PEEX Online Meeting/
Seminar at the ACCC Impact Week
Thursday, 11 April 2024

Seamless modelling of aerosol effects during wildfire episode in Ukraine

– by **Mykhailo Savenets** (savenets@uhmi.org.ua),
Ukrainian Hydrometeorological Institute (UHMI), Kyiv, Ukraine

Co-authors of study:
Mykhailo **Savenets**, Valeria **Rybchynska**, Alexander **Mahura**, Roman **Nuterman**, Alexander **Baklanov**, Markku **Kulmala** and Tuukka **Petäjä**

PEEX Online Meeting/
Seminar at the ACCC Impact Week
Thursday, 11 April 2024

A brief history of UHMI collaboration in PEEX

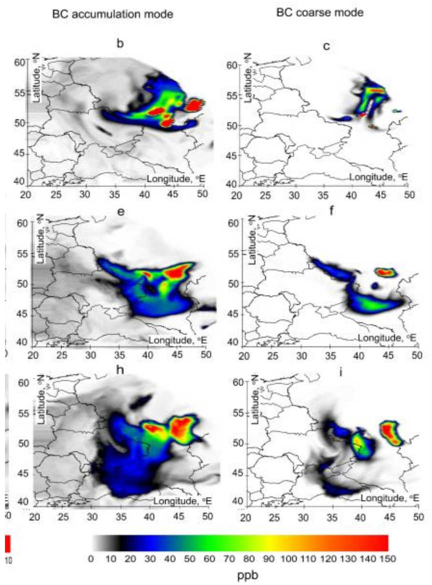
Started in 2018

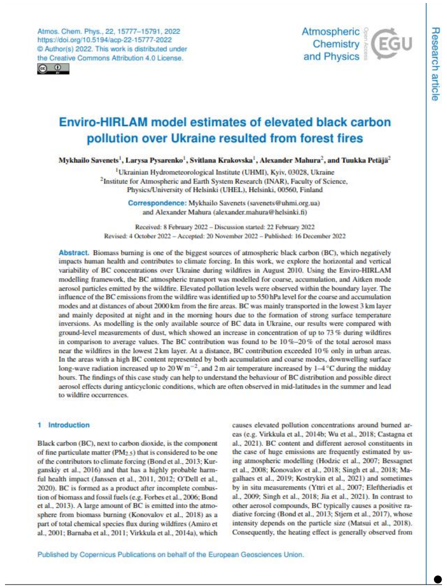
- Enviro-HIRLAM research training on online integrated modelling (at UHEL-INAR)
- summer school 'Formation and Growth of Atmospheric Aerosols', as a part of ENVRIplus project (Hyytiälä Forestry Field Station)

PEEX-related activities:

- seminars;
- training courses;
- conferences;
- tutoring at training courses;

and others





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

Atmospheric Chemistry and Physics

Research article

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

Mykhailo Savenets[1], Larysa Pysarenko[1], Svitlana Krakovska[1], Alexander Mahura[2], and Tuukka Petäjä[2]

[1]Ukrainian Hydrometeorological Institute (UHMI), Kyiv, 03028, Ukraine
[2]Institute for Atmospheric and Earth System Research (INAR), Faculty of Science, Physics/University of Helsinki (UHEL), Helsinki, 00560, Finland

Correspondence: Mykhailo Savenets (savenets@uhmi.org.ua) and Alexander Mahura (alexander.mahura@helsinki.fi)

Received: 8 February 2022 – Discussion started: 22 February 2022
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

Published by Copernicus Publications on behalf of the European Geosciences Union.

PEEX-related projects:

- Enviro-PEEX on ECMWF (2018-2020)
- HPC-Europa3 (2020-2022)
- PEEX-MP-Europa3 (2020-2022)
- PEEX-MP Research & Developments (2024 - …)

and others

Savenets, M., et al. (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

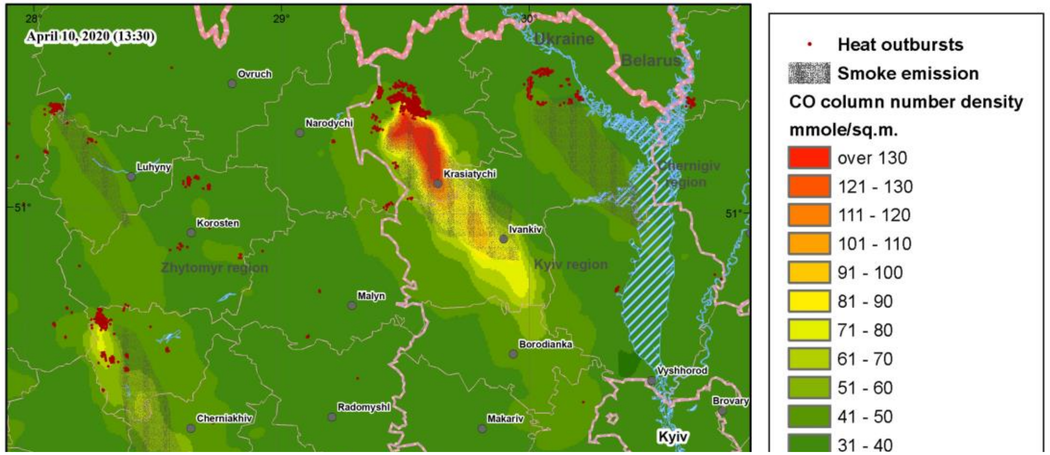
Two grants on integrated modeling:

- pollution atmospheric transport as result of accidental wildfires
- influence of land cover changes on regional weather

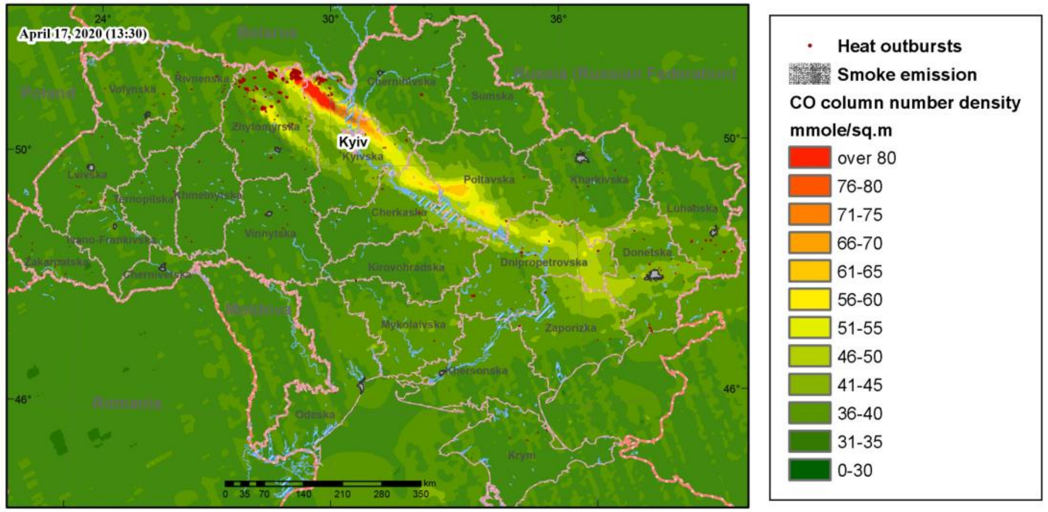
Enviro-HIRLAM model use in **Horizon-Europe CERTAINTY project (2024-2027)**

April 2020 wildfires in the Chornobyl Exclusion Zone (CEZ)

CO column number density and the direction of smoke emission



CO column number density and the direction of smoke emission



Savenets M., Osadchyi V., Oreshchenko A., Pysarenko L. Air Quality Changes in Ukraine during the April 2020 Wildfire Event. *Geographica Pannonica*. 2020. Vol.24. Is.4. P.271-284. https://doi.org/10.5937/gp24-27436

Data and Methodology

Model: Environment – **HIgh-Resolution Limited Area Model (Enviro-HIRLAM)** modeling system that is fully online-integrated (numerical weather prediction (NWP) and atmospheric chemical transport (ACT) modeling system) (Baklanov et al., 2017).

Studied area and model domains with names of selected synoptic stations and areas of interest.

Spatial resolution: 15 km spatial resolution with the following downscaling to 5 and 2 km resolution.

