# JOINT EFFECTS OF LARGE SCALE CIRCULATION AND ATMOSPHERIC OSCILLATIONS (ENSO, NAO) ON REGIONAL CLIMATE PARAMETERS

**Thesis of the PhD dissertation**

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## INVESTIGATED PROBLEMS, AIMS

Oceanic and atmospheric large scale circulation processes and their interactions have an important role in the climate system. One of the most complex phenomena is the so-called ENSO (El Niño / Southern Oscillation) with periodicity of 2-7 years. Most of its effects are detected in the tropical Pacific Ocean, however, regional climate of distant areas may be affected. Western/Eastern warm or cold oceanic currents remaining for several months in the tropics, and quasi-periodic air pressure change simultaneously occurring in the region refer to the ENSO phenomenon. El Niño, La Niña, and neutral phases can be distinguished. Regional scale extreme events associated with El Niño and La Niña involve serious economic and ecological consequences. Besides the strong ENSO effects on the tropical Pacific region, several climatological teleconnections to remote areas all around the world are studied and analysed.

Being one of the mid-latitude large scale oscillation phenomena, North Atlantic Oscillation (NAO) is strongly associated with the climate of Europe, and thus, Hungary. NAO is responsible for approximately one third of the total climatological variance of the North Atlantic region. According to the observations the Icelandic Low and the Azores' High tend to change simultaneously. In particular during winter, cyclones with very low pressure tend to form near Iceland, and in the meantime, anticyclones forming near the Azores Islands tend to develop with very high air pressure. More intense dipole structure of the sea level pressure, and consequently increased meridional pressure gradient indicates the positive phase of NAO. This entails more intense western air mass flow on the mid-latitudes. During negative phase of NAO weaker cyclones develop near Iceland, while Azores' anticyclones form with lower than usual pressure. As a consequence, the meridional sea level pressure gradient decreases.

In the dissertation joint effects of large scale circulation and climatic oscillation phenomena (ENSO, NAO) on the Northern mid-latitudes have been analysed. Two selected regions have been investigated: (1) the Carpathian Basin in the Atlantic-European area, (2) the Midwest in North America. Our main goal was to determine the statistical relationships, and then considering these findings, to build models that are able to estimate regional climate parameters.

## APPLIED METHODOLOGY

In our studies traditional mathematical statistical techniques (teleconnection analysis, EOF analysis, multivariate linear regression) and an alternate technique (fuzzy rule-based models) have been applied. Fuzzy logic is considered a new approach in the meteorology literature in Hungary.

The database under investigation contains several datasets: (1) oscillation phenomena are represented by time series of various index; (2) large scale circulation is represented by the monthly relative frequency of MCP types presented in section 2 of the dissertation, and time series of height and temperature of several geopotential levels; (3) regional climate parameters include monthly precipitation amount, monthly mean temperature, monthly amount of the elements of hydrological balance of the Lake Balaton, and monthly values of the Palmer Drought Severity Index (PDSI and PMDI).

In order to reveal statistical linkages between distant regions teleconnection analysis is used, namely, anomaly maps of height and temperature of several geopotential levels are compared during different phases of atmospheric oscillation phenomena. Furthermore, monthly relative frequency of large scale macrocirculation patterns and regional climate parameters is evaluated in case of these phases. EOF analysis uses empirical orthogonal functions to map spatial patterns of a given field possessing the largest variances during different ENSO phases. Numerical procedure of EOF serves to solve the eigenvalue equation of the correlation matrix of a given field. Eigenvectors provide EOF modes corresponding to the eigenvalues, which indicate percentages of contribution to total variance of the given field. Regions with the largest positive and negative values in the spatial patterns of EOF modes show the action centers of the given field.

Multivariate linear regression (MLR) and fuzzy rule-based (FRB) models determine the regional climate parameters using predictor variables. Large scale macrocirculation patterns (their monthly distribution) and several index characterizing climate oscillation phenomena – ENSO and NAO – (Southern Oscillation Index: SOI, and SST indices) are considered as predictors in case of both techniques. Fuzzy logic is able to consider several contradictory responses, which may be true to varying degrees.

In the dissertation sensitivity analysis of FRB models is carried out, furthermore, model outputs are compared to results from the MLR models using the same conditions (i.e., input variables, datasets).

## RESULTS, CONCLUSIONS

Based on our results the following conclusions can be drawn.

1. Besides the more direct effect of large scale macrocirculation, teleconnection of climatic oscillation phenomena (ENSO, NAO) is considerably present in the selected regions of the Northern mid-latitudes.

