Seamless modeling studies of aerosol-meteorology interactions at the Ukrainian Hydrometeorological Institute

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Ukrainian Hydrometeorological Institute (UHMI)

of the State Emergency Service of Ukraine and the National Academy of Sciences of Ukraine

Kyiv, Ukraine

UHMI is the main scientific research institution in Ukraine in the field of hydrometeorology

Departments

Department of **environmental radiation monitoring**

Department of **instruments design, metrology and standardization**

Department of **the atmosphere monitoring**

Department of **applied meteorology and climatology**

Department of **the atmosphere physics**

Department of **hydrochemistry**

Department of the **system hydrometereological researches**

Laboratory of **climate change influence on water resources**

Other divisions:

Field experimental meteorological base, Boguslav field hydrometeorological base, "George Gotovchiz" motor ship, etc.

Department of **hydrological research**

Main tasks

- theoretical and applied research in the field of hydrometeorology and environmental monitoring;
- methodological support of the Hydrometeorological Service and other organizations in Ukraine

https://uhmi.org.ua/

Image Source: https://science.nasa.gov/science-research/earth-science/climate-science/aerosols-small-particles-with-big-climate-effects/

Aerosol emissions from different sources can contribute to the modification of meteorological processes through direct and indirect aerosol effects, thereby impacting weather at regional and local scales. Considering the role of aerosol effects in complex atmospheric feedbacks and the need for seamless modeling approaches for such research, the Ukrainian Hydrometeorological Institute (UHMI) established research and modeling activities within the framework of the Pan-Eurasian EXperiment (PEEX) in close collaboration with the University of Helsinki (UHEL), using the Environment–HIgh Resolution Limited Area Model (Enviro-HIRLAM)

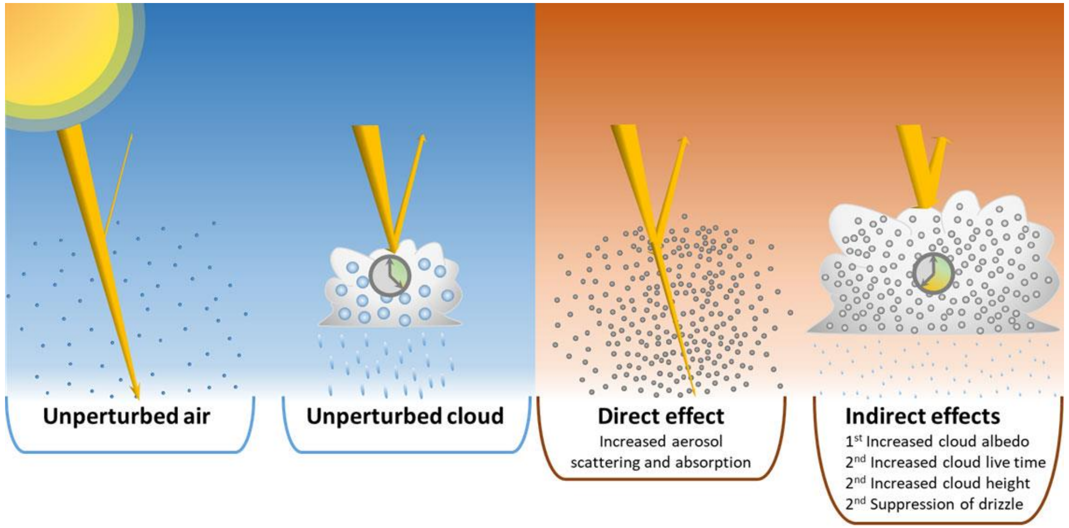


Image Source: https://user.eumetsat.int/resources/case-studies/more-sunshine-in-europe-due-to-cleaner-air

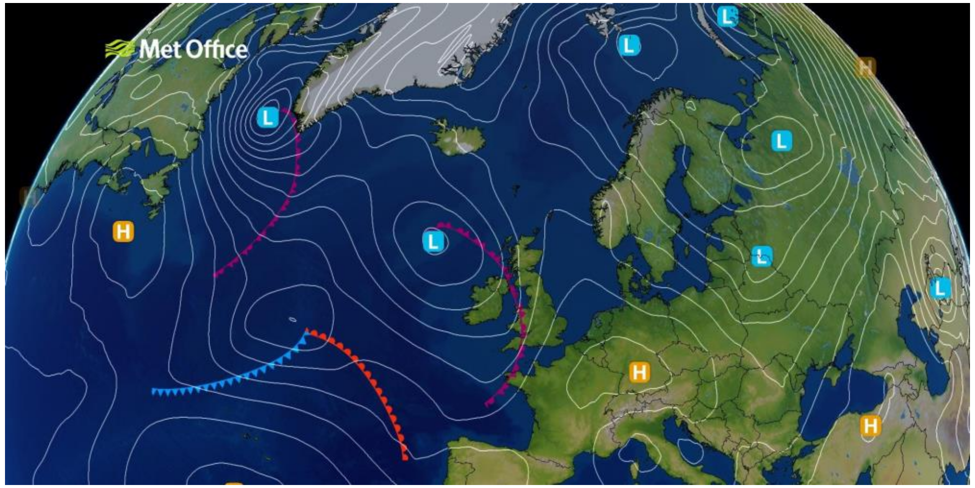


Image source: https://weather.metoffice.gov.uk/learn-about/weather/how-weather-works/synoptic-weather-chart

2018

The Influence of Land cover changes On Atmospheric Boundary Layer and Regional Climate Characteristics.

ENVRIplus project for Multi-domain Access to RI platforms
(H2020-INFRAIA-2014-2015, grant no.: 654182, 2018)