Domain size: 2-km domain (310×310 grid points) covered wildfires, CEZ, and the Kyiv metropolitan area; 5-km domain (310×310 grid points) covered Ukrainian territory; 15-km domain (190×240 grid points) covered Europe with the possibility to consider prevailing western and north-western atmospheric transport

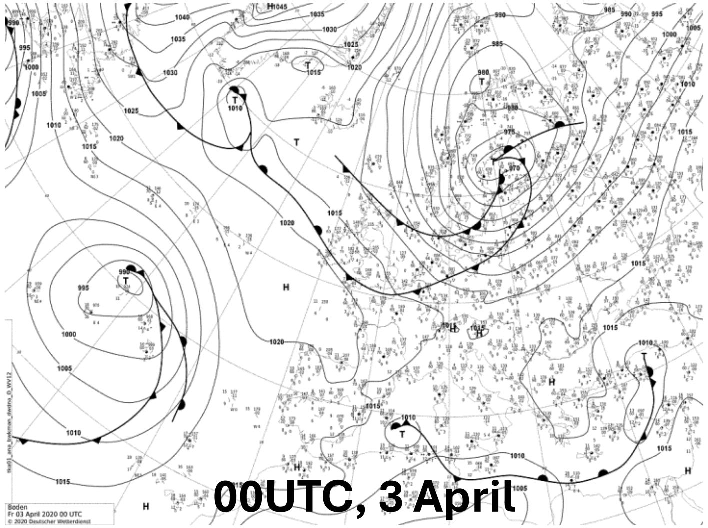
Temporal resolution: 240 s for 15-km resolution, 120 s for 5-km, and 60 s for 2-km.

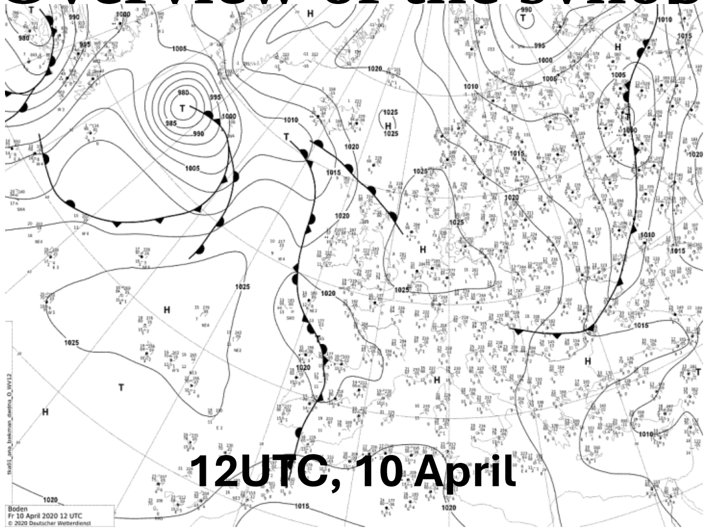
Model output: 3-hour step

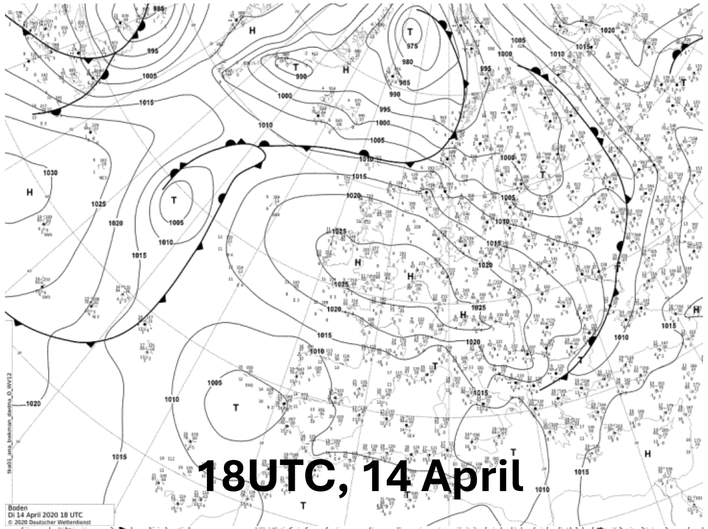
Vertical structure: 40 model levels.

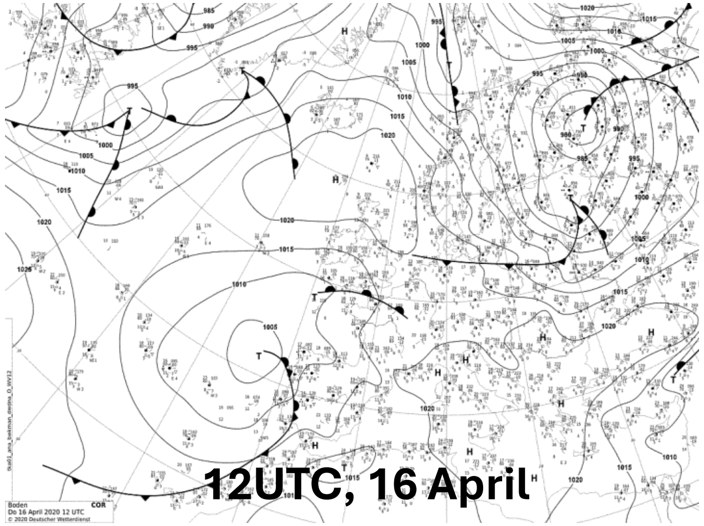
Running modes: reference (REF) run (without any aerosol effects included), direct (DAE), indirect (IDAE) and combined (COMB) aerosol effects included.

