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ANALYSIS OF TEMPERATURE TIME SERIES MEASURED IN ECOSYSTEMS

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ABSTRACT
This paper concerns the analysis of temperature time series using the empirical mode decomposition (EMD) and classical identification methods. The temperature time series were measured by meteorological stations which were deployed in the southern part of the Czech Republic. The data analysis was performed in both time and frequency domains. The focus of the work was to investigate the non-stationary stochastic temperature processes and to identify the structure and parameters of the dynamic model which describes the properties of this ecosystem. The data was processed using the Matlab programming environment.
Keywords: ecosystem, analysis, temperature

1. INTRODUCTION
The status of each ecosystem in terms of biodiversity and stability is directly dependent on two factors. The first is the energy balance, including the incoming and outgoing energy flows; the second is the hydrological balance. The monitoring and examination of ecosystems allows us to express the link between the directly and indirectly measured values as well as the landscape elements. Monitored ecosystems are examples of complex dynamic systems with distributed parameters which have a number of interactive variables [1,12]. Temperature is one of the most important parameters of all ecosystems. It is directly measurable and reflects both energy and hydrological conditions. For monitoring the landscape of southern Bohemia near the town of Trebon, twelve meteorological stations were installed to monitor an area of about 50 km^2 in diverse biotopes; e.g. a drained field, a meadow, an urbanized area, a concrete panel surface of a sewage water treatment plant, the surface of a artificial lake, etc. [8]. Ground meteorological stations (Figure 1) were equipped with sensors making it possible to measure the energy fluxes on the sites under observation. The following quantities were monitored and

Figure 1. The ground meteorological station

recorded at 10-minute intervals: precipitation, soil humidity, air temperature and humidity at 30 cm and 2 m, incidental and reflected global solar radiation in the short-wave region (0.3 – 2.8 μm), incidental and emitted radiation in the IR region (4.5 - 45 μm), wind speed and direction at 2 m, ten values for soil temperature measured every 10 mm of soil depth and then at depths of 200 mm and at 250 mm. In addition to using the ground meteorological stations, a 30m tall transportable meteorological station (Figure 2) for measuring temperatures and energy flows at the interface between vegetation and atmosphere was constructed. This unique device was developed under the NPV 2B06023 Project. It enables the measuring the vertical gradient of temperature, air moisture and air pressure. With its thermal imaging camera, it can record the temperature of a field with a area of up to 28x20 meters. The pole also has more types of sensors that the ground meteorological stations do not have. Measurements from all of the meteorological stations are recorded at 10 minute intervals and data is stored in the Fiedler-Magr database (https://stanice.fiedler-magr.cz). The database is accessible via the Internet to all of the participants in the project. Several times a year, the database was updated with thermograms taken by an airship (Figure 3) or by a Cessna TU 206 F aircraft (Figure 4) using a FLIR THERMACam PM 695 thermographic camera. The frequency of photographs was determined by the forward speed of the airship or the aircraft.