2018–2020

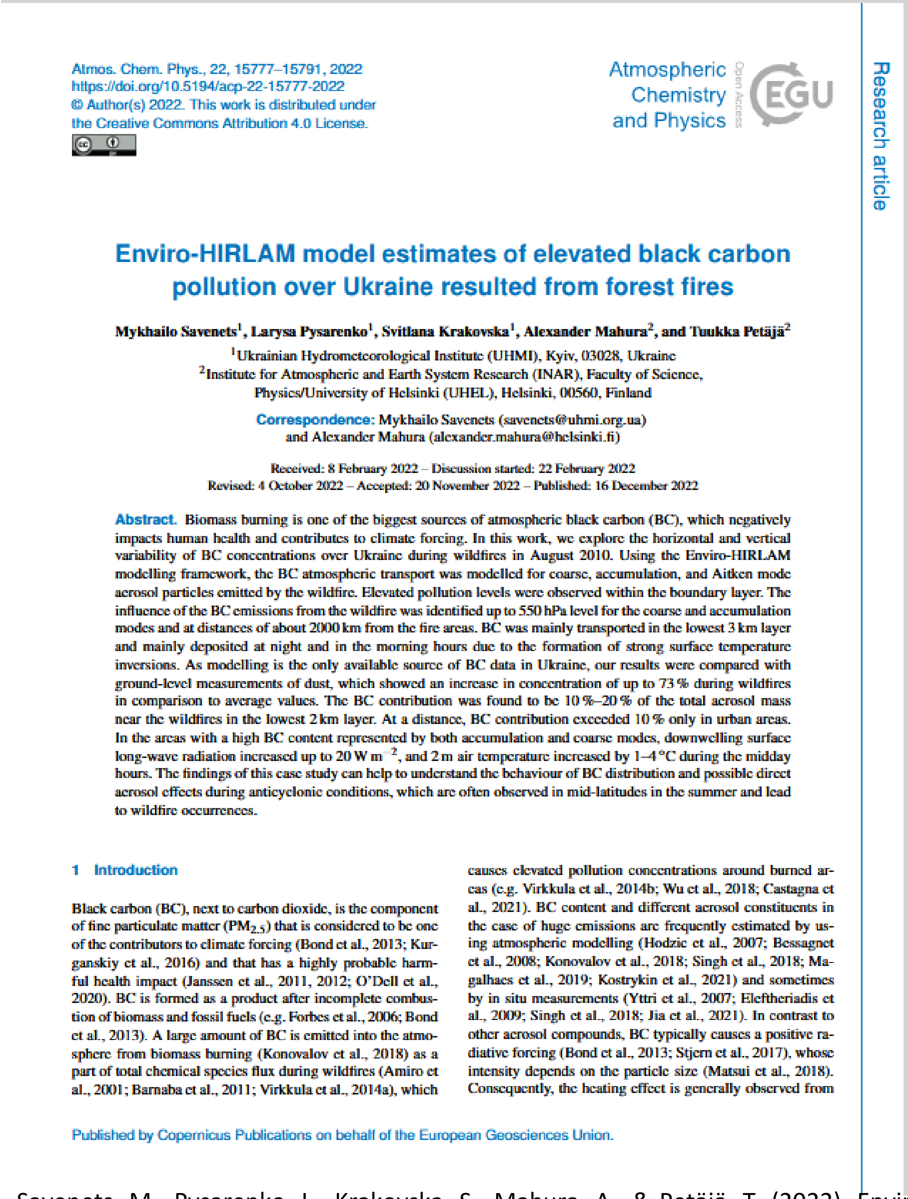
Pan-Eurasian Experiment PEEX

ECMWF

Enviro-PEEX on ECMWF HPC project

Pan-Eurasian Experiment (PEEX) Modelling Platform research and development for online coupled integrated meteorology-chemistry-aerosols feedbacks and interactions in weather, climate and atmospheric composition multi-scale modelling

Studying the role of black carbon from wildfires emissions during the heat-wave episode


Atmos. Chem. Phys., 22, 15777–15791, 2022
https://doi.org/10.5194/acp-22-15777-2022

Atmospheric Chemistry and Physics
Open Access
Research article

Enviro-HIRLAM model estimates of elevated black carbon pollution over Ukraine resulted from forest fires

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[2]Institute for Atmospheric and Earth System Research (INAR), Faculty of Science, Physics/University of Helsinki (UHEL), Helsinki, 00560, Finland

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Revised: 4 October 2022 – Accepted: 20 November 2022 – Published: 16 December 2022

Abstract. Biomass burning is one of the biggest sources of atmospheric black carbon (BC), which negatively impacts human health and contributes to climate forcing. In this work, we explore the horizontal and vertical variability of BC concentrations over Ukraine during wildfires in August 2010. Using the Enviro-HIRLAM modelling framework, the BC atmospheric transport was modelled for coarse, accumulation, and Aitken mode aerosol particles emitted by the wildfire. Elevated pollution levels were observed within the boundary layer. The influence of the BC emissions from the wildfire was identified up to 550 hPa level for the coarse and accumulation modes and at distances of about 2000 km from the fire areas. BC was mainly transported in the lowest 3 km layer and mainly deposited at night and in the morning hours due to the formation of strong surface temperature inversions. As modelling is the only available source of BC data in Ukraine, our results were compared with ground-level measurements of dust, which showed an increase in concentration of up to 73 % during wildfires in comparison to average values. The BC contribution was found to be 10 %–20 % of the total aerosol mass near the wildfires in the lowest 2 km layer. At a distance, BC contribution exceeded 10 % only in urban areas. In the areas with a high BC content represented by both accumulation and coarse modes, downwelling surface long-wave radiation increased up to 20 W m^{-2}, and 2 m air temperature increased by 1–4 °C during the midday hours. The findings of this case study can help to understand the behaviour of BC distribution and possible direct aerosol effects during anticyclonic conditions, which are often observed in mid-latitudes in the summer and lead to wildfire occurrences.

1 Introduction

Black carbon (BC), next to carbon dioxide, is the component of fine particulate matter ($PM_{2.5}$) that is considered to be one of the contributors to climate forcing (Bond et al., 2013; Kurganskiy et al., 2016) and that has a highly probable harmful health impact (Janssen et al., 2011, 2012; O'Dell et al., 2020). BC is formed as a product after incomplete combustion of biomass and fossil fuels (e.g. Forbes et al., 2006; Bond et al., 2013). A large amount of BC is emitted into the atmosphere from biomass burning (Konovalov et al., 2018) as a part of total chemical species flux during wildfires (Amiro et al., 2001; Barnaba et al., 2011; Virkkula et al., 2014a), which causes elevated pollution concentrations around burned areas (e.g. Virkkula et al., 2014b; Wu et al., 2018; Castagna et al., 2021). BC content and different aerosol constituents in the case of huge emissions are frequently estimated by using atmospheric modelling (Hodzic et al., 2007; Bessagnet et al., 2008; Konovalov et al., 2018; Singh et al., 2018; Magalhaes et al., 2019; Kostrykin et al., 2021) and sometimes by in situ measurements (Yttri et al., 2007; Eleftheriadis et al., 2009; Singh et al., 2018; Jia et al., 2021). In contrast to other aerosol compounds, BC typically causes a positive radiative forcing (Bond et al., 2013; Stjern et al., 2017), whose intensity depends on the particle size (Matsui et al., 2018). Consequently, the heating effect is generally observed from