2. Based on the analysis of the anomaly fields of the Atlantic-European region during El Niño events lower than usual geopotential heights occurred above the northern areas (centered at Scandinavia) in spring, while during La Niña events geopotential heights tend to be higher than during neutral phase. Temperature anomalies at the different geopotential levels during El Niño phase are negative above Scandinavia, and positive above the Iberian Peninsula and the Black Sea. While during La Niña phase geopotential temperature values are higher than usual at the northern areas, and lower than usual in the Mediterranean region.

3. The first EOF modes of the geopotential level heights of the Atlantic-European region can be characterized by zonal spatial patterns, and meridional patterns are present in the higher modes. Geographical locations of the action centers during El Niño and La Niña phases are considerably different in case of the 2nd, 3rd, and 4th EOF modes of the height and temperature fields of different geopotential levels.

4. In spring during El Niño events cyclonic MCP types tend to occur 20-25% more often than during neutral phase, while anticyclonic MCP types 12-27% less often in the Atlantic-European region.

5. Based on the ENSO teleconnection analysis for the 20th century during El Niño phase considerably colder December, January, and March, and warmer February can be

observed in Hungary. As far as the precipitation conditions, July and March tend to be wetter, while April is usually drier than usual. During La Niña phase February/March is colder, May/June is warmer than usual in Hungary. Furthermore, drier October/November, and wetter April, August can be observed.

6. Regional effects of NAO can be detected mainly in the zonal and meridional air mass flow. In the positive phase zonal MCP types tend to occur more often, while in the negative phase relative frequency of meridional MCP types is likely to increase. Further analysis considering flow direction showed that MCP types with western and eastern flow increased during positive and negative phase, respectively.

7. Based on the temperature and precipitation time series analysis for 20th century during the negative NAO phase colder and wetter months are more likely to occur in Hungary, while during the positive NAO phase warmer and drier months tend to occur more frequently.

8. Teleconnection analysis using correlation terms indicate that changes in the sea surface temperature (SST) of the tropical Pacific Ocean are followed by a 2-3 months lag period in the temperature changes of Hungary. In case of the strongest correlation the coefficient is -0.84. Correlation coefficients between the time series of SST and precipitation in Hungary are not significant. Because of the geographical proximity of the NAO phenomenon the time lag is shorter (only 1-2 months) than in case of ENSO. Also, stronger relationships can be found between the index time series and the regional climate parameters (e.g., in case of temperature the maximum value of the correlation coefficient is 0,87).

9. Regional climate information obtained from the fuzzy rule-based models using both the relative frequency of MCP types and the climatic oscillation phenomena as input variables are able to reproduce the statistical characteristics of the observed regional climate parameters. The best results can be achieved if (1) both zonality and cyclonic/anticyclonic dominancy are considered at MCP classification, (2) time lag of the climatic oscillation is also taken into account.

10. Simulated time series much better represent the observed time series if FRB models presented in the dissertation are used instead of MLR models. Based on the comparison

of different model error terms the same conclusion can be drawn: errors of the FRB models are smaller than those of the MLR models.

11. MLR models are not able to reproduce the extreme climate conditions (i.e., Palmer Index values that are larger than +3, or smaller than –3), not even in case of the training set. On the other hand, FRB models reproduce extreme Palmer Index values, as well, as normal climate conditions. The same conclusion can be drawn from the comparison of standard deviation values of time series simulated by MLR and FRB models. For example in case of Nebraska, the observed, the MLR-modeled, and the FRB-modeled PMDI time series possess standard deviations around 2.47, 1.20, and 2.46, respectively.

12. Statistical characteristics of the simulated PDSI datasets using FRB models are significantly closer to those of the observed datasets for all the 10 stations in Hungary than with MLR models. For example, comparing standard deviations of the observed, the MLR-modeled, and the FRB-modeled PDSI time series: they are between 1.5-2.3, 0.3-0.7, and 1.8-2.5, respectively.

13. Comparison of MLR and FRB model errors simulating monthly precipitation. Both MAE and RMSE are considerably smaller using FRB models than MLR models. Correlation coefficients between the observed and the simulated precipitation time series are between 0.4-0.5 in case of MLR models, while 0.7-0.8 in case of FRB models (both types of models use the same input variables).

Main advantage of applying fuzzy rule-based models includes long range estimation of climate parameters when regional climatological information is needed for a long period.

## SELECTED PUBLICATIONS

Pongrácz R. (1997): ENSO-fázisok hatáselemzése a közepes földrajzi szélességeken. In: *A meteorológus PhD-hallgatók I. országos konferenciája* (eds: Pongrácz R., Tóth Á.); *Egyetemi Meteorológiai Füzetek,* No.**9**., pp. 22–25.

Bartholy J., Pongrácz R. (1998): ENSO-szignálok értékelése az Atlanti-Európai térségben és a Kárpát-medencében. In: *Meteorológiai Tudományos Napok '97: Az* *éghajlatváltozás és következményei* (ed: Dunkel Z.), pp. 241–248., HMS, Budapest.

