PhD theses

Doctoral School of Earth Sciences

The effect of the atmosphere and soil moisture content on fog formation

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2024 Pécs

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1 Introduction

Fog is often associated with high concentrations of air pollutants. Due to the harmful effects on human health and significantly reduced visibility, it is important to know as much as possible about the environmental conditions of fog formation.
It is important to analyse the climatological data about the frequency or duration of fog events and the long-term trend of atmospheric parameters (e.g. temperature, relative humidity) that control fog formation. A decrease in the frequency of fog events has been observed worldwide in recent decades, which could be influenced by various processes. Climate change and changing socio-economic processes may have caused such changes in the atmosphere, resulting in a decrease in the frequency or duration of fog events. The variability of environmental conditions that play a role in fog formation (e.g. relative humidity, soil moisture, atmospheric pollution) has a significant impact on the life cycle and characteristics of fog.
During my PhD, I studied long-term changes in the frequency and duration of fog events and the physical processes behind them. I studied the role of relative humidity (RH) in the atmosphere and the soil-atmosphere interaction.

2 Objectives

The formation of fog is contingent upon the interaction between the surface and the atmosphere. The magnitude of relative humidity, which is a function of the short- and longwave radiation budget and vertical thermal and water vapour transport, is a determining factor in this process.
In the course of my research, I sought to answer the following questions:

Q1: How does the daily average relative humidity values defined in different methods impact the conclusions drawn regarding long-term changes.

Q2: Does the atmospheric RH change in the last decades in Hungary? If such a change has occurred, it would be valuable *to determine whether this shift is statistically significant. What kind of trend can be identified in RH across different seasons and times of the day?*

Q3: What is the impact of the long-term change of atmospheric temperature on RH?

Q4: Is there any relationship in RH change between at the surface and in the lower, 100 m layer of the atmosphere?

Q5: How do parameters of the atmosphere and soil influence evaporation of surface?

3 Research methods

In order to conduct a climatological analysis, databases from Hungarian meteorological stations were utilised. These databases were made available by the predecessor of HungaroMet Nonprofit Ltd., the Hungarian Meteorological Services. In order to define the changes in relative humidity (RH) and temperature over the past decades, a homogenised database created from measured data between 1961 and 2020 was analysed.
In the homogenised database, the daily average RH was determined from the daily four measured data. The influence of the methods used to determine the daily average values on the result was examined. The uncertainty was studied using the "raw" database of meteorological data. The daily average was calculated with two different methods (i) evaluation of the daily average of the observed RH values; (ii) derived from the daily mean temperature and the daily mean water specific humidity. The uncertainty of the results for long-term change can be estimated by the difference between the results from the different methods.
The long-term change in relative humidity (RH) was determined based on climatological normal values between 1961 and 1990, divided into seasons and on time of day (12 UTC and 00 UTC). An estimation of changes for the last six decades was conducted, assuming a linear trend. Significance of these changes at each meteorological station was also evaluated.

The relative humidity of the atmosphere is dependent upon the concentration of water vapour and the temperature of the atmosphere. The objective of this study was to ascertain the role of long-term, local changes in temperature and water vapour in the long-term change of RH, utilising an equation derived from the Clausius-Clapeyron connection.

I studied the change in relative humidity (RH) in the lower 100 m layer of the atmosphere using radio sounding data observed in Budapest between 2007 and 2018. Using the measured data, an estimation was made of the change in RH at the altitudes of 50 and 100 m. The objective of the analysis of the relationship between the RH data measured at the surface and at 50 and 100 m altitude is to determine whether the long-term change of RH near the surface could be extended into the boundary layer.

The interaction between the atmosphere and soil was investigated both before fog formation and during fog events using the HYDRUS-1D numerical model. The study was conducted on four case studies. The meteorological and soil temperature data (at depths of 5, 10, 20 and 50 cm) used for model simulations were retrieved from the HungaroMet database. The soil moisture sensors (at depths of 10, 20 and 50 cm) were installed in close proximity to the meteorological station. The soil texture was defined on the basis of measurements obtained from four different depths. To ascertain the reliability of the evaluated evaporation from the surface, a comparison was conducted between the observed and simulated soil moisture and soil temperature data at varying depths. Due to the absence of observed soil moisture data between the surface and at the depth of 10 cm, the initial soil moisture profile for the simulations was only estimated in this layer. It is hypothesized that the moisture content of this soil layer can significantly influence the evaporation from the surface. Consequently, a sensitivity study was implemented with different initial soil moisture profiles. The modelled accumulated surface evaporation was then used to estimate the role of soil parameters in fog formation. Finally, a relation was sought between the changes of water vapour content derived from observed data and the modelled accumulated evaporation.