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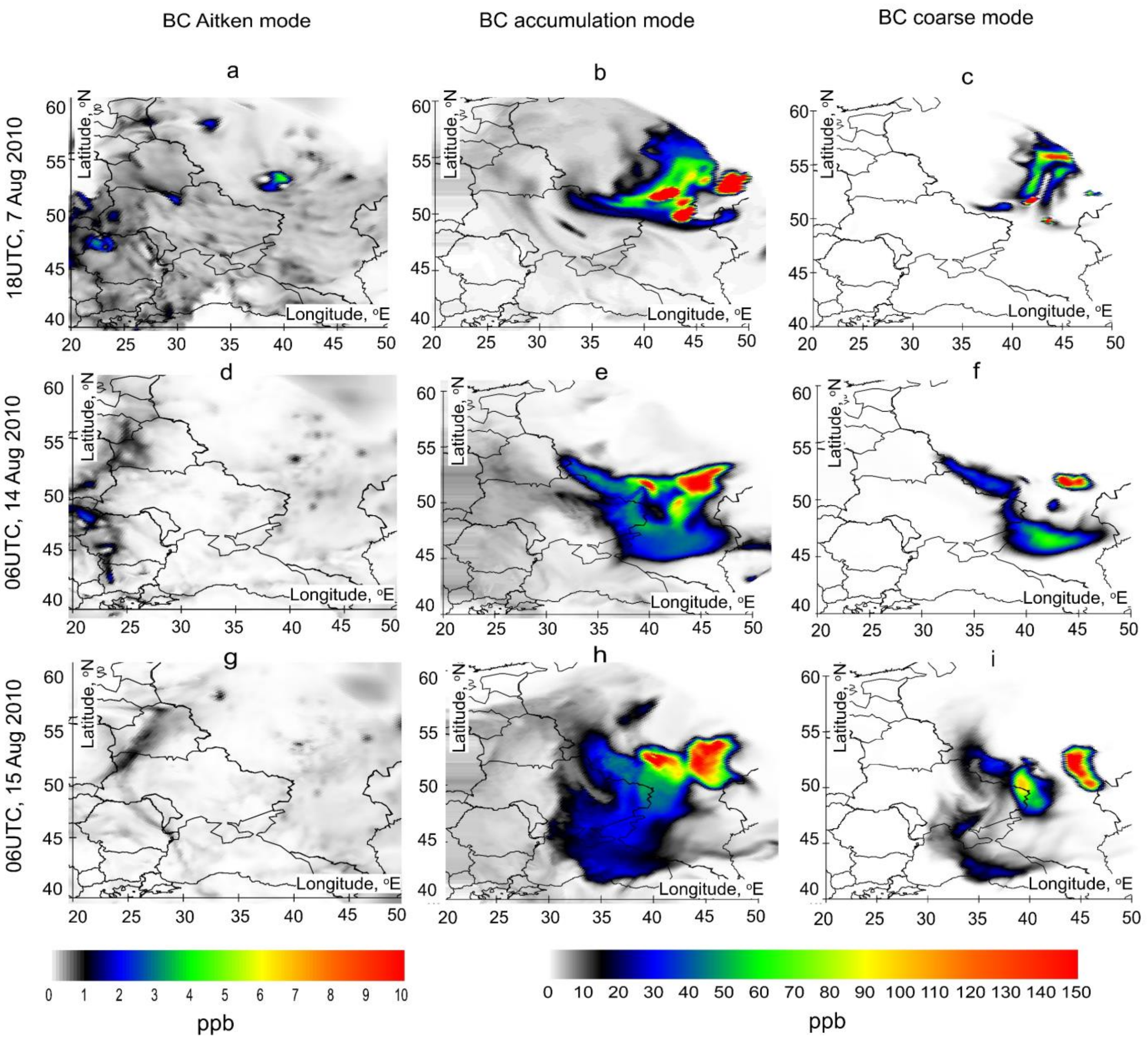
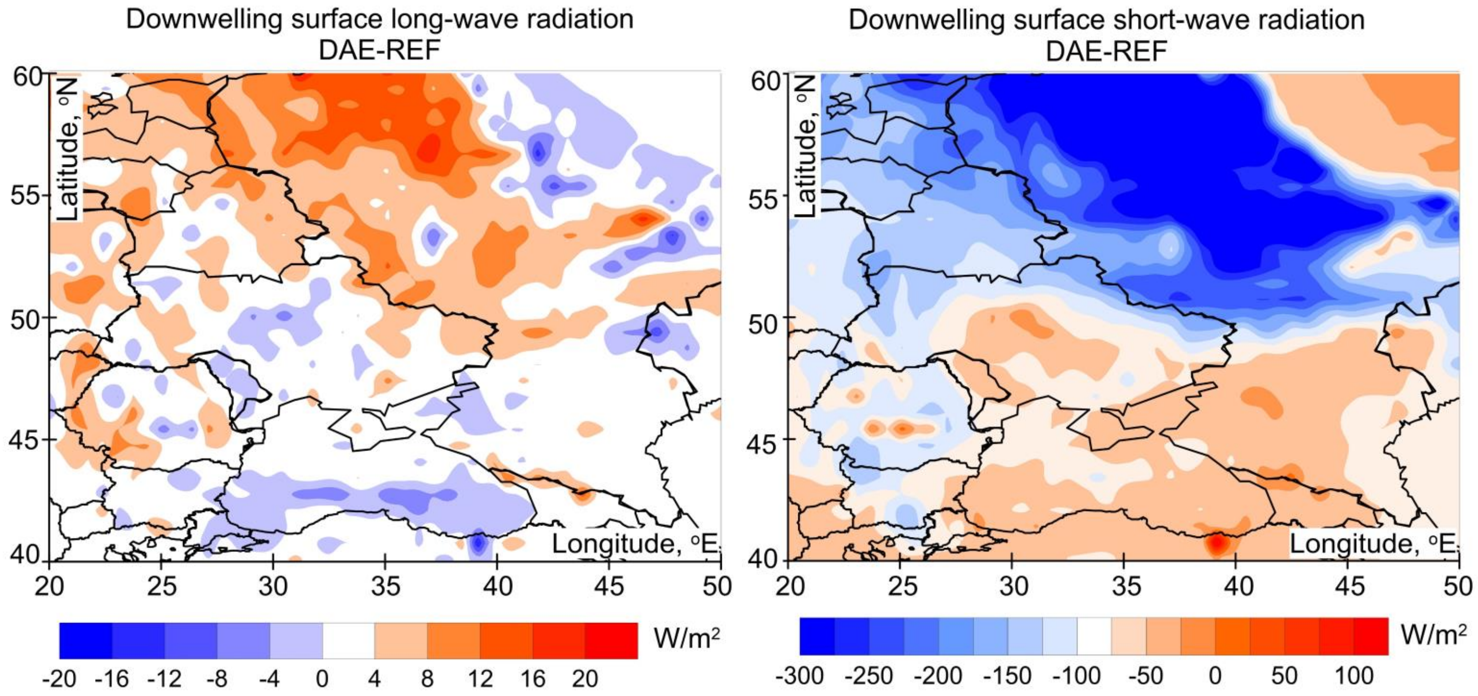
Savenets, M., Pysarenko, L., Krakovska, S., Mahura, A., & Petäjä, T. (2022). Enviro-HIRLAM model estimates of elevated black carbon pollution over Ukraine resulted from forest fires, Atmos. Chem. Phys., 22, 15777–15791, https://doi.org/10.5194/acp-22-15777-2022



by Savenets et al. (2022), https://doi.org/10.5194/acp-22-15777-2022

Studying the role of black carbon from wildfires emissions during the heat-wave episode



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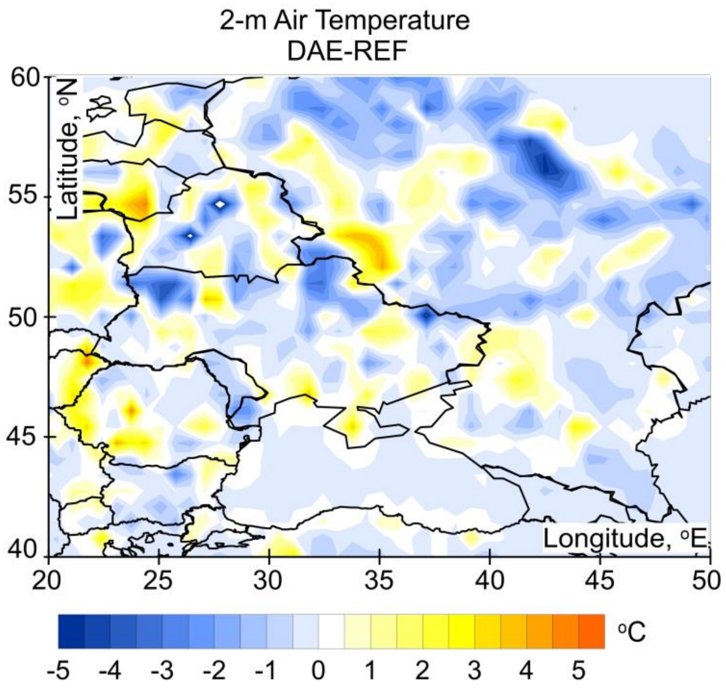

by Savenets et al. (2022), https://doi.org/10.5194/acp-22-15777-2022

In areas with high BC content represented by the accumulation and coarse modes, downwelling long-wave radiation with direct aerosol effects was higher by 20–25 W m^{-2} during the midday hours. The 2 m air temperature was 1–4 °C higher in these regions, with coarse mode BC exceeding 20–30 ppb.