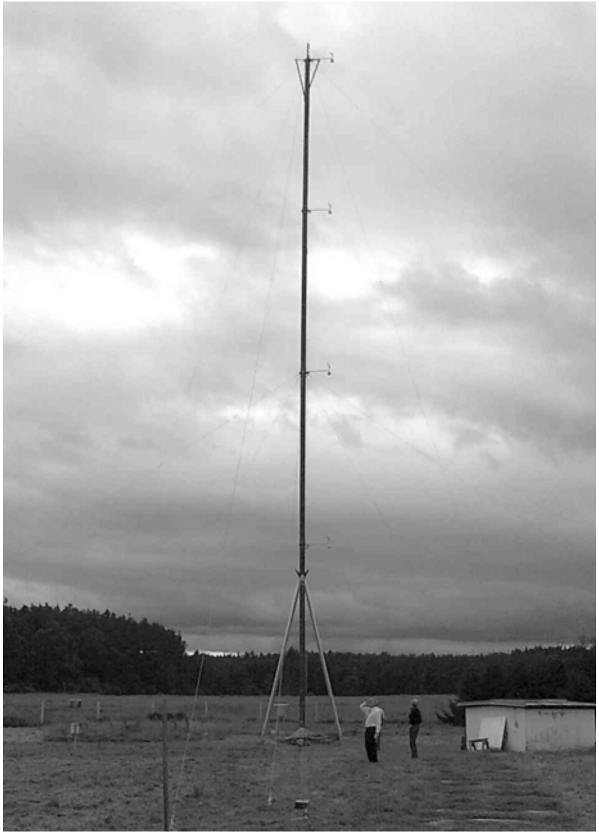

Figure 2. The transportable meteorological station

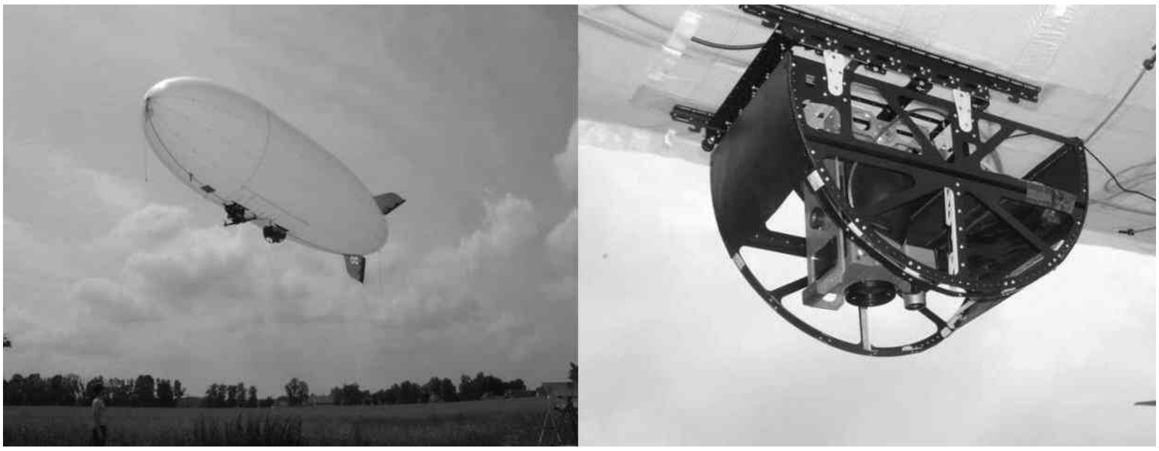

Figure 3. The airship with the thermographic camera

2. PROCESSING TEMPERATURE DATA

The measured data was processed mostly in the Matlab environment developed by MathWorks, Inc. The main goal was to judge the states of ecosystems and to estimate their future development. Water, thanks to its high capacity for storing energy in the form of latent heat, is able to redistribute much of the solar heat energy received by the Earth through the water cycle by evapotranspiration and condensation. Therefore, water evapotranspiration and condensation play an instrumental role in climate control with regard to temperature distribution in time and space, i.e. by reducing the peaks and modulating the amplitudes of high and low temperatures on the land surface and thus creating conditions on Earth suitable for life. For this purpose, the energetic and hydrologic processes ongoing in ecosystems were modeled. The hydrologic models require evapotranspiration estimates. The intensity of evapotranspiration is mainly determined by mathematical models rather than by direct measurement. Most mathematical models are used to calculate the evapotranspiration estimates based on the energy balance of the evaporating surfaces. The evapotranspiration of ecosystems was estimated using the Penman-Monteith method and by the method based on the use of the Bowen ratio [1,2,3,10,11]. Both approaches are based on the fact that the evaporation of water consumes high amounts of energy. The energetic and hydrologic processes were modeled on the empirical and analytic identification, where the temperatures were the most important parameters that reflect both the energetic and hydrologic processes. The air and soil temperatures were measured with thermocouples. In addition to using thermocouples the surface temperature was measured with CG3 pyrgeometers manufactured by the Kipp & Zonen company [5]. Effective surface temperature T_{gr}, using the pyrgeometer, was calculated according to

$$T_{gr} = \sqrt[4]{\frac{E_{CG3}}{\sigma}} \text{ , [K]} \qquad (1)$$

where E_{CG3} is the far infrared irradiance measured with the CG3 pyrgeometer [W.m^{-2}] and σ is the Boltzmann's constant (σ=5.6697 10^{-8} W.m^{-2}.K^{-4}) [5, 9]. The infrared pictures obtained by the airship at 200 m, combined with information of the proper weather conditions (such as humidity, outside temperature, etc.), provide accurate data. For this purpose, the ThermaCamTM Researcher software from the FLIR company was used to process the results and determine the accurate surface temperatures from the infrared images. The ThermaCamTM Researcher also allows the exporting of data from an infrared image into Matlab, where it can be easily processed. The infrared images converted into Matlab are shown in Figure 4 and 5. It can be visualized as a standard matrix or a 3-D image with a wide range of settings.

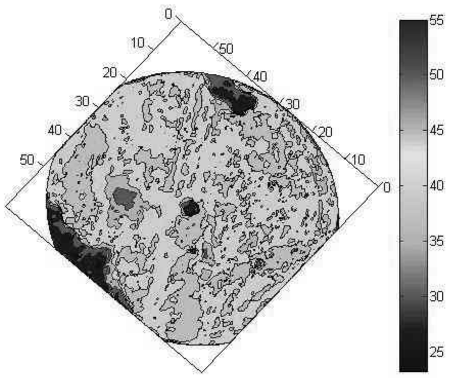

Figure 4. Surface temperatures [°C]

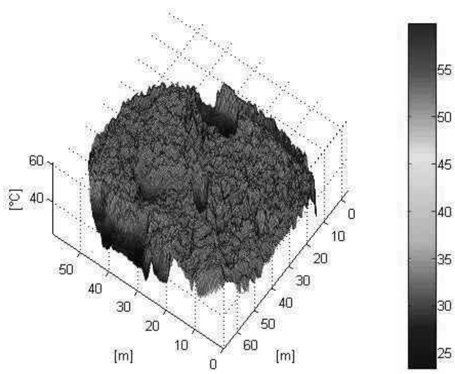

Figure 5. Surface temperatures in 3D [°C]