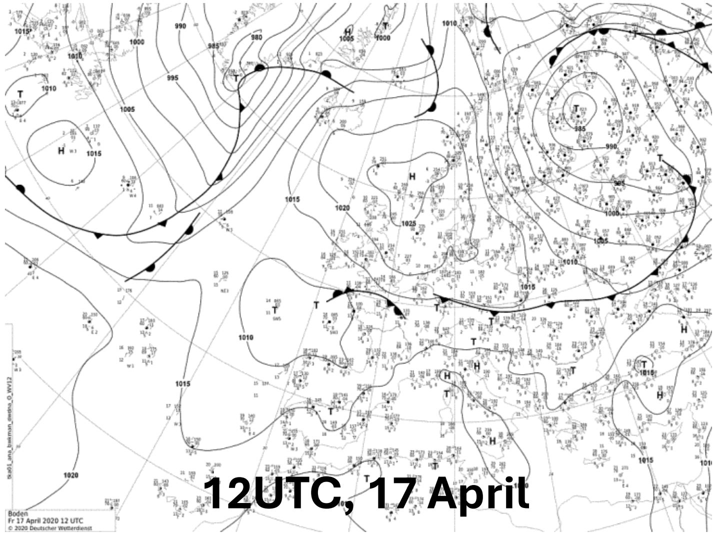
Overview of the synoptic situation

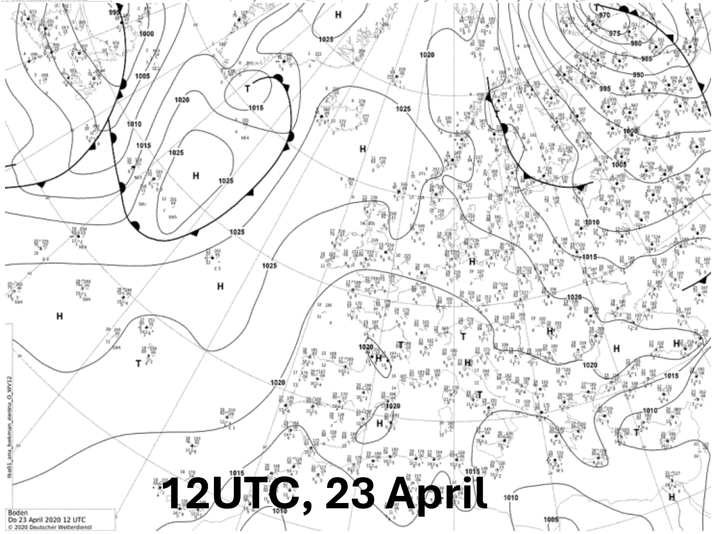






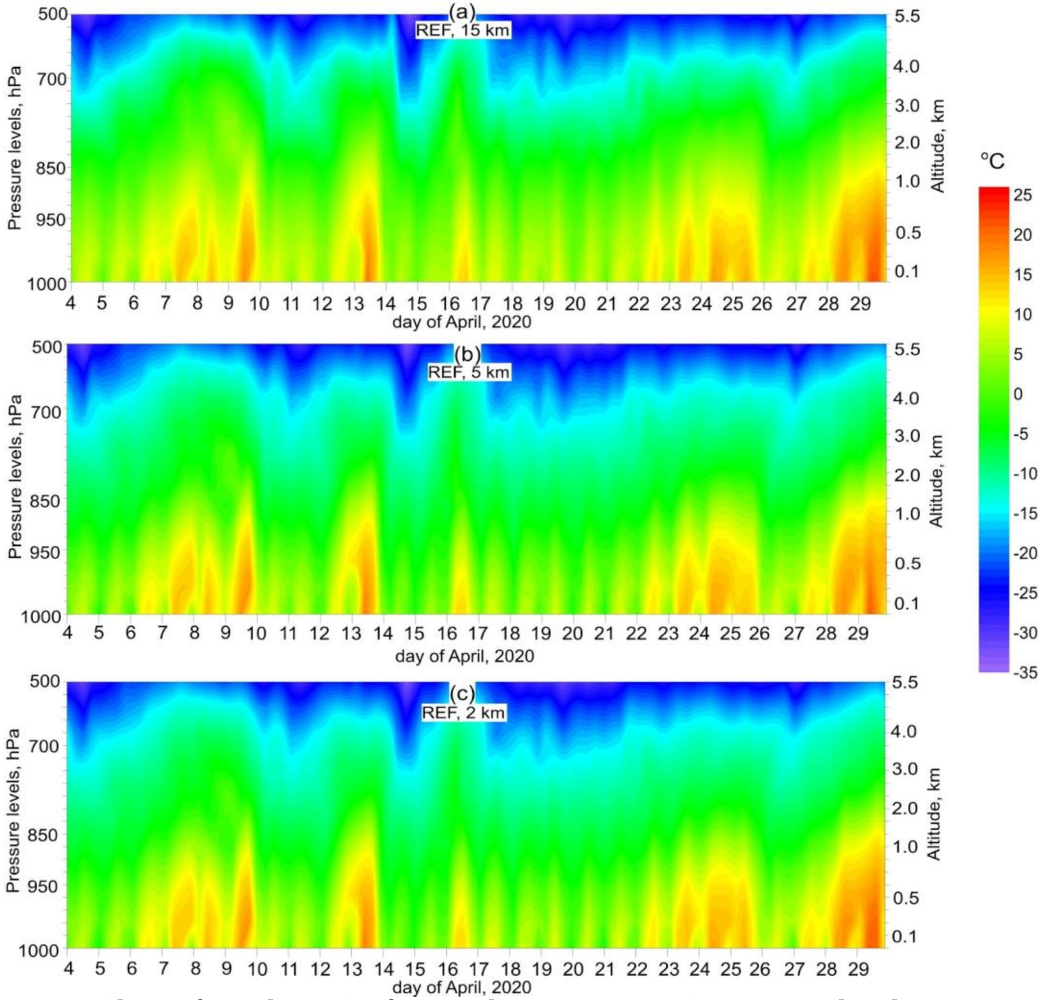




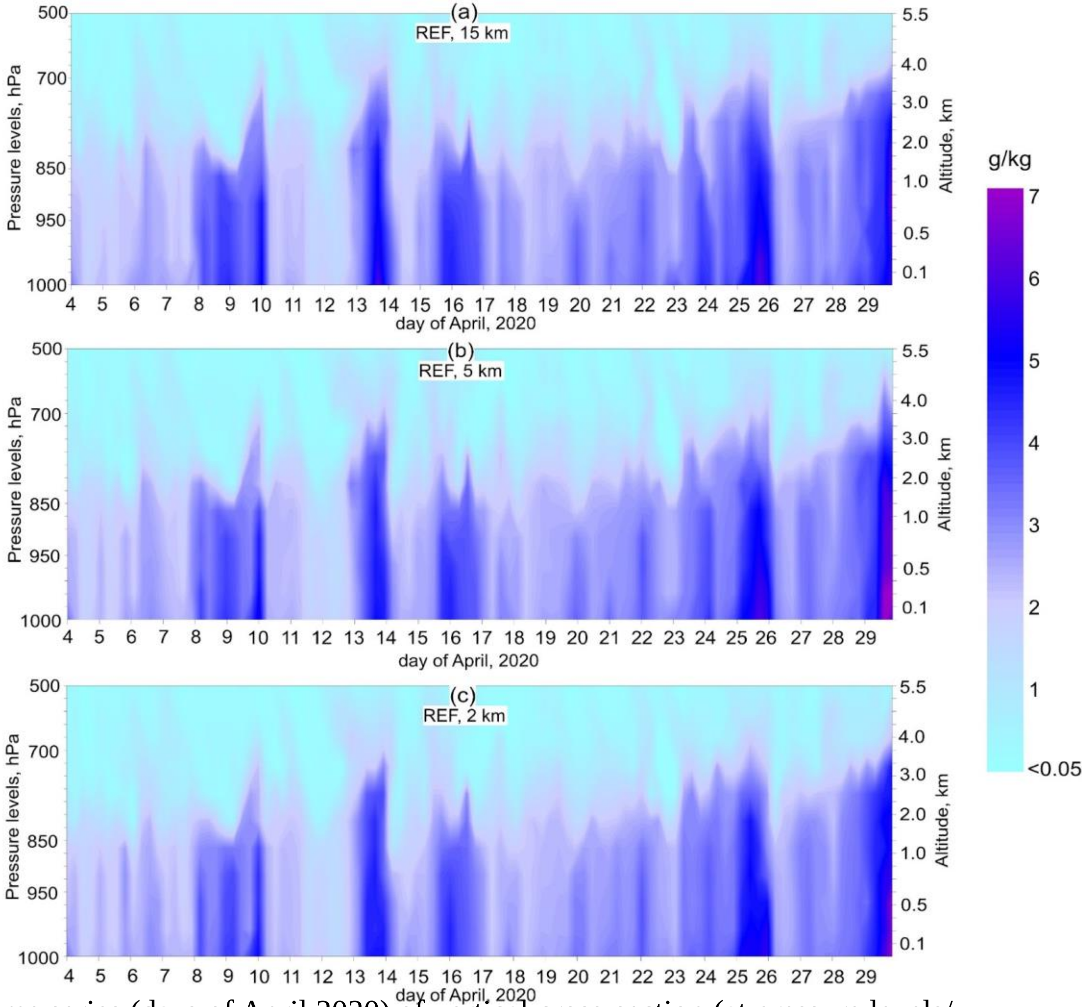


source https://www.wetter3.de/archiv_dwd_dt.html

Modeled weather conditions without aerosol effects



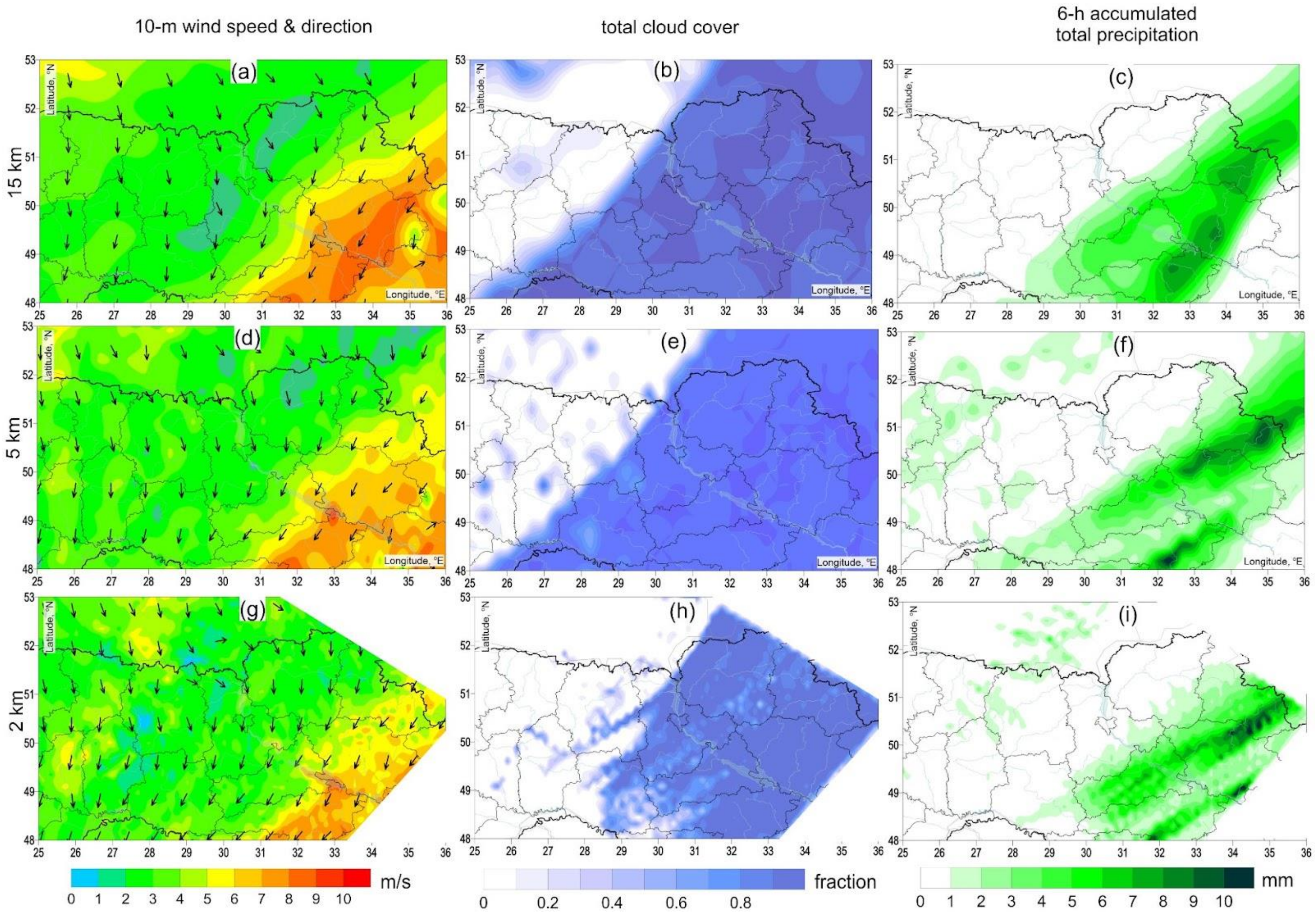
Time series (days of April 2020) of vertical cross-section (at pressure levels/ altitudes) of air temperature (T, °C) over wildfires area in the CEZ (for Enviro-HIRLAM reference (REF) run for 15 (a), 5 (b) and 2 (c) km horizontal resolutions)



Time series (days of April 2020) of vertical cross-section (at pressure levels/ altitudes) of specific humidity (g/kg) over wildfires area in the CEZ (for Enviro-HIRLAM reference (REF) run for 15 (a), 5 (b) and 2 (c) km horizontal resolutions)