Pongrácz R., Bogardi I., Duckstein L., Bartholy J. (1998): Fuzzy rule-based techniques to link El Nino and regional drought. In: *Proceedings of EUFIT '98, 6th European Congress on Intelligent Techniques and Soft Computing*, pp. 1048-1051., Aachen, Germany.

Pongrácz R., Bartholy J. (1998): ENSO related NAO signal comparison. In: *Proceedings of the 2nd European Conference on Applied Climatology, ECAC98* (ed: P. Steinhauser), CD-ROM. 7p. Zentralanstalt für Meteorologie und Geodynamik, Wien, Austria.

Pongrácz R., Bartholy J. (1998): Éghajlati távkapcsolatok elemzése a Kárpát-medence térségére. In: *II. Erdő és Klíma Konferencia* (eds: Tar K., Szilágyi K.), pp. 37–41., Kossuth Univ. Press, Debrecen.

Pongrácz R., Bogardi I., Duckstein L., Bartholy J. (1998): Risk of regional drought influenced by ENSO. In: *Risk-Based Decision Making in Water Resources VIII, Proceedings of the Eighth Conference* (eds: Y.Y. Haimes, D.A. Moser, E.Z. Stakhiv), pp. 114-125., ASCE, Reston, Virginia.

Pongrácz R. (1999): Az ENSO-jelenség és az Északi-hemiszféra cirkulációjának együttes regionális hatásai. In: *A meteorológus PhD-hallgatók II. országos konferenciája* (eds: Kircsi A., Pongrácz R.); *Egyetemi Meteorológiai Füzetek*, No.**13**., pp. 50–56.

Pongrácz R., Bogárdi I., Duckstein, L. (1999): Application of fuzzy rule-based modeling technique to regional drought. *J. Hydrology*, **224**, pp. 100-114.

Bartholy J., Pongrácz R. (1999): Interactions between macroscale atmospheric circulation, SST anomalies and ENSO phases in the Atlantic European region. In: *Proceedings of the 8th Conference on Climate Variations* (eds: C.F. Ropelewski et al.), pp. 62-67., AMS, Boston, Massachusetts.

Pongrácz R., Bogardi I., Duckstein L. (1999): Fuzzy rule-based prediction of droughts. In: *Proceedings of EUROFUSE-SIC '99, 4th Meeting of the Euro Working Group on Fuzzy Sets and 2nd International Conference on Soft and Intelligent*

*Computing* (eds: B. De Baets, J. Fodor, L.T. Kóczy.), pp. 371-375., Budapest, Hungary.

Pongrácz R., Bogardi I., Duckstein L. (1999): Drought forecasting using atmospheric circulation and ENSO information. In: *Hydraulic Engineering for Sustainable Water Resources Management at the Turn of the Millennium: Proceedings* (eds: M.N. Abbott et al.), CD ROM. 8p. Graz, Austria.

Pongrácz R., Bartholy J., (2000): Statistical linkages between ENSO, NAO, and regional climate. *Időjárás*, **104**, pp. 1-20.

Pongrácz R., Bogardi I., Duckstein L. (2000): How do weather patterns and ENSO influence extreme hydrology in Hungary? In: *Proceedings of the International Conference on Water Resources Management in the 21st Century with particular reference to Europe* (eds: I. Ijjas et al.), pp.169-176., Budapest.

Bogardi I., Duckstein L., Pongrácz R., Galambosi A. (2001): Experience with fuzzy rule-based modeling of hydrological extremes. In: *Risk-Based Decisionmaking in Water Resources IX*, *Proceedings of the Ninth Conference* (eds: Y.Y. Haimes, E.Z. Stakhiv, D.A. Moser), pp. 44-60., ASCE, Reston, Virginia.

Pongrácz R., Bartholy J., Bogardi I. (2001): Fuzzy rule-based prediction of monthly precipitation. *Physics and Chemistry of the Earth, Part B.* **26**, pp. 663-667.

Pongrácz R., Kugler Sz., Csík A., Bogárdi I. (2002): A Balaton vízháztartási elemeinek modellezése fuzzy-szabályok segítségével. *Hidrológiai Közlöny*, **82**, pp. 94-98.

Bogardi I., Pongrácz R., Csík A., Kugler Sz., Dezső Zs., Rózsa E. (2002): A Balaton vízháztartásának modellezése. In: *Az időjárás előrejelzése. Meteorológus TDK Iskola.* (eds: Weidinger T. et al.), *Egyetemi Meteorológiai Füzetek*, No.**17**., pp. 113-120.

Pongrácz R., Bogárdi I., Duckstein, L. (2002): Climatic forcing of droughts: A Central European example. *Hydrological Sciences Journal*, **48**, in press.