Under specific conditions, BC can enhance unfavorable near-surface temperature regime

2020–2022

High Performance Computing Europa-3 (HPC-Europa3) Transnational Access programme (INFRAIA-2016-1-730897)

1) Integrated modelling for assessment of potential pollution regional atmospheric transport as result of accidental wildfires

2) Integrated modelling and analysis of influence of land cover changes on regional weather conditions/patterns

2021–2023

Enviro-PEEX(Plus) on ECMWF

Research and development for integrated meteorology – atmospheric composition multi-scales and – processes modelling for the Pan-Eurasian Experiment (PEEX) domain for weather, air quality and climate applications

atmosphere MDPI

Article

Seamless Modeling of Direct and Indirect Aerosol Effects during April 2020 Wildfire Episode in Ukraine

Mykhailo Savenets [1,*], Valeriia Rybchynska [1,2], Alexander Mahura [3], Roman Nuterman [4], Alexander Baklanov [4,5], Markku Kulmala [3] and Tuukka Petäjä [3,*]

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2 Department of Physics and Astronomy, University of Bologna, 40126 Bologna, Italy
3 Institute for Atmospheric and Earth System Research, University of Helsinki, 00014 Helsinki, Finland; alexander.mahura@helsinki.fi (A.M.); markku.kulmala@helsinki.fi (M.K.)
4 Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark; nuterman@nbi.ku.dk (R.N.); abaklanov@wmo.int (A.B.)
5 World Meteorological Organization, CH-1211 Geneva, Switzerland
* Correspondence: savenets@uhmi.org.ua (M.S.); tuukka.petaja@helsinki.fi (T.P.)

Abstract: Wildfires frequently occur in Ukraine during agricultural open-burning seasons in spring and autumn. High aerosol concentrations from fire emissions can significantly affect meteorological processes via direct and indirect aerosol effects. To study these impacts, we selected a severe wildfire episode from April 2020 in the Chornobyl Exclusion Zone (CEZ) and its surrounding area as a case study. We employed the Enviro-HIRLAM modeling system to simulate reference (REF) meteorological conditions, along with direct (DAE), indirect (IDAE), and combined (COMB) aerosol effects. In our simulations, black carbon (BC) and organic carbon (OC) comprised 70–80% of all aerosol mass in the region, represented in two layers of higher concentrations: one near the surface and the other 3–4 km above the surface. Our simulations showed that the inclusion of aerosol effects into the modeling framework led to colder (up to −3 °C) and drier (relative humidity drop up to −20%) conditions near the surface. We also observed localized changes in cloudiness, precipitation (mainly redistribution), and wind speed (up to ±4 m/s), particularly during the movement of atmospheric cold fronts. Larger uncertainties were observed in coarser model simulations when direct aerosol effects were considered. Quantifying the aerosol effects is crucial for predicting and promptly detecting changes that could exacerbate unfavorable weather conditions and wildfires. Such knowledge is essential for improving the effectiveness of emergency response measures.

Keywords: Chornobyl Exclusion Zone; forest fires; black carbon; organic carbon; Enviro-HIRLAM

check for updates

Citation: Savenets, M.; Rybchynska, V.; Mahura, A.; Nuterman, R.; Baklanov, A.; Kulmala, M.; Petäjä, T. Seamless Modeling of Direct and Indirect Aerosol Effects during April 2020 Wildfire Episode in Ukraine. *Atmosphere* 2024, 15, 550. https://doi.org/10.3390/atmos15050550

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Accepted: 26 April 2024
Published: 29 April 2024

1. Introduction

Wildfires are a major natural source of aerosols, affecting both air quality [1] and atmospheric processes [2]. Globally, large areas are burned every year, with a concerning trend towards increased wildfire frequency due to climate change [3,4]. This problem is particularly relevant for Ukraine, where the wildfire frequency is rising [5], exacerbated by the negative impact of the Russia–Ukraine war [6,7]. Among the most dangerous were wildfires in the Chornobyl Exclusion Zone (CEZ) that occur in the abandoned radioactively contaminated areas. In April 2020, a few sporadic fires turned into one of the most devastating wildfire episodes in Ukraine and raised concern among scientists because of the possible environmental consequences, e.g., air quality impacts [8], emission of radioactive materials [9], and atmospheric transport and dispersion of radionuclides [10].

Aerosols induce climatological and meteorological changes at the global [11,12], regional [13,14], and local [15] scales through direct and indirect aerosol effects [16]. Including aerosol effects in numerical weather prediction (NWP) models can notably enhance weather and air quality forecasts [17]. Previous studies have reported that biomass burning aerosols

Savenets, M., Rybchynska, V., Mahura, A., Nuterman, R., Baklanov, A., Kulmala, M., & Petäjä, T. (2024). Seamless Modeling of Direct and Indirect Aerosol Effects during April 2020 Wildfire Episode in Ukraine. *Atmosphere*, 15, 550. https://doi.org/10.3390/atmos15050550

TUNCAP

Atmospheric Pollution Research
Available online 10 January 2026, 102906
In Press, Corrected Proof What's this?

Diverse aerosol effects revealed during wildfire and dust storm events in Ukraine in April 2020

Mykhailo Savenets [a], Alexander Mahura [b], Roman Nuterman [c], Markku Kulmala [b], Tuukka Petäjä [b]

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Highlights

- Aerosol effects are dependent on certain synoptic conditions.
- Most aerosol effects on meteorology are localized.
- Biomass burning aerosols caused local warming and drying behind the warm front.
- The diverse aerosol effects detected during the cold front passages.

Savenets, M., Mahura, A., Nuterman, R., Kulmala, M., & Petäjä, T. (2026). Diverse aerosol effects revealed during wildfire and dust storm events in Ukraine in April 2020. *Atmospheric Pollution Research*, 102906. https://doi.org/10.1016/j.apr.2026.102906

Role of Natural Disasters and Anthropogenic Upheavals in Complex Atmosphere–Chemistry Interactions and Feedbacks