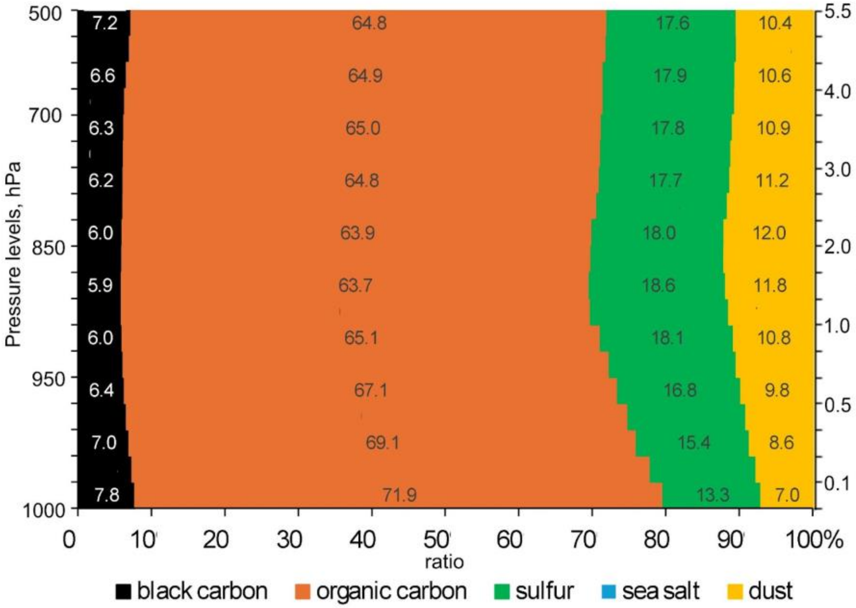
PEEX Online Meeting/
Seminar at the ACCC Impact Week
Thursday, 11 April 2024

Modeled weather conditions without aerosol effects

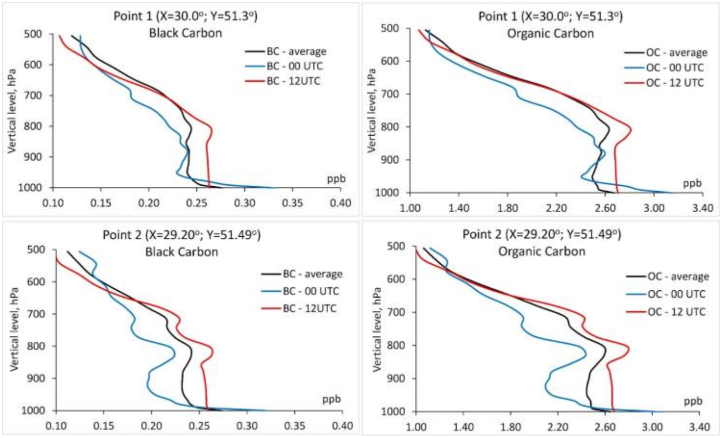


An example of Enviro-HIRLAM simulations over area of interest for the wind (at 10m) speed and direction (a,d,g), total cloud cover fraction (b,e,h) and accumulated 6-hour total precipitation (c,f,i) which observed during atmospheric stationary front conditions on 14 April 2023 at 18 UTC (for REF run at 15 (a,b,c), 5 (d,e,f) , and 2 (g,h,i) km horizontal resolutions)

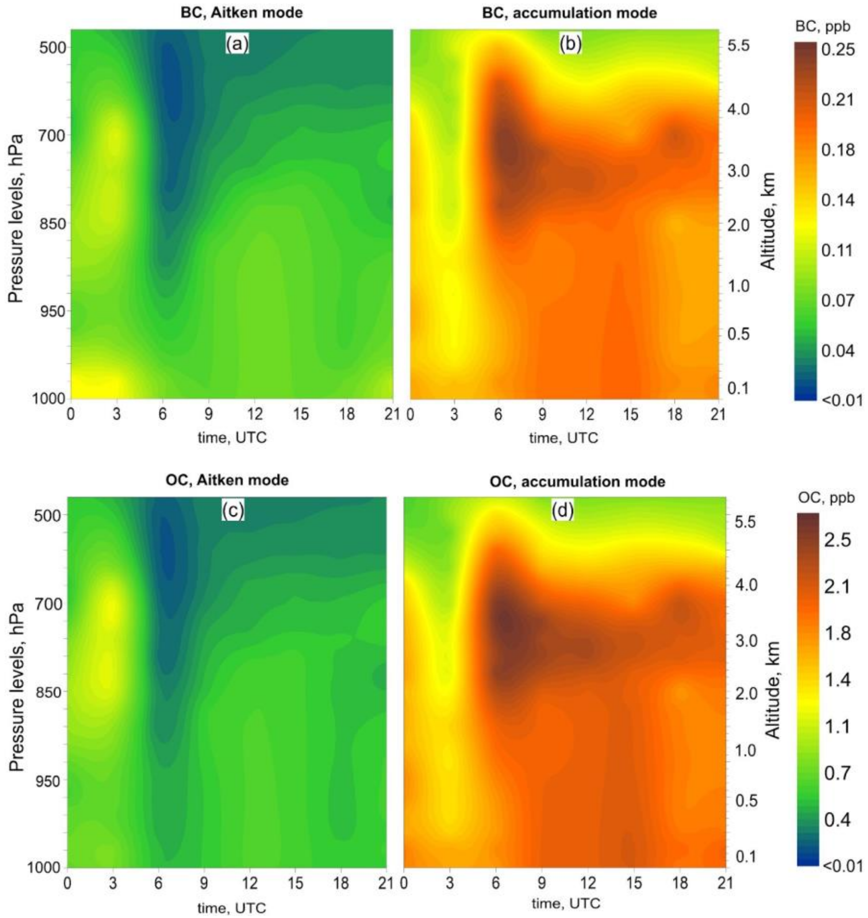
Modeled atmospheric composition



Vertical distribution of average aerosol compounds ratio over CEZ /sea salt contribution is negligible being less than 0.01%/