4 Summary of results

During the first period of my PhD research, I evaluated climatological trends of fog in Hungary. The results of the climatological study indicate that the duration of mist, fog and dense fog has decreased at every meteorological station over the past three decades. The greatest reduction was observed in the north-eastern region of Hungary. In the subsequent phase of research, two questions were investigated: firstly, whether there is a connection between the reduction of fog events in Hungary and long-term changes in relative humidity (RH), and secondly, what the role of surface evaporation is in fog formation. The following section presents the answers to the questions outlined in the Objectives, based on the findings of this study:

1. *The discrepancy between the daily average RH values generated through disparate methodologies can be as large as 2–4%. While the divergence between two average RH values is unambiguous, the sign of the long-term trend remains unaffected by the averaging methods (see Fig. 1). Nevertheless, the magnitude of the discrepancy between the two daily average values is analogous to the magnitude of climate change. This suggests that the magnitude of the long-term change may be contingent upon the averaging method employed.*

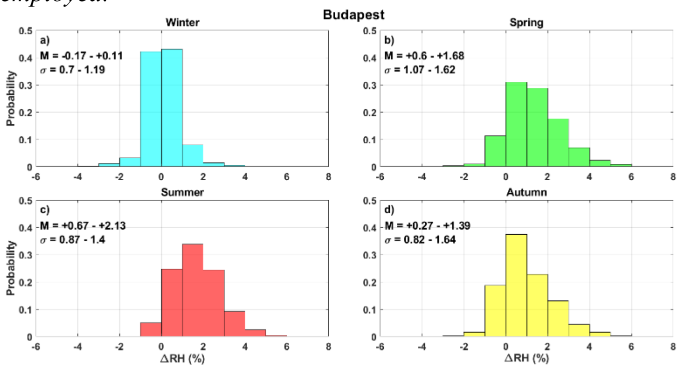

Fig. 1 The uncertainty of RH at Budapest meteorological station

2. *The change in atmospheric relative humidity (RH) between 1961 and 2020 exhibits a clear seasonal pattern, with fluctuations occurring throughout the day and across different locations. A notable decline in RH was observed at all stations during the spring and summer seasons. The extent and direction of the change in RH vary considerably between stations during the autumn and winter months (Fig. 2). Although the topography and land use of the country are relatively uniform, the long-term change of RH depends on the location of the stations. The estimated change in RH during the daytime is more significant than during night-time, with RH reducing at all stations except in autumn. However, the estimated change in RH during night-time is less significant than during the daytime, with a reducing trend observable in spring. A comparison of the results from each station suggests that the topography and land use of the country have a greater impact on changes in RH during night-time than during the daytime.*

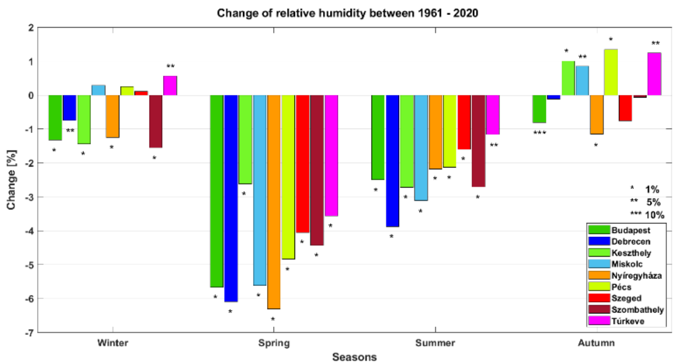

Fig. 2 The predicted change of RH in last decades. The % values represent the significance of the changes.

3. *The rise in atmospheric temperature exerts a disparate influence on the alteration of atmospheric RH across seasons (see Fig. 3). During autumn and winter, the augmented evaporation resulting from the elevated temperature serves to*

offset the impact of rising temperatures. This compensatory effect is less pronounced in spring, and the enhanced evaporation mitigates the effect of increasing temperature in summer to a negligible extent. Consequently, in summer, the change in RH is contingent upon the change in temperature.

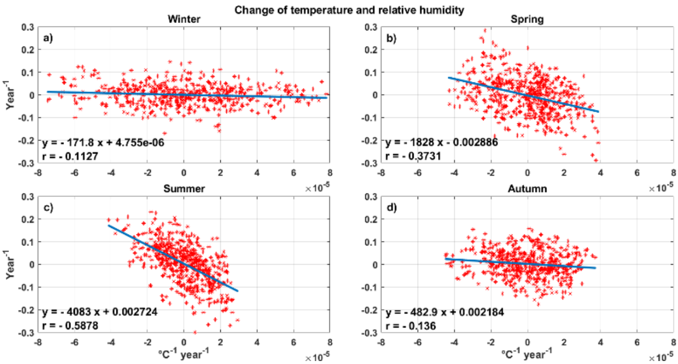

Fig. 3 The correlation between the change of atmospheric RH and temperature

4. *Radio sounding data observed at Budapest was used to determine the change of RH at daylight and at night at the surface and at altitudes of 50 and 100 m (see in Fig. 4). While an increase in RH was observed in all seasons at the surface and at altitudes of 50 and 100 m at noon, a reduction in RH was noted in the atmosphere and an increase at the surface during the nighttime hours in summer and autumn. It can be concluded that the long-term change in RH determined at the surface may be extended to the lower boundary layer if daytime trends are considered.*