Chapter | First Online: 02 January 2026
pp 521–545 | Cite this chapter

Nexus of Sustainability

Mykhailo Savenets, Larysa Pysarenko, Lyudmyla Nadtochii & Volodymyr Osadchyi

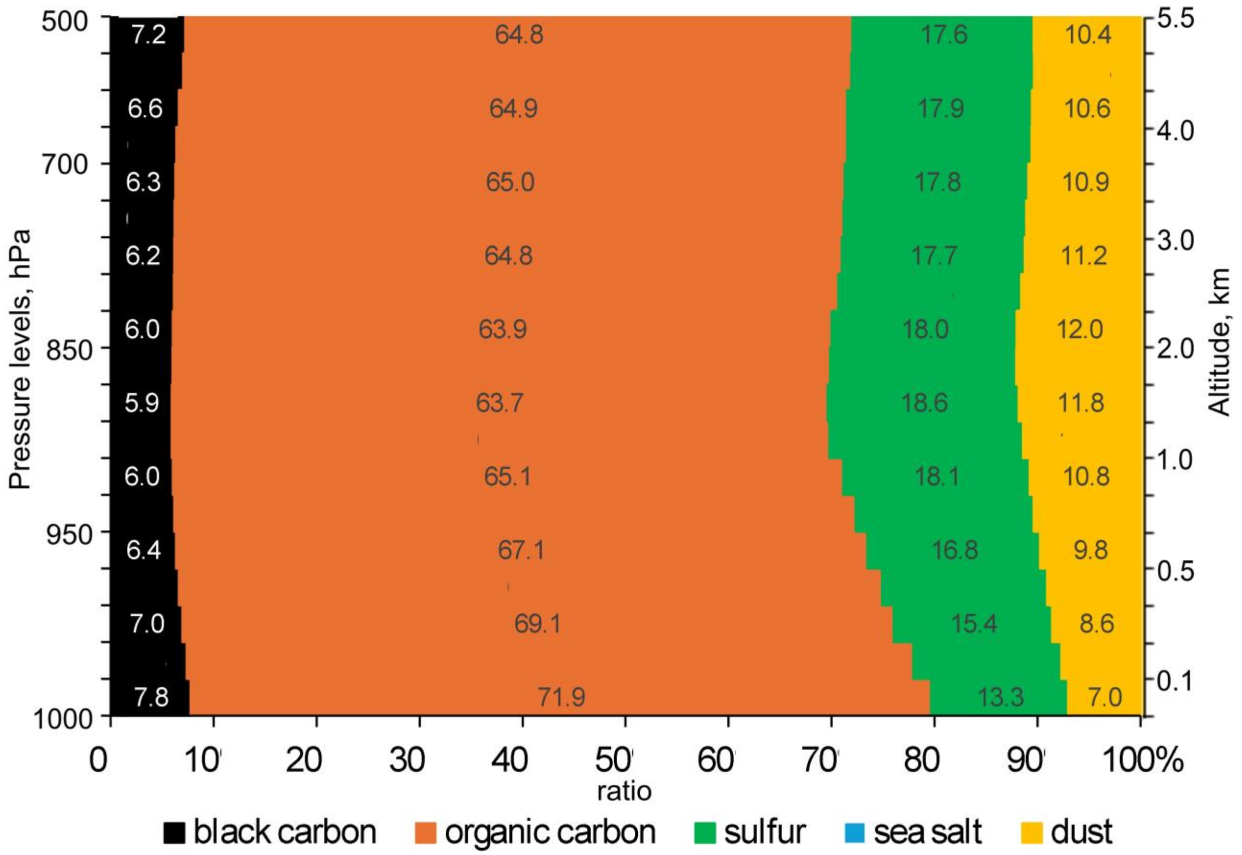
Part of the book series: Studies in Systems, Decision and Control ((SSDC,volume 627))

Abstract

A wide range of natural disasters and anthropogenic upheavals, including military actions, have led to additional pollutant emissions into the atmosphere. Aerosols with diverse chemical compositions and physical properties exert significant direct, semi-direct, and indirect effects on meteorological conditions. Emitted during natural and anthropogenic disasters, aerosols can amplify complex interactions and feedbacks in the atmosphere, altering radiative transfer, temperature, moisture, wind regimes, as well as cloudiness and precipitation patterns. Using remote sensing data and seamless numerical modeling results, we present a compilation of studies examining how atmospheric aerosols, influenced by natural and anthropogenic processes, impact local and regional meteorological conditions. We focus on the aftermath of the Kakhovka Dam destruction

Savenets, M., Pysarenko, L., Nadtochii, L., & Osadchyi, V. (2026). Role of Natural Disasters and Anthropogenic Upheavals in Complex Atmosphere-Chemistry Interactions and Feedbacks. In: Zagorodny, A., Bogdanov, V., Zaporozhets, A., Ermolieva, T. (eds) *Nexus of Sustainability. Studies in Systems, Decision and Control*, 627. Springer, Cham. https://doi.org/10.1007/978-3-032-03616-2_22

Studying impact of biomass burning aerosols



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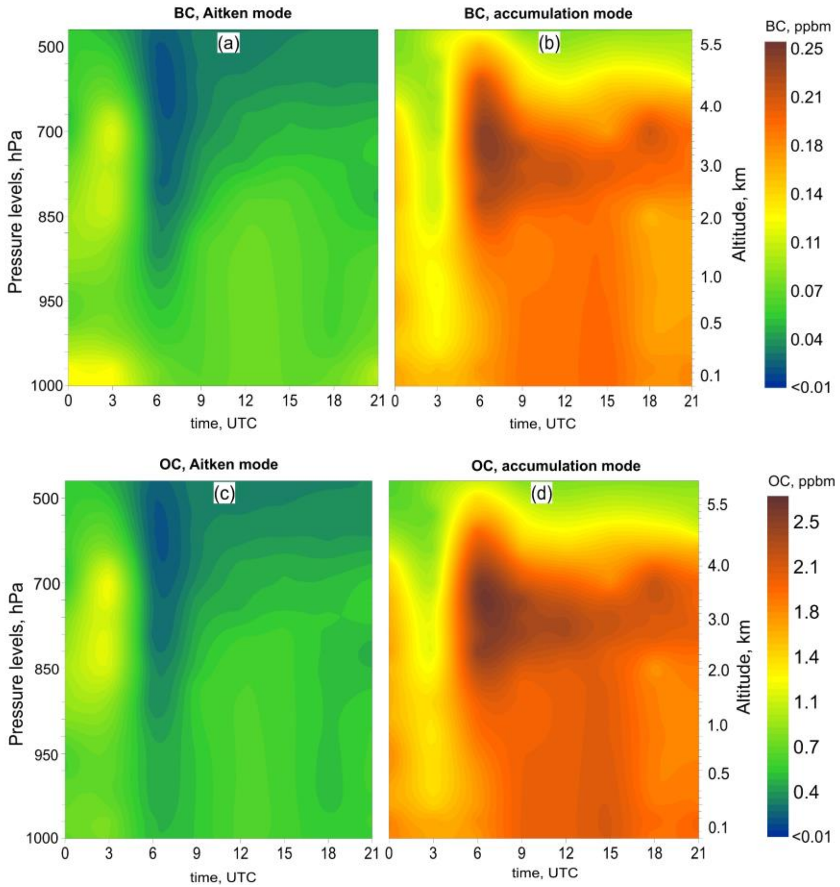

