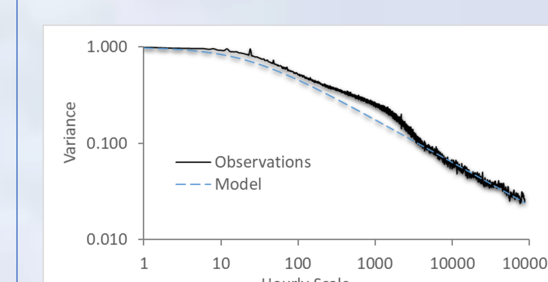


Figure 15. Hydropower Climacogram

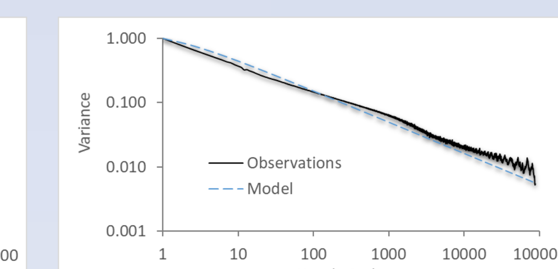


Figure 16. Wind power Climacogram

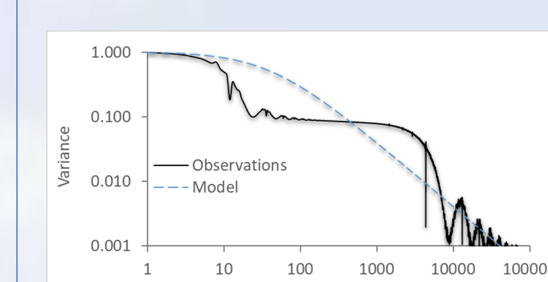


Figure 17. Solar power Climacogram

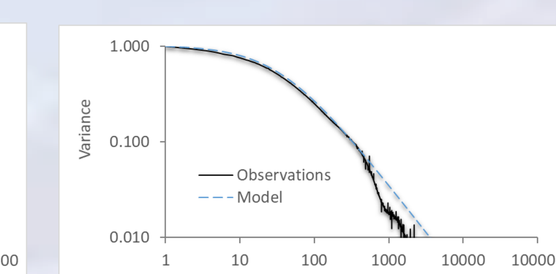


Figure 18. Marine power Climacogram.

The effect of the double cyclo-stationarity (diurnal and seasonal, e.g. **[10]**) of the presented processes can be easily depicted in the above climacograms.

Energy	Hydro	Aeolic	Solar	Marine
H	0.78	0.76	0.50	0.50

4.Natural processes climacograms and allocation of renewable energy sources capacity

