# Analysis of the European Wind Power Climatology and the Possible Cosmic Radiation Forcing on Global Lightning Activity

PÉTER KISS

Abstract of the Doctoral Thesis

Supervisor: Prof. Imre M. Jánosi, D.Sc.

Eötvös Loránd University, Faculty of Science
Graduate School in Physics
Head: Prof. Zalán Horváth, MHAS

Statistical Physics, Biological Physics, and
Physics of Quantum Systems Program
Head: Prof. Jenő Kürti, D.Sc.

Department of Physics of Complex Systems
Eötvös Loránd University

Budapest, 2009

## Introduction and objectives

The understanding of our climate system is one of the most important scientific goals today. An issue, which is tightly linked to climate speculations is our energy usage and its obvious unsustainability. Regardless of the possible effects on our climate, it seems inevitable to change fossil fuels for different energy sources in the future because of the finite reserves. Out of the few already existing alternatives, wind energy – and also solar thermal and photovoltaic energy – seem to be the most promising technologies. However the fossil fuel burning power plants cannot be simply replaced by wind farms because of the wildly fluctuating wind fields. In this work we try to quantitatively assess the fluctuations of various hypothetical all-European wind power networks using different models and data-mining techniques. Our aim is to demonstrate, what the limits of the European wind resource are. We also give a detailed statistical analysis of Europe's wind climatology.

After the first part of the thesis dealing with the European wind energy possibilities, which is essentially applied research, we turn our attention to a more fundamental physical question in connection with lightning activity.

There is a long standing debate on how and to what extent cosmic radiation affects our climate. In the second part of the thesis we try to identify the connection between cosmic rays and lightning activity using similar statistical and data-mining tools as we use in the case of European wind energy calculations. Lightning activity is obviously only a tiny sub-process in the climate system, however the cosmic rays – lightning activity connection seems to be relatively well supported theoretically and its clarification could possibly lead to a better understanding of more general processes.

## Data and methods

We used various statistical tools and different data-mining techniques on wind speed, lightning activity, cosmic ray flux, etc. datasets, which include the European Centre for Medium-Range Weather Forecasts' ERA-40 reanalysis wind fields (at 10 m and at 1000 hPa) for Europe; Hungarian wind turbine measurements; the electricity consumption time series of a Hungarian factory; optical satellite measurements of the Lightning Imaging Sensor (LIS); ground radio data of the Lightning Detection And Ranging (LDAR) facility, and the World Wide Lightning Location Network (WWLLN); Schumann resonance intensity records of the Northern California Earthquake Data Center (NCEDC) as a proxy of global lightning activity; ground neutron flux measurements at Jungfraujoch, Climax, and Haleakala; proton fluxes at the Polar Orbiting Environmental Satellites (POES); etc.



In the case of the lightning datasets, extensive processing was needed, therefore we implemented various filtering, averaging and clustering algorithms. With a simple model we also accounted for the multitude of spectral peaks visible in the LIS records.

Besides extracting basic statistical properties (average, standard deviation, etc.) from the various datasets, we used the maximum likelihood method to fit Weibull and generalized gamma distributions to wind speed data.

To analyze the temporal behavior of the records, we used spectral methods (Fast Fourier Transform and the Lomb algorithm) and different "seasonal" averages. Correlation matrices and autocorrelation functions were extracted as well.

The optimal configuration of wind turbines, which minimizes the fluctuations of the aggregated wind power time series, was calculated using an iterative Monte Carlo algorithm.

We used the superposed epoch method to test the link between cosmic rays and lightning activity.

## New scientific results

1. We found that the 3-parameter generalized gamma distribution is flexible enough to provide a good and simple statistical model for wind speed values over the European continent and the surrounding maritime areas. The geographical distribution of the

generalized gamma parameters reveals the possible climatological origin of different wind speed distributions at different locations [1,2,3].