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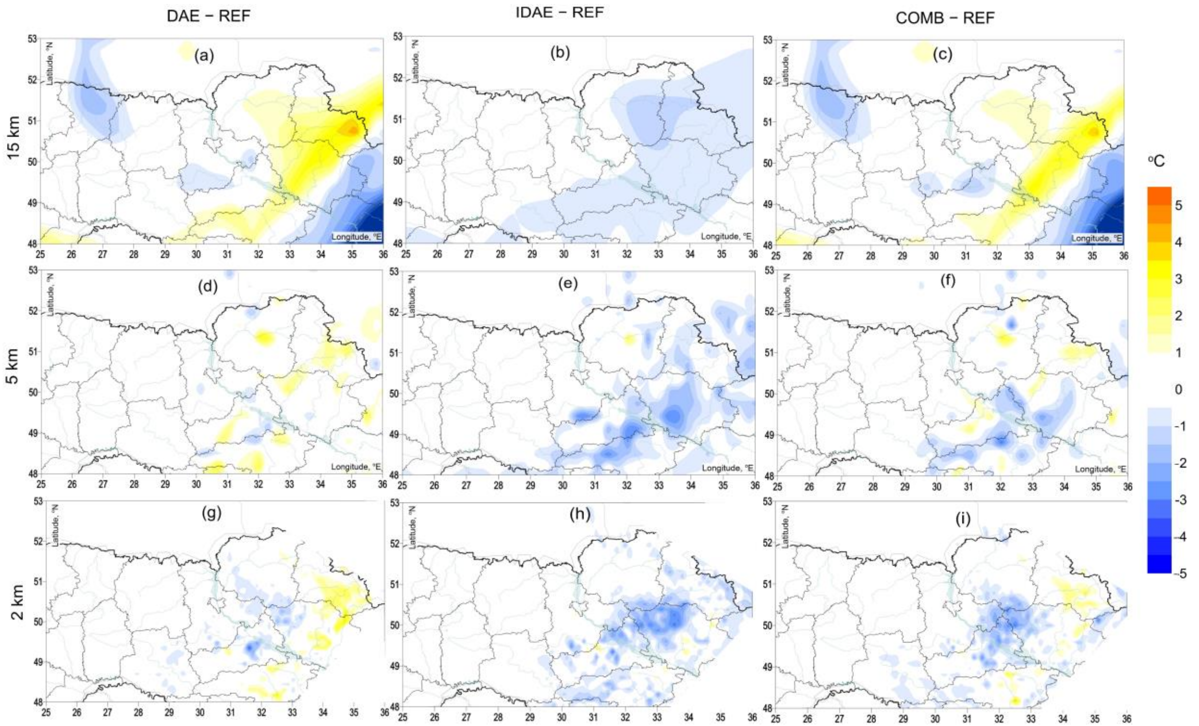
April 2020 wildfire case in the Chornobyl Exclusion Zone

Black carbon (BC) and organic carbon (OC) comprised 70–80% of all aerosol mass in the region, represented in two layers of higher concentrations: one near the surface and the other 3–4 km above the surface.

Studying impact of biomass burning aerosols

2 m air temperature on 10 April 2020 at 12 UTC



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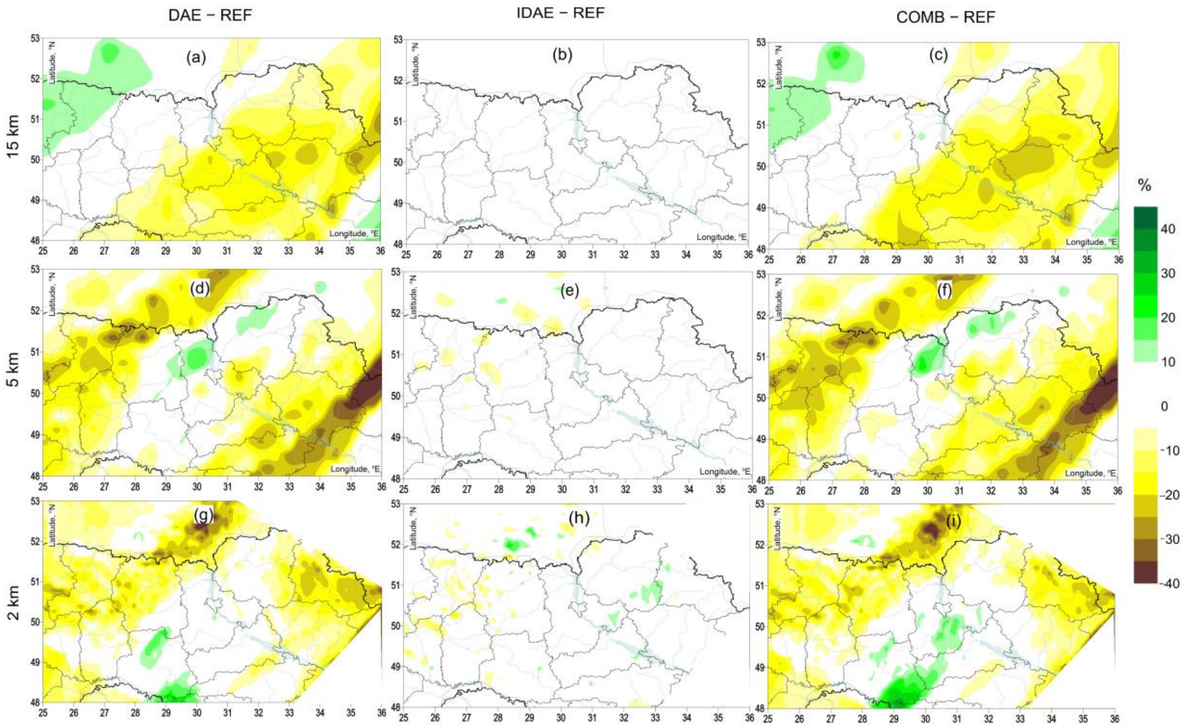
2 m relative humidity on 14 April 2020 at 18 UTC

