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Investigation and stochastic simulation of the music of wind and precipitation

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HS7.4/CL2.29/NP3.7: Hydroclimatic change and unchange

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1. Introduction

Sound volume can be used as a means to detect and measure hydrometeorological variables that can generate sound. Thereby, rain and wind over the sea surface can be estimated by the sound they produce if the ocean ambient noise is removed. A loud and distinctive sound is produced when the raindrops hit the ocean surface but waves also generate sound when they break. While rain and wind are difficult to measure over the ocean as gauges have to be mounted on surface buoys or ships, acoustic gauges placed beneath the ocean surface have been used as an alternative of measurement. The data that are collected from these gauges are then analyzed using empirical models.

2. Aim

The purpose of this study is to suggest a pioneering way for estimating the rainfall rate and the wind speed using the sound they produce. The tools that are used are the widely acclaimed power spectrum and the groundbreaking climacogram. Through stochastic processes both tools are compared and evaluated in terms of which one is the most suitable to be applied in the design of a model focused on describing phenomena such as wind speed and rainfall rate.

3. Methodology

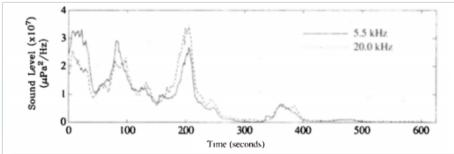
1. Sound volume time series collected by research papers are digitized using cad software
2. Through Fast Fourier Transformation Sound Spectrums of rain and wind are derived
3. Through scaling average processes the Climacograms of rain and wind are also produced
4. Generation of a thousand synthetic time series for the purpose of sensitivity analysis and comparison of the methods above

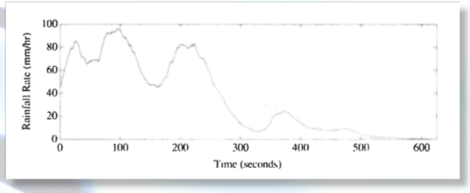
Climacogram

The plot of variance of the averaged process X_t (assuming stationary) versus averaging time scale k. It is symbolized as *γ(k)*.
The climacogram is useful for detecting the long term change, or else dependence, persistence and clustering of a process.

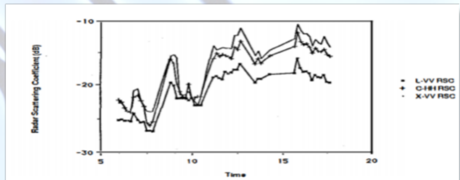
4. Data collection

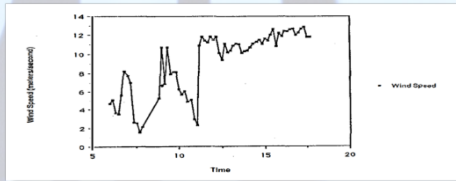
Field observations of sound generated by heavy rainfall took place during an experiment at the National Data Buoy Center's (NDBC) Ocean Test Platform (OTP) located at the Gulf of Mexico[1] .





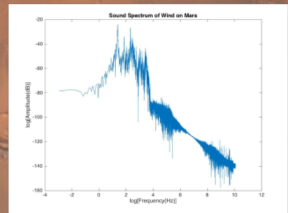
Text During the Norwegian Continental Shelf Experiment (NORSEX) radar observations of the wind took place by a scattermeter that was mounted on a ship. This instrument collected data in which fluctuations in speed of 2 to 13 m/s were experienced during a ten hour period as the ship transited an oceanographic/meteorological front[2].

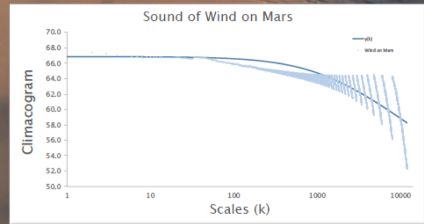




Analysis of Martian Wind

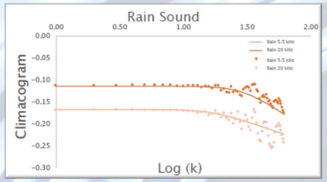
Martian wind sound recorded by NASA's InSight Lander is in the audible range of human hearing. In this study, the sound signal available by NASA was divided into three segments. The first segment corresponds to the original sound as has been recorded by the seismometers, the second segment features the same sound transported two octaves up and the last one presents the sound recorded using air pressure sensor. The sound spectrum of the first segment is demonstrated below:



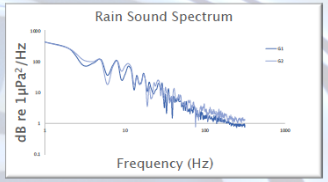


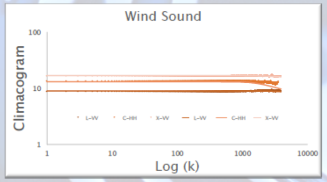
Using Vagle et al. (1990) model, we estimate the SPL at 8 kHz from the power spectrum model as derived through the proposed climacogram-based model (and not directly from the power spectrum of data) as 9.8, and the resulted wind speed as 2 m/s.

5. Results

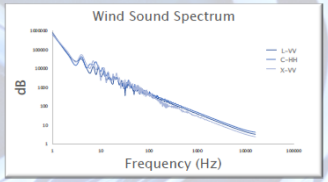


Using the field observations presented in the research papers the Climacograms and the Power Spectrums are derived as shown in this section.





In order to make a comparison and decide which of the two analysis tools is more likely to be applied in a model designing process, 1000 synthetic time series were created by the actual rainfall rate field observations that were presented in the research paper of the experiment held at the Gulf of Mexico.

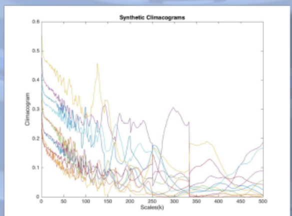


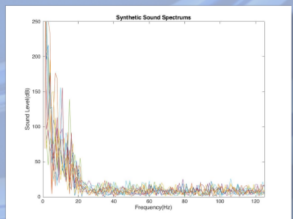
Climacogram

$$\gamma(k) = \frac{\lambda}{\left[1 + \left(\frac{k}{q}\right)^{2M}\right]^{\frac{1-H}{M}}}$$

- λ: Variance at scale zero
- k: Scale
- q: Scale parameter
- M: Fractal parameter
- H: Hurst Coefficient

Comparison





6. Conclusions

- Using the sound of weather variables as a means to evaluate the stochastic behavior thereof is a novel and promising method for estimating phenomena, such as rainfall rate and wind speed, which may prove useful particularly in locations where conventional measurement approaches may be infeasible.
- Power spectrum based stochastic analysis of wind and rainfall sound inserts a higher uncertainty in the models whereas climacogram based analysis seems more effective. Therefore it is suggested to use climacograms to investigate the wind and rain variables from the generated sound.

7. References

[1] Jeffrey A. Nystuen Charles C. McGlothin, and Michael S. Cook – The underwater sound generated by heavy rainfall, 1993
[2] Onsott, Robert G. – Scatterometer measurements of wind, waves, and ocean fronts during NORCSEX, 1989
[3] P. Dimitriadis, D. Koutsoyiannis, and P. Papanicolaou, Stochastic similarities between the microscale of turbulence and hydrometeorological processes, Hydrological Sciences Journal, 61 (9), 1623–1640, doi:10.1080/02626667.2015.1085988, 2016.
[4] P. Dimitriadis, and D. Koutsoyiannis, Climacogram versus autocovariance and power spectrum in stochastic modelling for Markovian and Hurst–Kolmogorov processes, Stochastic Environmental Research & Risk Assessment, 29 (6), 1649–1669, doi:10.1007/s00477-015-1023-7, 2015.
[5] P. Dimitriadis, and D. Koutsoyiannis, Stochastic synthesis approximating any process dependence and distribution, Stochastic Environmental Research & Risk Assessment, 32 (6), 1493–1515, doi:10.1007/s00477-018-1540-2, 2018.
[6] Barry B. Ma, Jeffrey A. Nystuen, and Ren-Chieh Lien – Prediction of underwater sound levels from rain and wind, 2005

Links:
Background picture: https://medium.com/@bonpay/everything-you-need-to-know-about-ripple-a018e8d47e30
Mars picture: https://pngimg.com/download/61174