For static models, the models described in [1,11] were mainly used. The dynamic processes were described in the time domain (mostly using ARX models) and the frequency domain (with linear models). The time and frequency analyses were performed using the System Identification Toolbox (the toolbox for Matlab), which constructs mathematical models of dynamic systems from measured input-output data. In addition to this toolbox the Hilbert-Huang transform (HHT) for temperature analysis was also used. It consists of two parts, the empirical mode decomposition (EMD) followed by the Hilbert spectral analysis [6,7]. The EMD algorithm breaks down the signal into its components, called intrinsic mode functions (IMF), to which the Hilbert analysis can be applied. The HHT is applicable for nonlinear and nonstationary analysis. Figure 6 shows an example of the Hilbert amplitude spectrum for air temperature. In this case, the sampling interval was 10 minutes. The HHT was used for identification, filtering, prediction, simulation and fault detection by using environmental data [4].

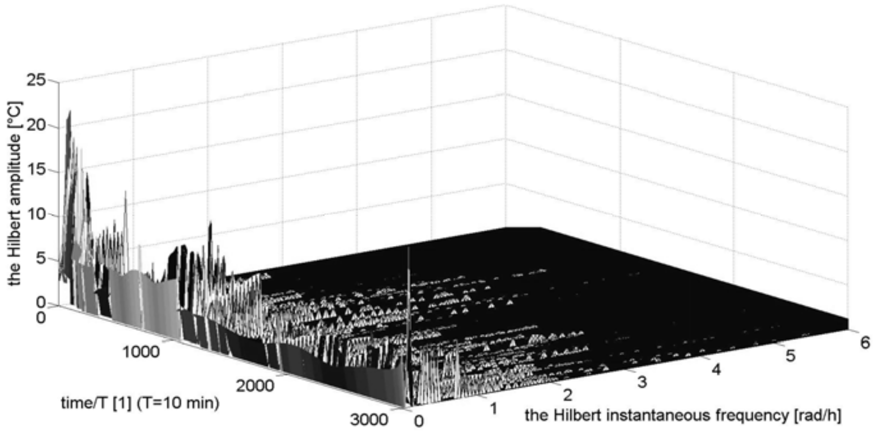

Figure 6. The Hilbert amplitude spectrum for the air temperature

3. CONCLUSION

The measured data and obtained models were used for the estimation of the static and dynamic characteristics in the time and frequency domain. This was done using the measurable parameters to: model the temperature field, to quantitatively describe the energy fluxes and the evapotranspiration and evaluate the temperature trends within the selected area. The main goal of this research was to evaluate the impact of human activity on the landscape and to estimate the future development of selected ecosystems. The results validate the idea that wetlands, sufficiently supplied with water, are important in the energy and water budget of drained agricultural landscapes.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

[1] Allen, R.G., Pereira L. S., Raes D. , Smith M.: Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements, FAO Irrigation and drainage paper 56, Food and Agriculture Organization of United Nations, Rome, 1998.,

[2] Arya S. P.:Introduction to Micrometeorology, Academic Press, San Diego, 2001.,

[3] Brutsauert W.: Evaporation into the Atmosphere, Kluwer Academic Publishers, Dordrecht. 1991.,

[4] Hofreiter M.: The Application of Hilbert-Huang Transform to Non-Stationary Environmental Data Sets, Proceedings of the 14 International Conference TMT 2010. Zenica: Faculty of Mechanical Engineering in Zenica, pp. 309-312, 2010.

[5] Hofreiter M. - Jirka, V.Analysis of Evapotranspiration Estimation Uncertainty, Proceedings of VI-International Conference on Enviromental Hydrology, Cairo: American Society of Civil Engineers - Egypt Section, 15 p., 2009.

[6] Huang N. E., Shen S. P.: Hilbert-Huang Transform and Its Applications, World Scientific Publishing Co. Pte. Ltd., 2005.,

[7] Huang N. E., Shen Z., Long S., Wu M. C., Shih H. H., Zheng Q., Yen N.C., Tung C. C., Liu H. H.: The empirical mode decomposition and Hilbert spectrum for nonlinear and non-stationary time series analysis, Proc. R. Soc. London A 454,pp. 903-995, 1998.

[8] Jirka V., Hofreiter M., Pokorny J., Novak M.: Method for Estimation of Surface Fluxes of Solar Energy in Landscape Based on Remote Sensing, Proceedings of VI-International Conference on Environmental Hydrology, Cairo: American Society of Civil Engineers - Egypt Section, 13 p, 2009.

[9] Kipp & Zonen B. V.: Instruction Manual-Net Radiometer CNR 1, Delft. 46 p, 2002.

[10] Monteith, J.L.: Principles of Environmental Physics, Edward Arnold (Publishers) Limited, London, 1973.,

[11] Novák, V.: Evaporation of Water in Nature and Methods of its Determining, (in Slovak) VEDA SAV, Bratislava, 1995.,

[12] Ward A. D., Trimble S. W.: Environmental Hydrology, CRC Press LLC, Boca Raton, 2004.,