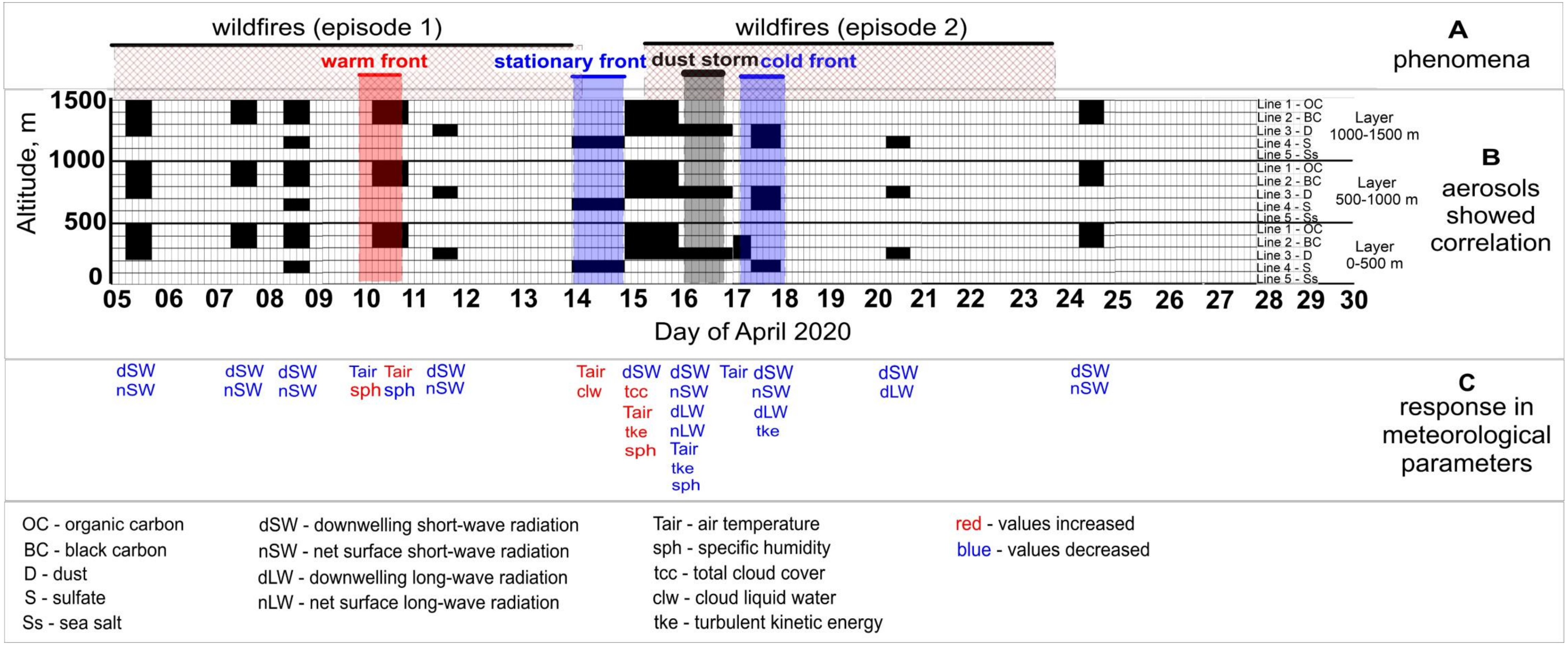


by Savenets et al. (2024), https://doi.org/10.3390/atmos15050550

The inclusion of aerosol effects into the modeling framework led to colder (up to −3 °C) and drier (relative humidity drop up to −20%) conditions near the surface. We also observed localized changes in cloudiness, precipitation (mainly redistribution), and wind speed (up to ±4 m/s), particularly during the movement of atmospheric cold fronts.

Under specific conditions, biomass burning aerosols can enhance unfavorable moisture regime at a local scale

Studying impact of biomass burning and dust aerosols under various synoptic patterns

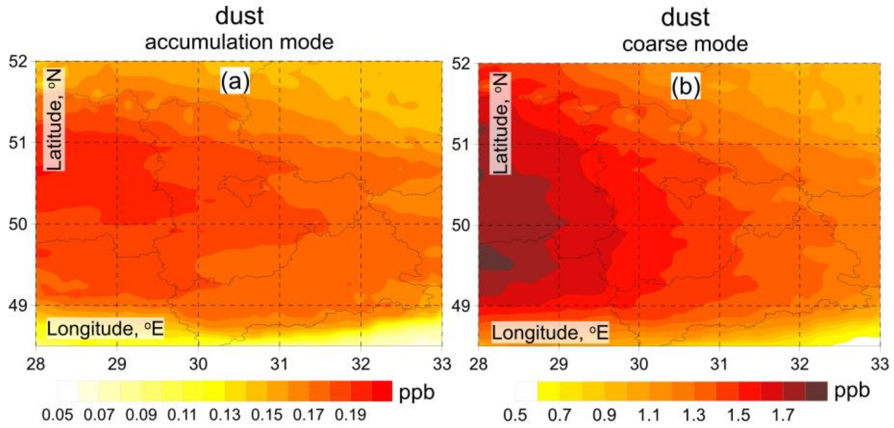


by Savenets et al. (2026), https://doi.org/10.1016/j.apr.2026.102906

- Aerosol effects are dependent on certain synoptic conditions.
- Most aerosol effects on meteorology are localized.
- Biomass burning aerosols caused local warming and drying behind the warm front.
- The diverse aerosol effects detected during the cold front passages

Studying impact of biomass burning and dust aerosols under various synoptic patterns

Dust storm, 16 April 2020



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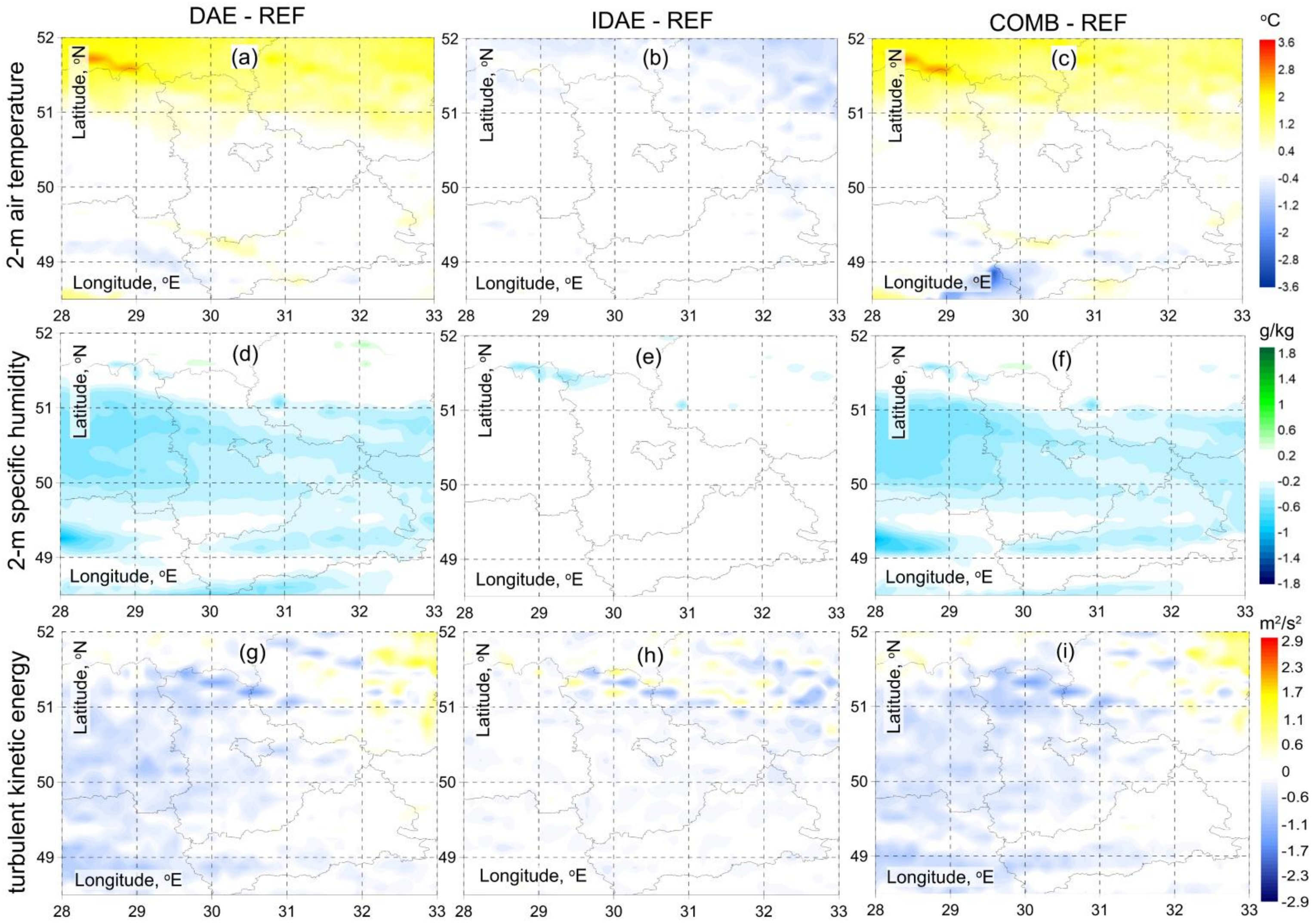

2024–2027

CERTAINTY

CLOUD–AEROSOL INTERACTIONS
& THEIR IMPACTS IN THE EARTH SYSTEM

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№101137680, HORIZON Research and Innovation Actions (Horizon Europe)