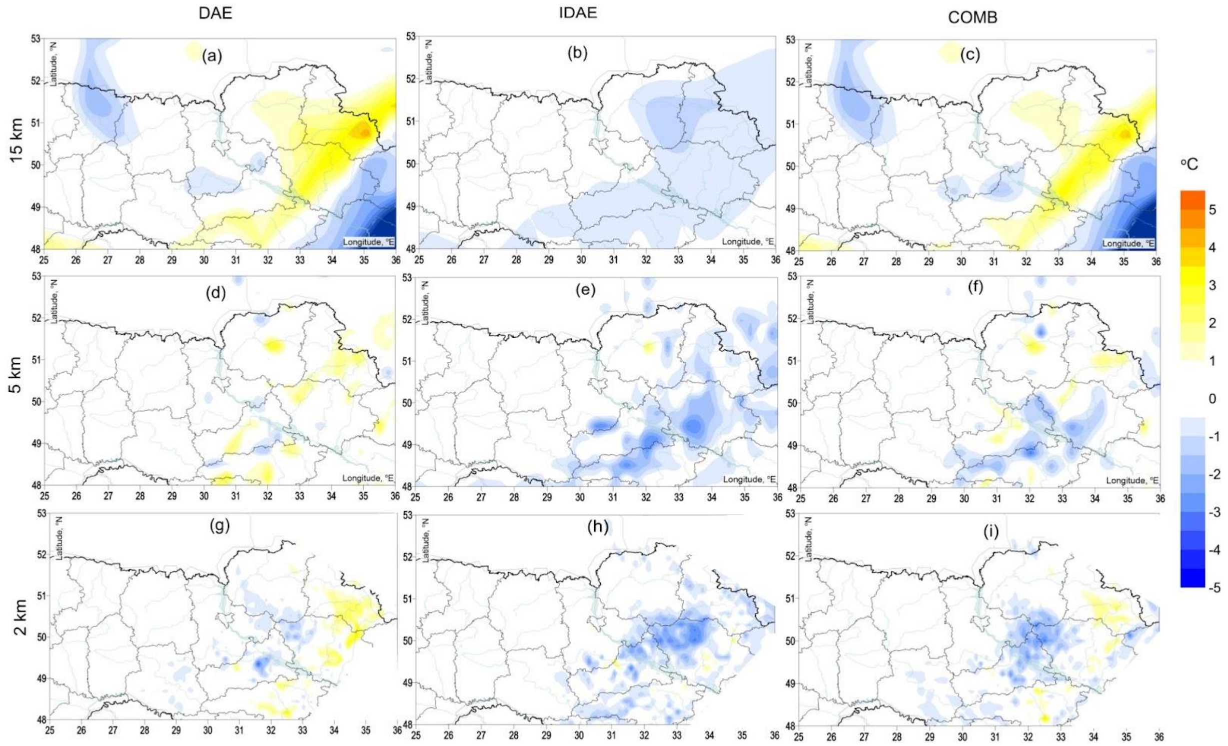
Vertical profiles of average, nighttime (00 UTC) and daytime (12UTC) concentrations of BC and OC over two points with intense wildfires (*x-axis for BC and OC are different for better visibility*). Point 1 refers to the CEZ; point 2 refers to the wildfires at the border of Zhytomyr and Kyiv regions.



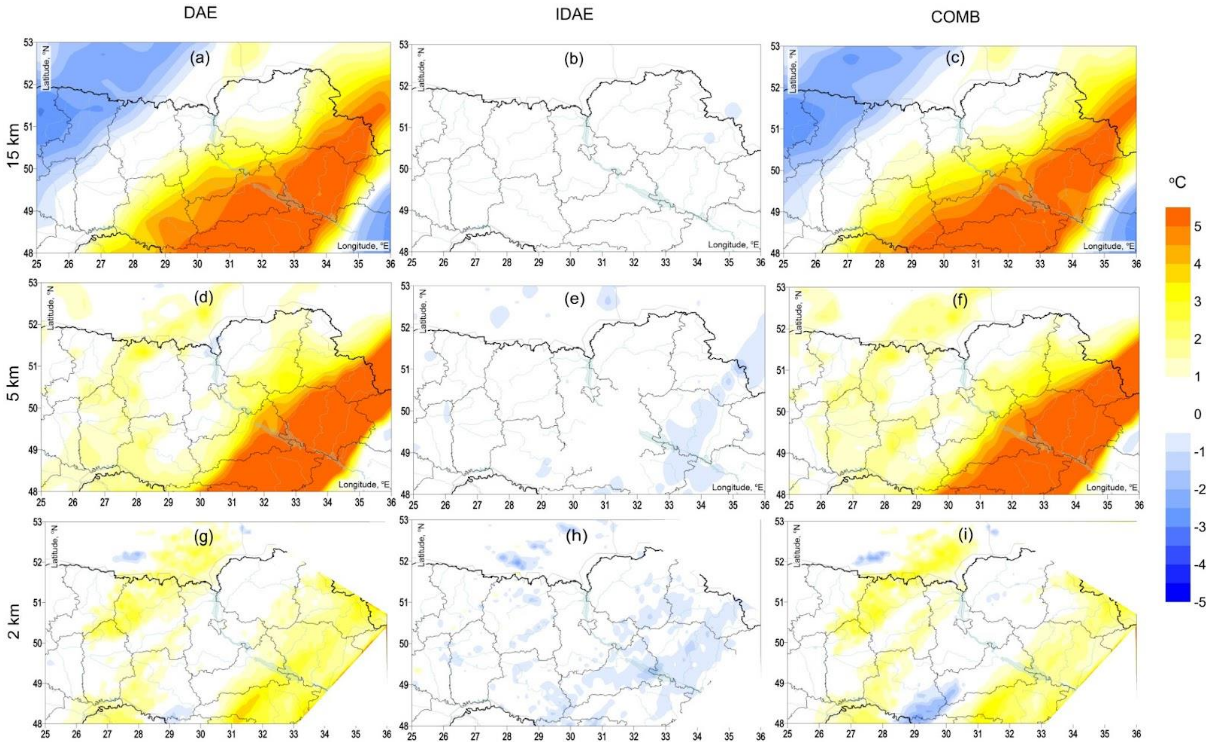
Diurnal cycle (over 05-29 April 2020) of vertical cross-section over wildfires in CEZ (at pressure levels/ altitudes) of BC (a,b) and OC (c,d) for the Aitken and accumulation modes (*color scales for BC and OC are different for better visibility*)