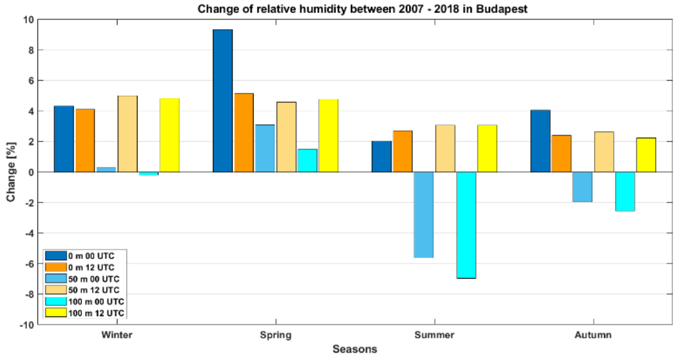

Fig. 4. The predicted changes of RH at the surface and at altitudes of 50 and 100 m based on observations at 00 and 12 UTC

5. *The results of the numerical modelling of surface evaporation (see Fig. 5) demonstrate that the evaporation of the surface is influenced by the atmospheric conditions (primarily relative humidity) and the moisture content of the upper 10 cm soil layer. The results of the sensitivity study indicate that the atmosphere became saturated as a result of two consecutive processes that occurred over time. (i) Evaporation from the surface ceases before fog formation, as evidenced by measurements; (ii) the saturated condition of the atmosphere, which is essential for fog formation, can be reached by a reduction in the temperature of the atmosphere (radiation fog) or by vertically turbulent mixing of water vapour. It is important to note that these results are the output of simulations conducted over a few days, during which the atmospheric relative humidity was consistently high (>70%). It can be assumed that surface evaporation may play a more significant role in fog formation in drier atmospheres.*

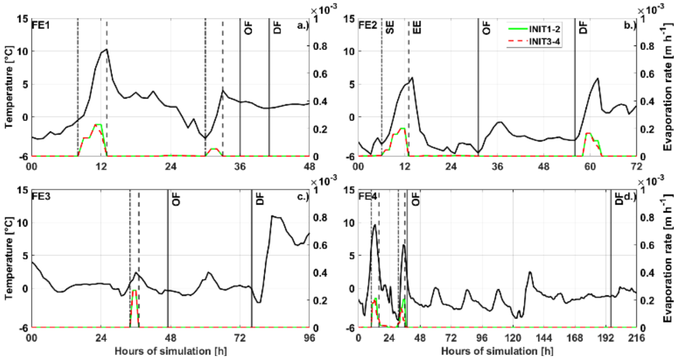

Fig. 5. The accumulated evaporation profiles of the four case studies

List of scientific papers published in the topic

Scientific articles published in periodicals or to be published:

Cséplő, A., Sarkadi, N., Horváth, Á., Schmeller, G. and Lemler, T. (2019): *Fog climatology in Hungary.* Időjárás 123, 241-264. DOI:10.28974/idojaras.2019.2.7 **Q4**

Cséplő Anikó, Schmeller Gabriella, Czigány Szabolcs, Sarkadi Noémi, Pirkhoffer Ervin, Jeevan Kumar Bodaballa, Geresdi István (2021): *Még nem nagykorú, de már adatbázis: Meteorológiai állomás a botanikus kert szélárnyékában.* Légkör: Az Országos Meteorológiai Szolgálat Szakmai Tájékoztatója 66:1, 11-18. 8pp. **A journal is not classified in the Scmiago list**

Anikó Cséplő, Beatrix Izsák and István Geresdi (2022): *Long-term trend of surface relative humidity in Hungary.* Theoretical and Applied Climatology, 149, 1629-1643. DOI: 10.1007/s00704-022-04127-z **Q2**

Anikó Cséplő, Szabolcs Czigány, István Geresdi (2024): *The impact of soil moisture on fog formation: evaluation of surface evaporation by the Hydrus-1D numerical model.* Vadose Zone Journal. **Q1**
Under review

Conference announcement:

Anikó Cséplő (2019): The climatical change of relative humidity in Hungray. In: Katalin Németh (eds.) Conference of Spring Wind 2019. International multidisciplinary conference. Abstract volume. National Association of Doctoral Students, Budapest, 2019. ISBN: 978-615-5586-42-2

Anikó Cséplő, István Geresdi and Ákos Horváth (2020): *Climatology of the relative humidity in the Carpathian Valley.* EGU General Assembly. https://doi.org/10.5194/egusphere-egu2020-17816

Anikó Cséplő, István Geresdi, Szabolcs Czigány (2023): *The Impact of Soil Properties on Fog Formation.* In: Czech University of Life Sciences Prague and PC-Progress, s.r.o. Prague. 7th International Conference HYDRUS Software Application to Subsurface Flow and Contaminant Transport Problems. Prague, Czech Republic. ISBN 978-80-213-3264-5