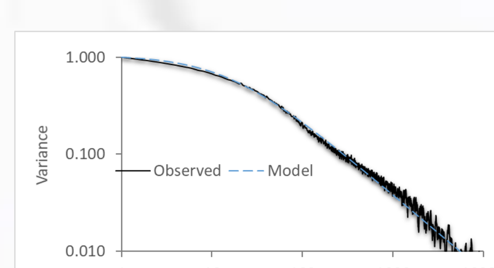


Figure 12. Climacogram for wind speed **[5]**

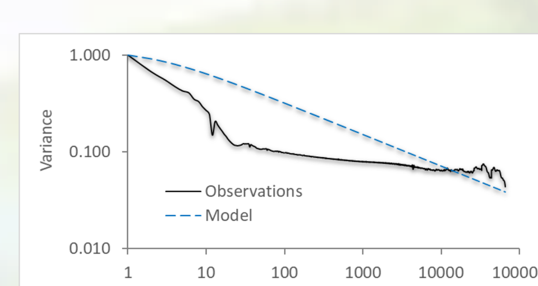


Figure 13. Climacogram for solar radiation **[6]**

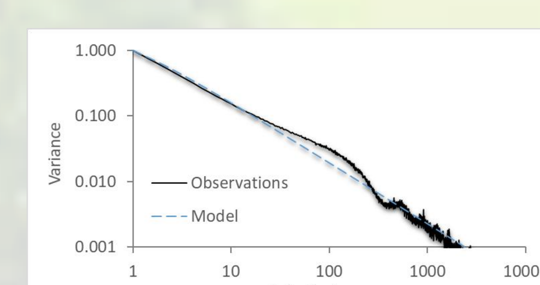
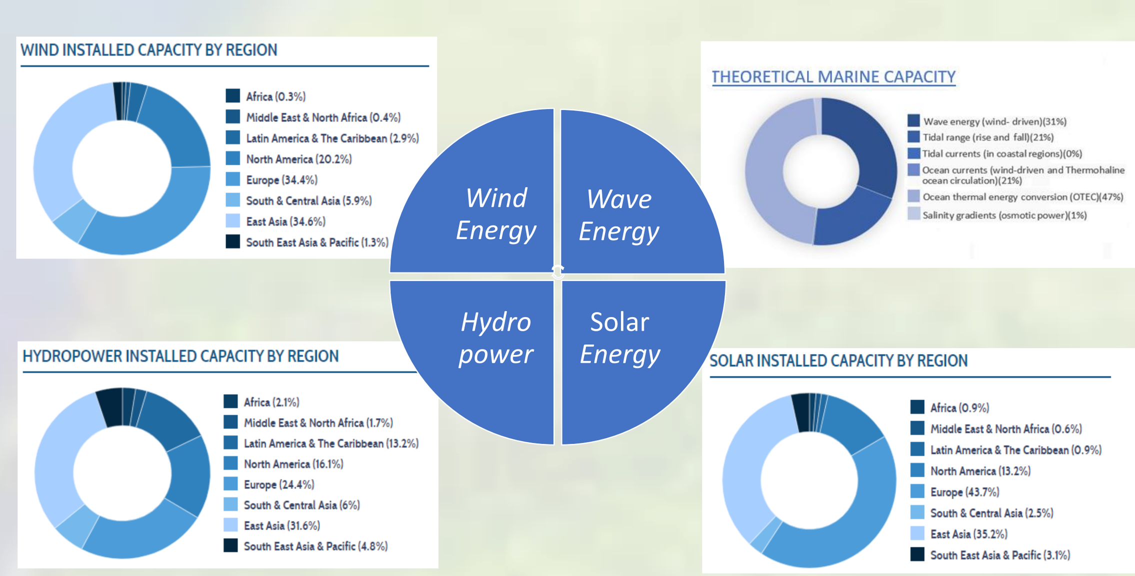


Figure 14. Climacogram for precipitation **[7]**



On the left diagram the theoretical capacity is presented for the RES of wind, hydropower, marine and solar **[4]**, (additional sources: http://www.noaa.gov/ http://www.pacioos.hawaii.edu/ https://www.worldenergy.org/)

Observations	H
Wind speed	0.61
Precipitation	0.54
Solar radiation	0.81

6.Conclusions

- The climacogram analyses revealed that in long time scales, the larger the Hurst parameter the wider the predictability window. On the other hand, concerning the short time periods, as the log-log slope of the climacogram increases so does the uncertainty, aggravating the degree of predictability.
- The Hurst parameter variates across different time scales, which is also supported by recent research outcomes **[10]**.
- The Hurst parameter is estimated greater than 0.5 ($H > 0.5$, using a biased estimator through the climacogram) for the all examined time series. Consequently, several natural processes (marine, precipitation, sun and wind) exhibit the Hurst-Kolmogorov behaviour and not a Markovian or a white noise one.
- Since the Hurst parameter is greater than 0.5, the processes that are associated with renewable energy resources systems are governed by a great degree of uncertainty. Therefore, stochastic analysis is essential in the renewable energy management.
- The aforementioned outcomes have been also demonstrated by means of an on-going project in the island of Astypalaia, illustrating how the uncertainty of several renewable energy sources can be sufficiently managed through stochastic analysis.

7.References

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