Direct and indirect aerosol effects on the atmosphere

2-m air temperature



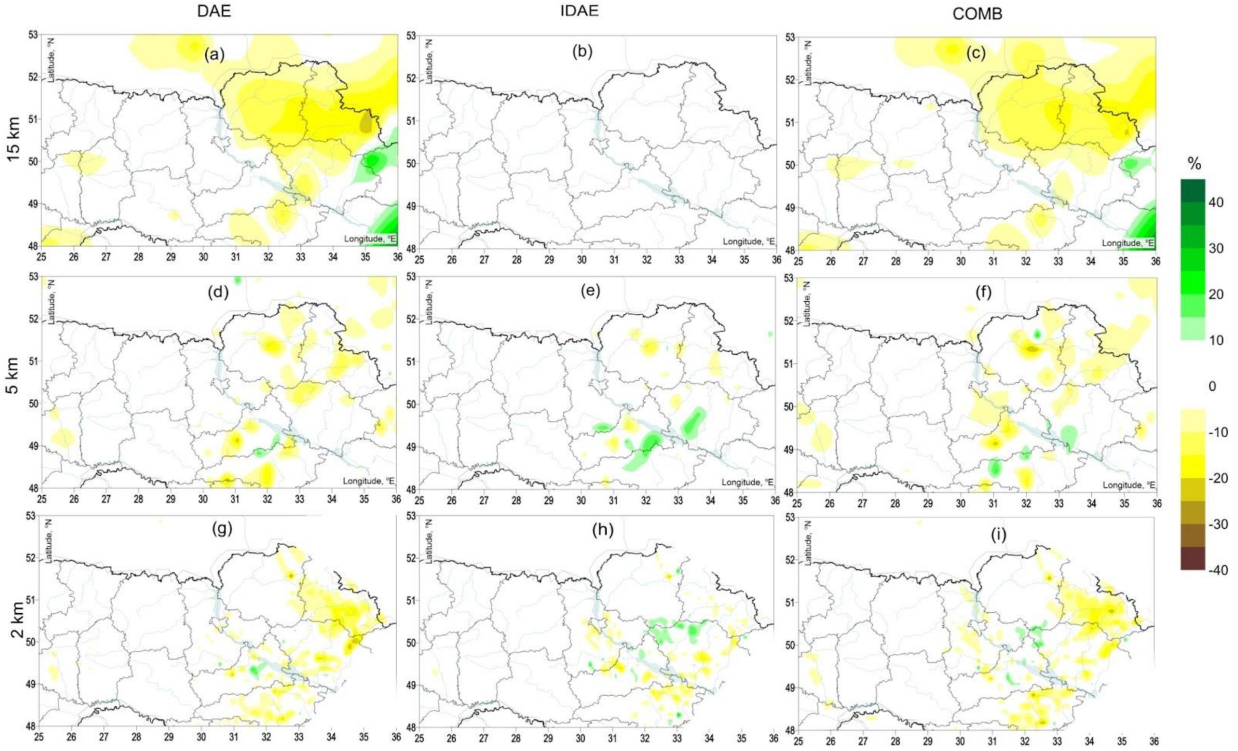
Difference between the Enviro-HIRLAM modified (with aerosol effects) and reference (control) runs for direct (DAE) (a,d,g), indirect (IDAE) (b,c,h) and combined (COMB) (c,f,i) aerosol effects included on **2-m air temperature on 10 April 2020 at 12 UTC**



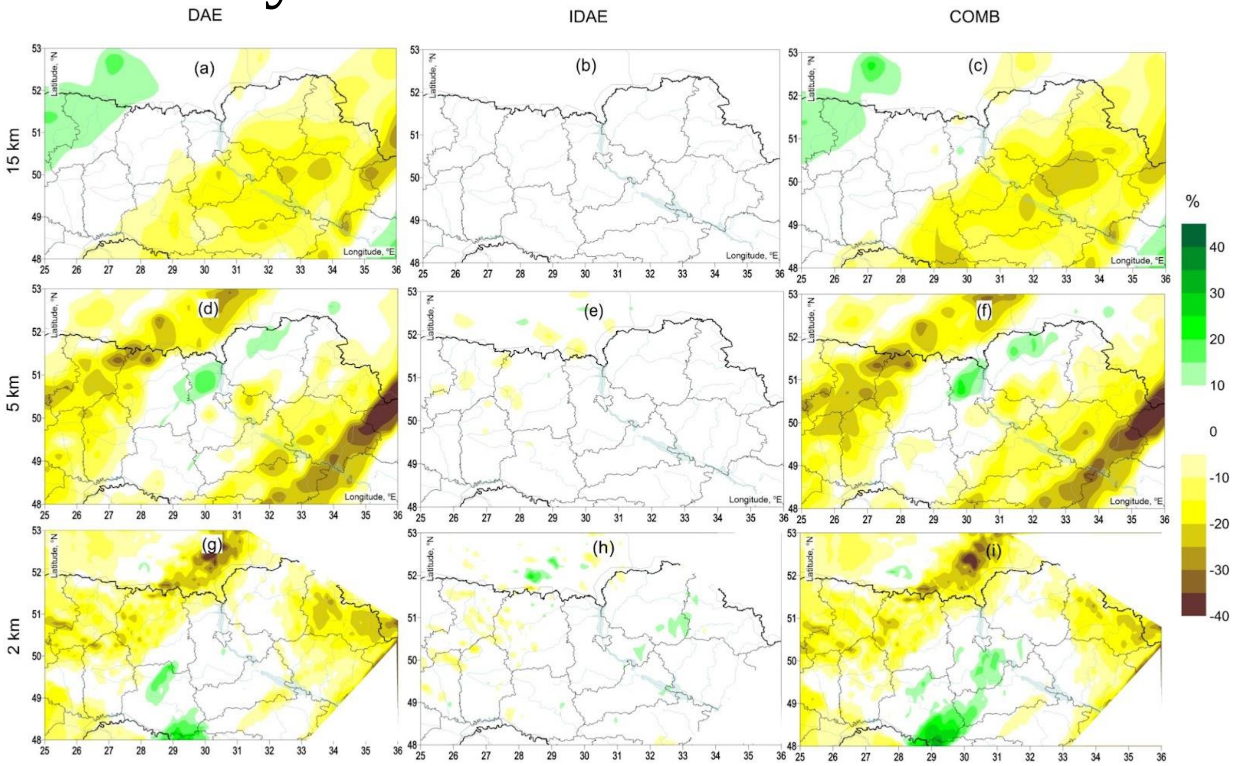
Difference between the Enviro-HIRLAM modified (with aerosol effects) and reference (control) runs for direct (DAE) (a,d,g), indirect (IDAE) (b,c,h) and combined (COMB) (c,f,i) aerosol effects included on **2-m air temperature on 14 April 2020 at 18 UTC**

Direct and indirect aerosol effects on the atmosphere

2-m relative humidity



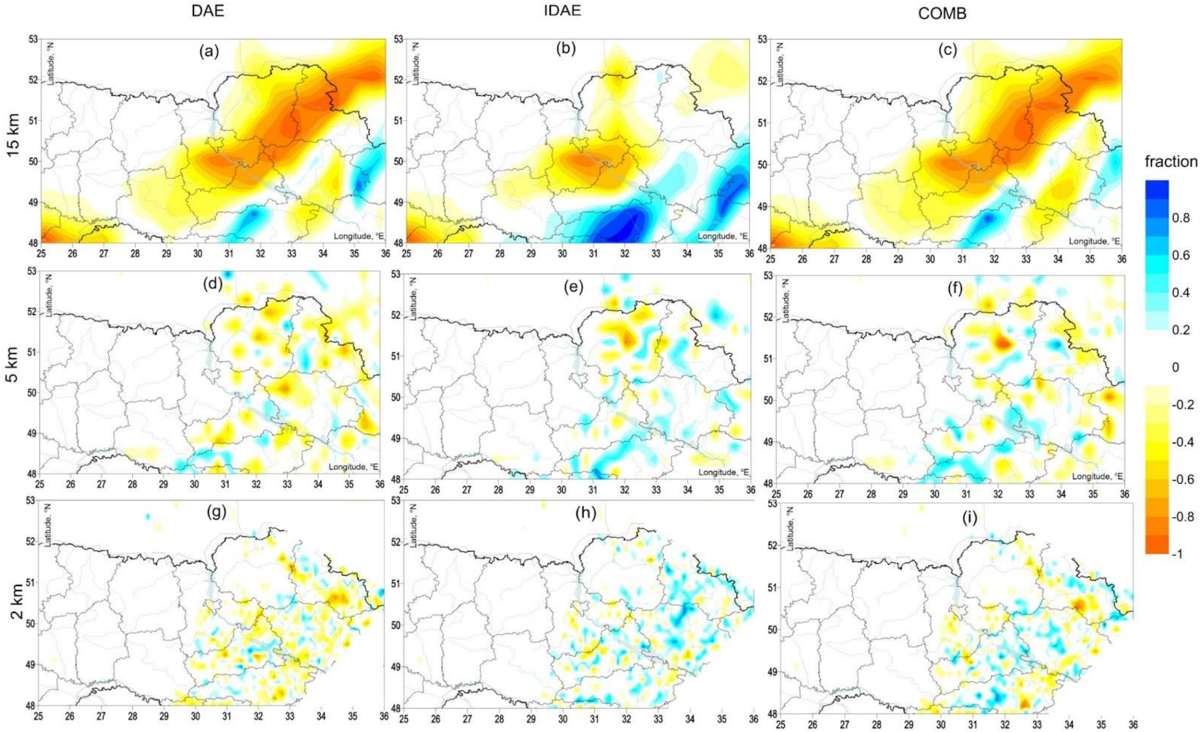
Difference between the Enviro-HIRLAM modified (with aerosol effects) and reference (control) runs for direct (DAE) (a,d,g), indirect (IDAE) (b,c,h) and combined (COMB) (c,f,i) aerosol effects included on **2-m relative humidity on 10 April 2020 at 12 UTC**