2024–2026

PEEX-MP-at-CSC

1) ACM–EWAI: “Effects of Aerosol-Cloud-Meteorology interactions on Extreme Weather events under Anthropogenic Impact”
2) ACM–LCC: “Influence of Aerosol-Cloud-Meteorology interactions on extreme weather events under Land use/ land Cover Changes”

2025–2027

Enviro-PEEX(Next) on ECMWF

Research and development for seamless modelling of meteorology – atmospheric composition on multi-scales for the Pan-Eurasian EXperiment (PEEX) domain for weather, air quality and climate applications

2026

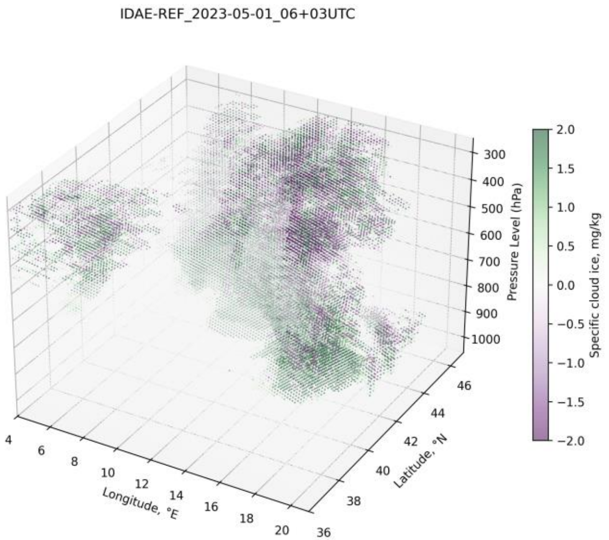
“AMITRA – Aerosol-Meteorology Interactions during TRAnsboundary pollution cases”.

IRISCC Fast-Track Call for Access.

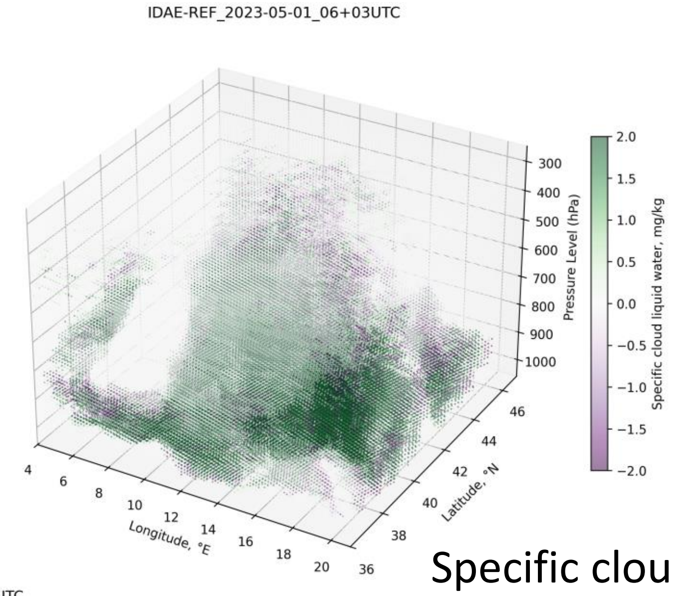
Supported by the European Commission under the Horizon 2020 – Research and Innovation Framework Programme, H2020-INFRAIA-2020-1, Grant Agreement number: 101008004

Studying complex aerosol-meteorology interactions

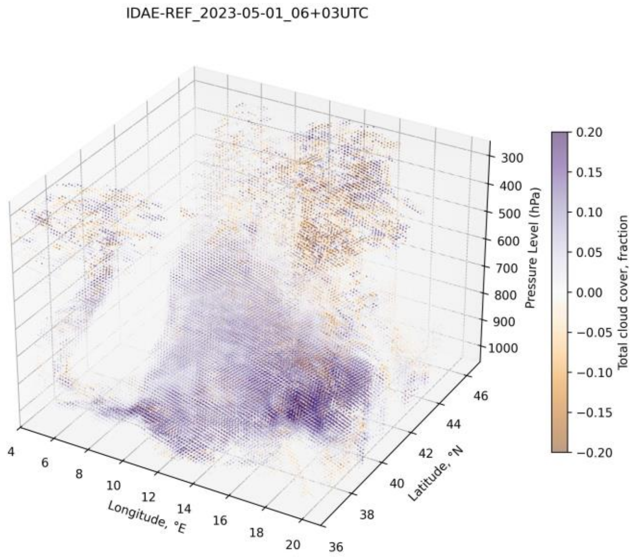
Difference fields between IDAE and REF (IDAE minus REF)



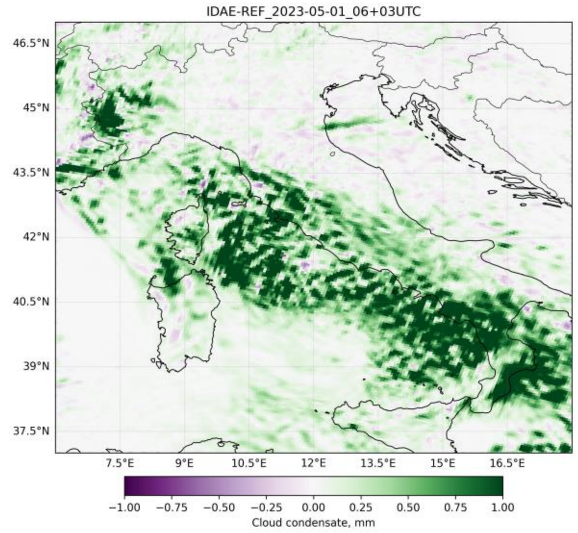
Specific cloud ice



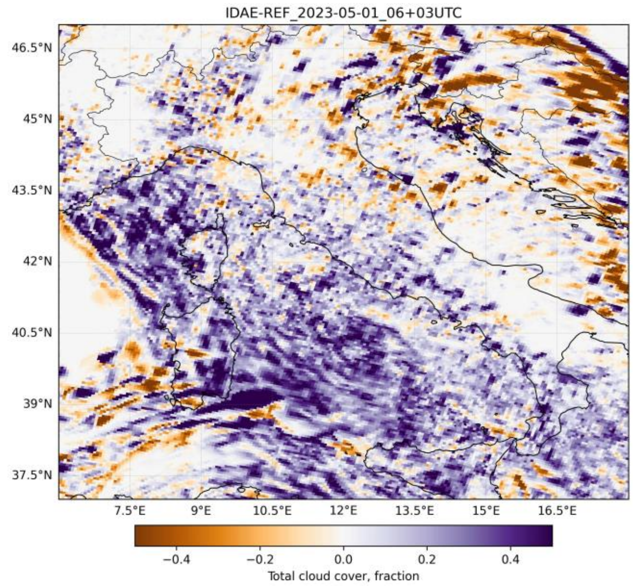
Specific cloud liquid water



Cloud fraction



Cloud condensate



Cloud fraction

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Research Council of Finland

Національна Академія Наук України 1918

For partnership and collaboration:

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UNIVERSITY OF HELSINKI

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METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

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CERTAINTY
CLOUD–AEROSOL INTERACTIONS & THEIR IMPACTS IN THE EARTH SYSTEM

IRISCC
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