2. After removing the daily and yearly component from the wind speed records, the remaining main component – which is due to the passages of cyclones / anticyclones and which can be described by a Lorentzian spectrum – got very close to the generalized gamma model (~1 % unexplained variance), which demonstrates its appropriateness [1,3].
3. We estimated the Hellmann exponent in the power law approximation of the wind profile where it was possible, but we used an average empirical wind profile instead and the measured power curve of a Hungarian wind turbine to transform European wind fields to wind power data [2,3,4,5,6].
4. We compared reanalysis based wind speed and power data with Hungarian turbine measurements, and we found a relatively good agreement of the fluctuations (the coefficient of correlation is > 0.7), however the average empirical wind profile underestimates hub height wind speeds at the particular turbine by ~30 %. The best agreement of wind power data was achieved, when wind speeds were scaled by the ratio (turbine to reanalysis) of the average wind speeds [7].
5. Using reanalysis based wind power estimations we evaluated the statistics of European hypothetical ideal wind power networks. In



the case when we „deployed" turbines over the whole continent, we obtained a low average aggregated output with significant yearly periodicity and large fluctuations. Constraining the wind power network to smaller but windier areas resulted in greater average power output and considerably increased fluctuations. The reasons for the large fluctuations were identified in the correlation properties of the wind field, which is coherently fluctuating over large areas. The fluctuations cannot be decreased to arbitrarily small levels either by optimizing turbine installations or by dynamic control [2,3,4,5,6].

6. Based on high time resolution data we compared the electricity demand of a big factory with wind power aggregated from two Hungarian sites. The results show that by matching maximum consumption and average wind power, the factory is supplied with sufficient electricity in only 34 % of time. Stable baseload supply cannot be achieved by installing excess wind power capacities. Furthermore, the length of the supplied periods shows power-law distribution (with an exponent ~-1.4), which does not change substantially with increased wind power capacities. The above results hold in the case when the real consumption pattern is replaced with constant demand as well [8].
7. We tried to identify the assumed cosmic ray – lightning activity connection by using the superposed epoch method on global lightning flash rate anomaly time series. The superposed epoch

averaging was centered on the Forbush decreases of the cosmic ray flux. However we found no significant correlation. A weak positive correlation was apparent between equatorial lightning frequency and cosmic ray flux, but the details do not support the hypothesized connection either [9,10].

## Bibliography


1. *Comprehensive empirical analysis of ERA-40 surface wind speed distribution over Europe,* P. Kiss, and I.M. Jánosi, **Energy Conversion and Management**, **49**, 2142-2151, (2008)
2. *Wind power availability over Europe,* P. Kiss and I. M. Jánosi, **poster** at the Zukunftskolleg Summer School, Konstanz, Germany, (2008)
3. *Wind field construction assessment report and maps of potential wind energy production over Europe,* P. Kiss, I. M. Jánosi, F. Bono, E. Gutierrez, ManMade **Project Delivarable** 4.1, Sixth Framework Programme (2008)
4. *Limitations of wind power availability over Europe: A conceptual study,* P. Kiss, I. M. Jánosi, **Nonlinear Processes in Geophysics**, **15**, 803-813, (2008)




5. *Wind power availability over Europe,* P. Kiss, I. M. Jánosi, **Acta Pericemonologica Debrecina**, Tomus **3**, 106-116, (2008).
6. *Az európai szélpotenciál korlátai,* P. Kiss, I.M. Jánosi, IV. Kárpát-medencei Környezettudományi Konferencia, **2**, 80-85 (2008)
7. *Comparison of wind power estimates from ECMWF reanalyses with direct turbine measurements.,* P. Kiss, L. Varga, and I.M. Jánosi, **Journal of Renewable and Sustainable Energy**, **1**, 033105, (2009)
8. *Contrasting Electricity Demand with Wind Power Supply: Case Study in Hungary,* P. Kiss, L. Varga and I. M. Jánosi, **Energies**, **2**(4), "Wind Energy" special issue, 839-850, (2009)
9. *Kozmikus sugárzás, időjárás, klíma: hol a hiányzó láncszem?,* Kiss P., Csabai I., Lichtenberger J., Jánosi I. M., **Fizikai Szemle**, **59**:238-243, (2009)
10. *On the missing link between space weather and lightning activity,* P. Kiss, I. Csabai, J. Lichtenberger, I. M. Jánosi, **poster** at the Summer School on „Climate Variability & Climate Change: Estimating and Reducing Uncertainties", Visegrád, Hungary, (2009)