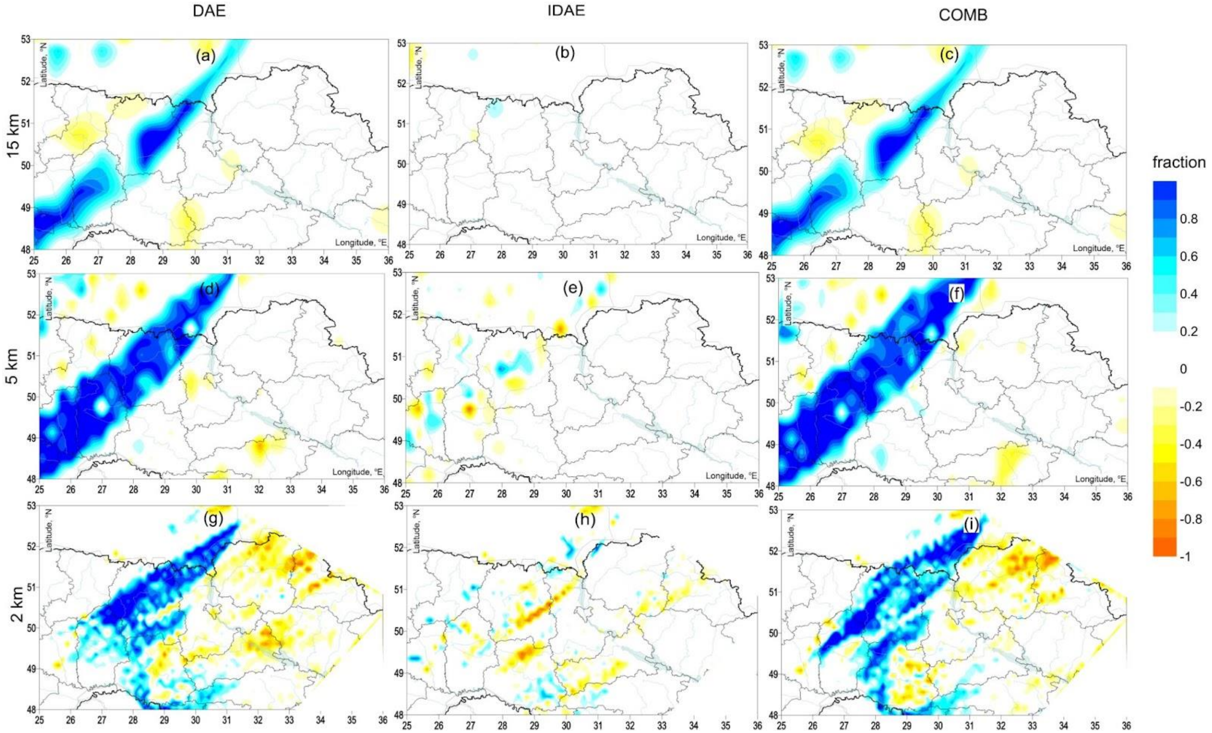
Difference between the Enviro-HIRLAM modified (with aerosol effects) and reference (control) runs for direct (DAE) (a,d,g), indirect (IDAE) (b,c,h) and combined (COMB) (c,f,i) aerosol effects included on **2-m relative humidity on 14 April 2020 at 18 UTC**

Direct and indirect aerosol effects on the atmosphere

total cloud cover



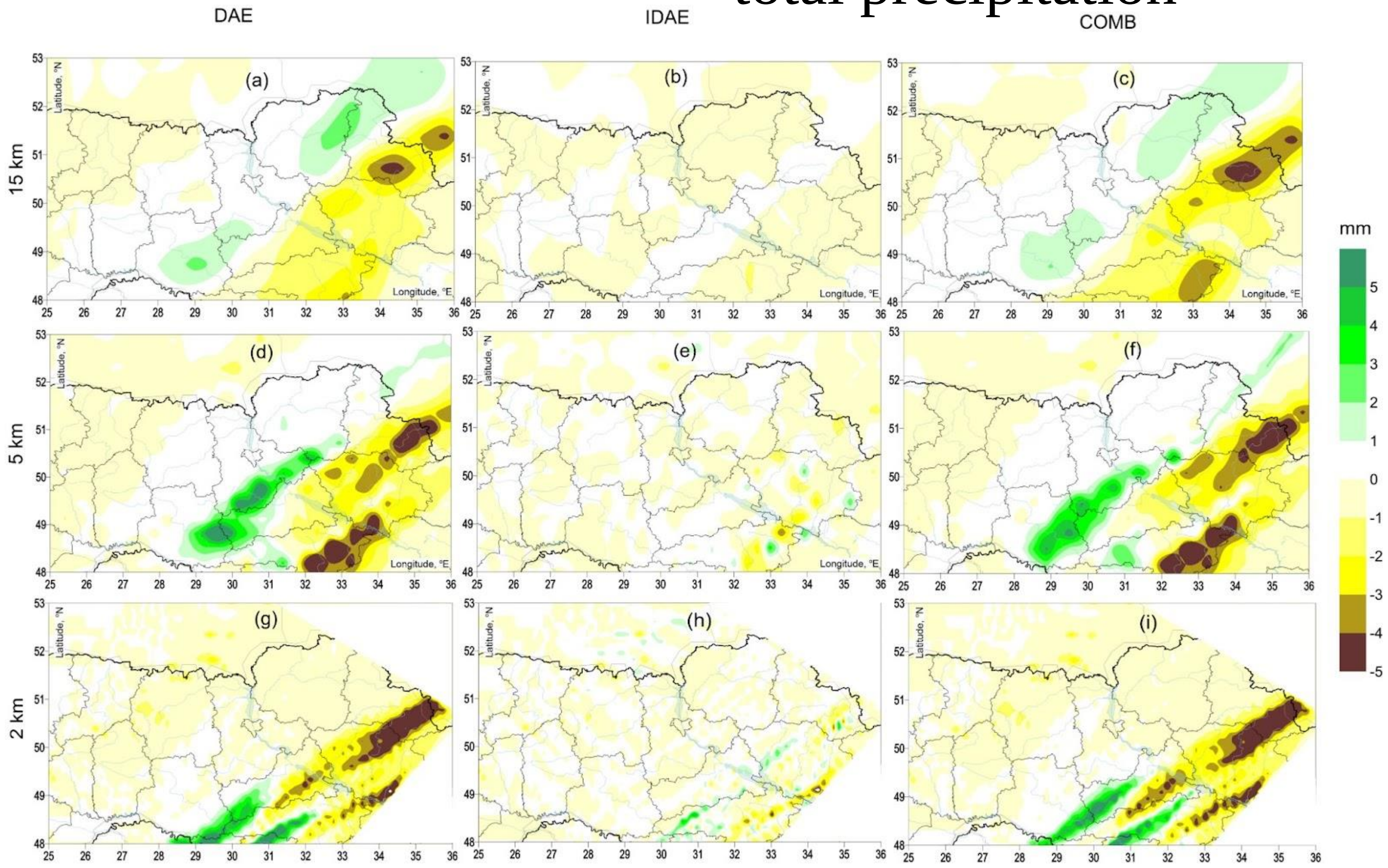
Difference between the Enviro-HIRLAM modified (with aerosol effects) and reference (control) runs for direct (DAE) (a,d,g), indirect (IDAE) (b,c,h) and combined (COMB) (c,f,i) aerosol effects included on **total cloud cover on 10 April 2020 at 12 UTC**



Difference between the Enviro-HIRLAM modified (with aerosol effects) and reference (control) runs for direct (DAE) (a,d,g), indirect (IDAE) (b,c,h) and combined (COMB) (c,f,i) aerosol effects included on **total cloud cover on 14 April 2020 at 18 UTC**

Direct and indirect aerosol effects on the atmosphere

total precipitation



Difference between the Enviro-HIRLAM modified (with aerosol effects) and reference (control) runs for direct (DAE) (a,d,g), indirect (IDAE) (b,c,h) and combined (COMB) (c,f,i) aerosol effects included on **total precipitation on 14 April 2020 at 18 UTC**

Pan-Eurasian Experiment PEEX

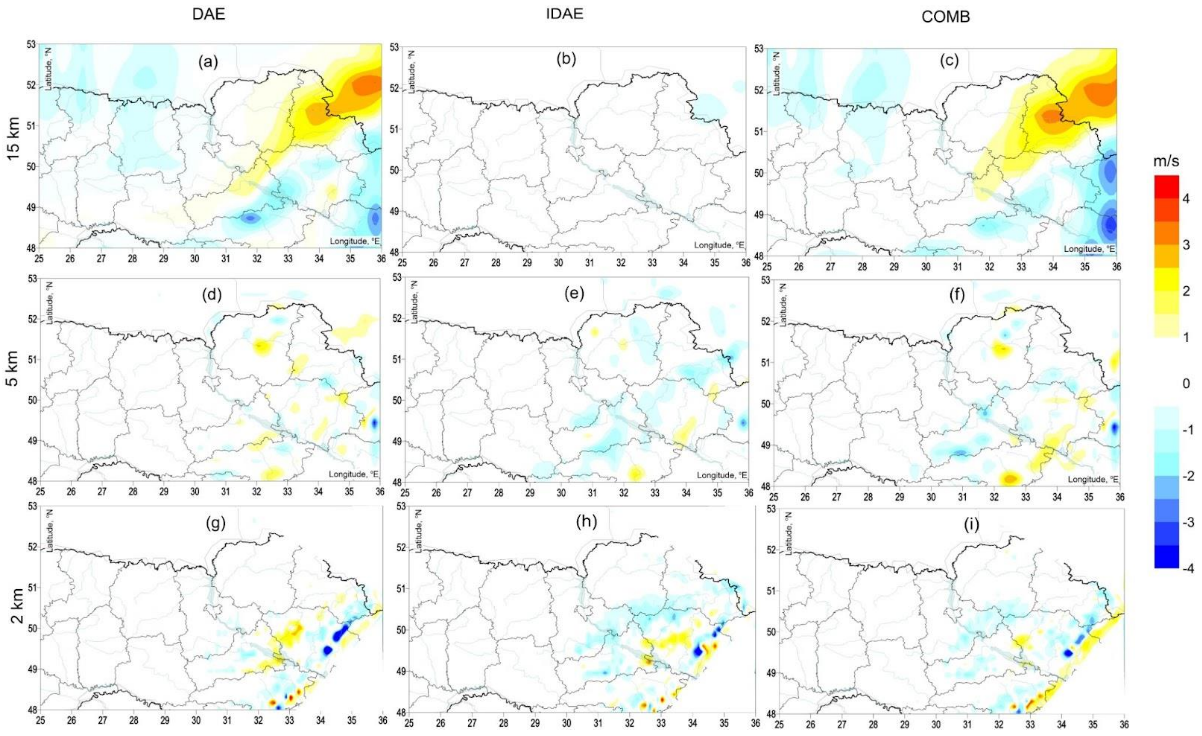
PEEX Online Meeting/
Seminar at the ACCC Impact Week
Thursday, 11 April 2024

INAR INSTITUTE FOR ATMOSPHERIC AND EARTH SYSTEM RESEARCH

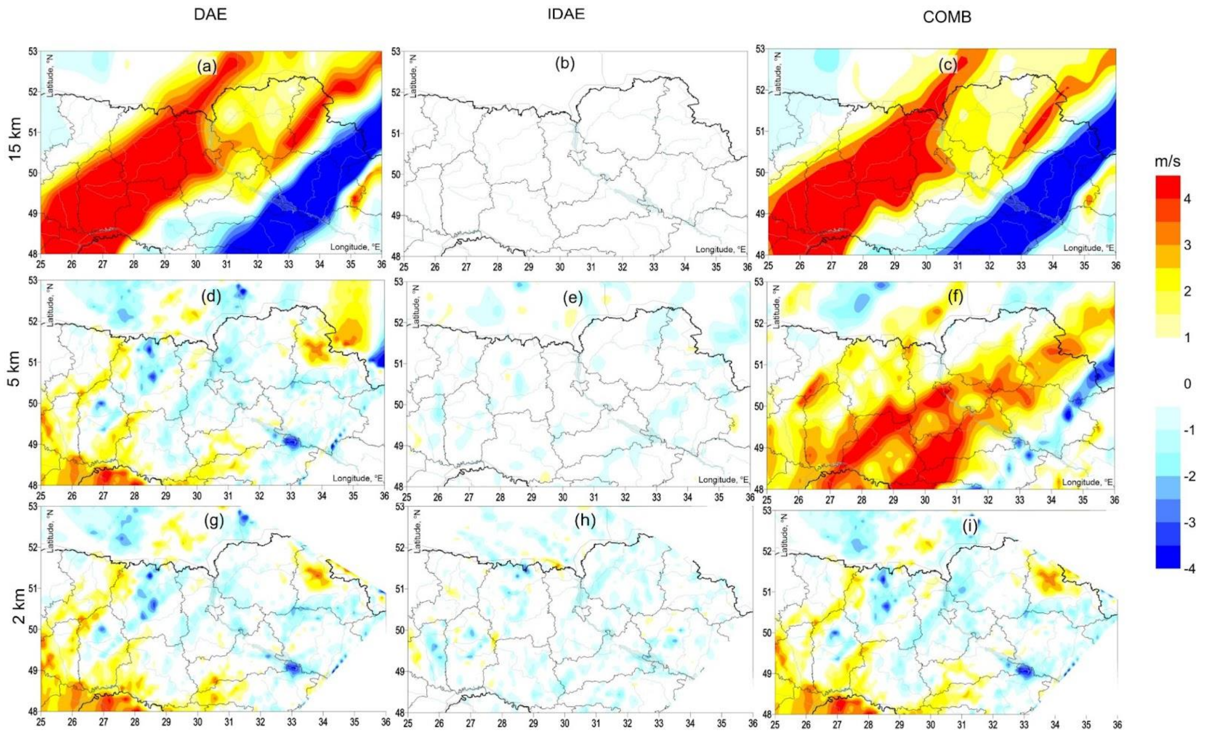
Ukrainian Hydro Meteorological Institute

Direct and indirect aerosol effects on the atmosphere

10-m wind speed



Difference between the Enviro-HIRLAM modified (with aerosol effects) and reference (control) runs for direct (DAE) (a,d,g), indirect (IDAE) (b,c,h) and combined (COMB) (c,f,i) aerosol effects included on **10-m wind speed on 10 April 2020 at 12 UTC**



Difference between the Enviro-HIRLAM modified (with aerosol effects) and reference (control) runs for direct (DAE) (a,d,g), indirect (IDAE) (b,c,h) and combined (COMB) (c,f,i) aerosol effects included on **10-m wind speed on 14 April 2020 at 18 UTC**

Conclusions

The April 2020 wildfire episode in Ukraine appeared as a joint consequence of anthropogenic (seasonal open burning) and natural (weather conditions) factors. Although there were observed not so high air temperatures, rather dry conditions influenced the severity of wildfires that determined aerosol composition over the region. In the CEZ, BC and OC (mostly their accumulation mode) accounted for 80% of all aerosol components in the lowest atmospheric layer, being the primary reason for the observed direct and indirect aerosol effects. In the layer 2-4 km above the surface, the largest variability of BC and OC characteristics were observed. It was the layer where the Aitken mode exceeded accumulation mode at nighttime hours, followed by the rapid changes in BC and OC content and size distribution in the morning.

The elevated content of carbonaceous aerosols resulted in colder and drier air conditions. At finer resolution model runs, the local features showed more influence, and in particular, the 2-m air temperature difference decreased by -3^{o}C and the 2-m relative humidity dropped by 20%. The most intensive and variable differences (with opposite effects) were observed during the atmospheric frontal passages. Aerosol effects caused, in general, changes of both signs in total cloud cover and accumulated precipitation. At edges of the atmospheric fronts the areas with precipitation had increased, even though there were no significant changes in cloudiness. Some changes in cloudiness and precipitation corresponded to the areas where differences (caused by DAE and IDAE effects) in wind speeds (were up to ±4 m/s, which mostly indicated spatial shifts of cloudiness and precipitation patterns in response to aerosol effects.

Acknowledgements

The work has been performed under the Project **HPC-EUROPA3 (INFRAIA-2016-1-730897)**, obtained while conducting the project "Integrated modelling for assessment of potential pollution regional atmospheric transport as result of accidental wildfires" (2020-2022) with the support of the EC Research Innovation Action under the H2020 Programme; in particular, the author gratefully acknowledges the computer resources and technical support provided by the Center for Science Computing (CSC) HPC (Finland).

Thank you!

savenets@uhmi.org.ua