Studio dell’influenza delle emissioni da incendi boschivi ed agricoli sulla variabilità atmosferica dell’anidride carbonica osservata presso il sito atmosferico ICOS di Monte Cimone (Italia, 2165 m asl)

P.Cristofanelli[1], D.Putero[2], P. Trisolino[1], F. Calzolari[1], C. Fratticioli[1], M. Busetto[1], P. Bonasoni[1], C.R. Calidonna[3], D. Biron[4], S. Amendola[4]

[1]*ISAC-CNR, Via Gobetti 101, I-40129 Bologna;* [2]*ISAC-CNR, Corso Fiume, 4 10133 Torino (TO);* [3]*ISAC-CNR, Zona Industriale-Comparto 15-presso Fondazione Mediterranea Terina-88046 Lamezia Terme (CZ);* [4]*Centro Aeronautica Miltare di Montagna (CAMM), Aeronautica Militare, Via delle Ville, 40 - 41029 Sestola (MO)*

***Contact**: p.cristofanelli@isac.cnr.it*

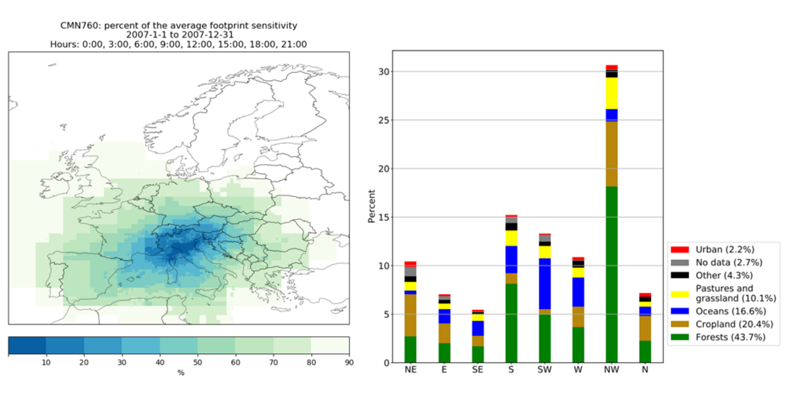
National Research Council of Italy
Institute of Atmospheric Sciences and Climate

Introduzione

Nel marzo 2020, rispetto al periodo 2018-2019, è stata osservata un’anomalia positiva dei valori atmosferici di CO_2 presso il sito ICOS atmosferico di Monte Cimone (2165 m asl), gestito dal CNR-ISAC in collaborazione con il CAMM dell’Aeronautica Militare, negli Appennini settentrionale. L’analisi della variabilità in-situ della CO_2 e del monossido di carbonio (CO), unitamente ad analisi del trasporto atmosferico attraverso le retro-traiettorie calcolate con LAGRANTO (Lagrangian Analysis Tool) ed all’identificazione di aree interessate da incendi attraverso i dati satellitari MODIS (Moderate Resolution Imaging Spectroradiometer), hanno permesso di attribuire gli elevati valori di CO_2 a vasti incendi occorsi nell’Europa orientale.

In questo lavoro, verranno proposti e commentati i risultati di un primo studio sistematico (2018–2020) condotto per valutare la possibile influenza di emissioni da incendi di vegetazione occorsi sul dominio Europeo sulla variabilità della CO_2 osservata a Monte Cimone. A tal fine, saranno considerati in modo sinergico: (i) le simulazioni del trasporto atmosferico mediante l’uso delle retro-traiettorie, (ii) i risultati delle simulazioni di CO_2 prodotte dal modello Lagrangiano STILT (Stochastic Time Inverted Lagrangian Transport), (iii) le osservazioni satellitari di incendi da MODIS, e (iv) le osservazioni del rapporto CO/CO_2 a Monte Cimone.

Methodology – Measuremen site



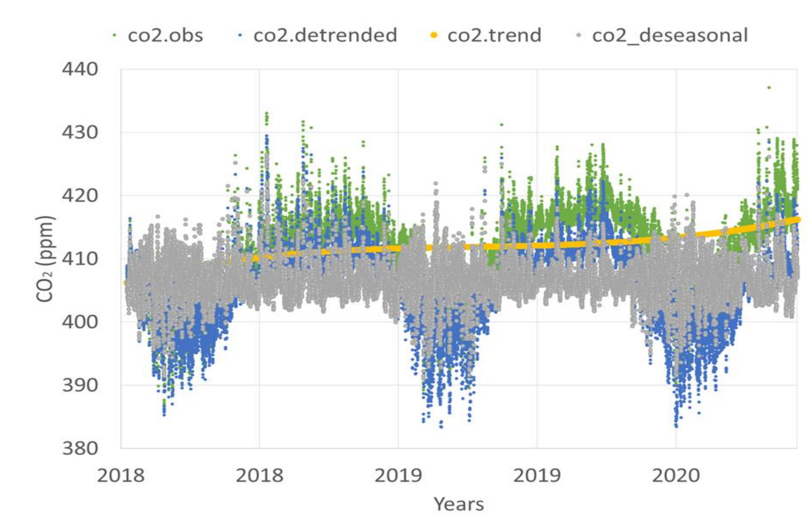
Right: Sensitivity area map of the average footprint/sensitivity area for CMN based on STILT model footprint. **Left**: Contributions of different land cover types within Monte Cimone´s average footprint is shown in the land cover bar graph.

The ICOS site at the CNR «O. Vittori» observatory is hosted by the CAMM (Italian Air Force)

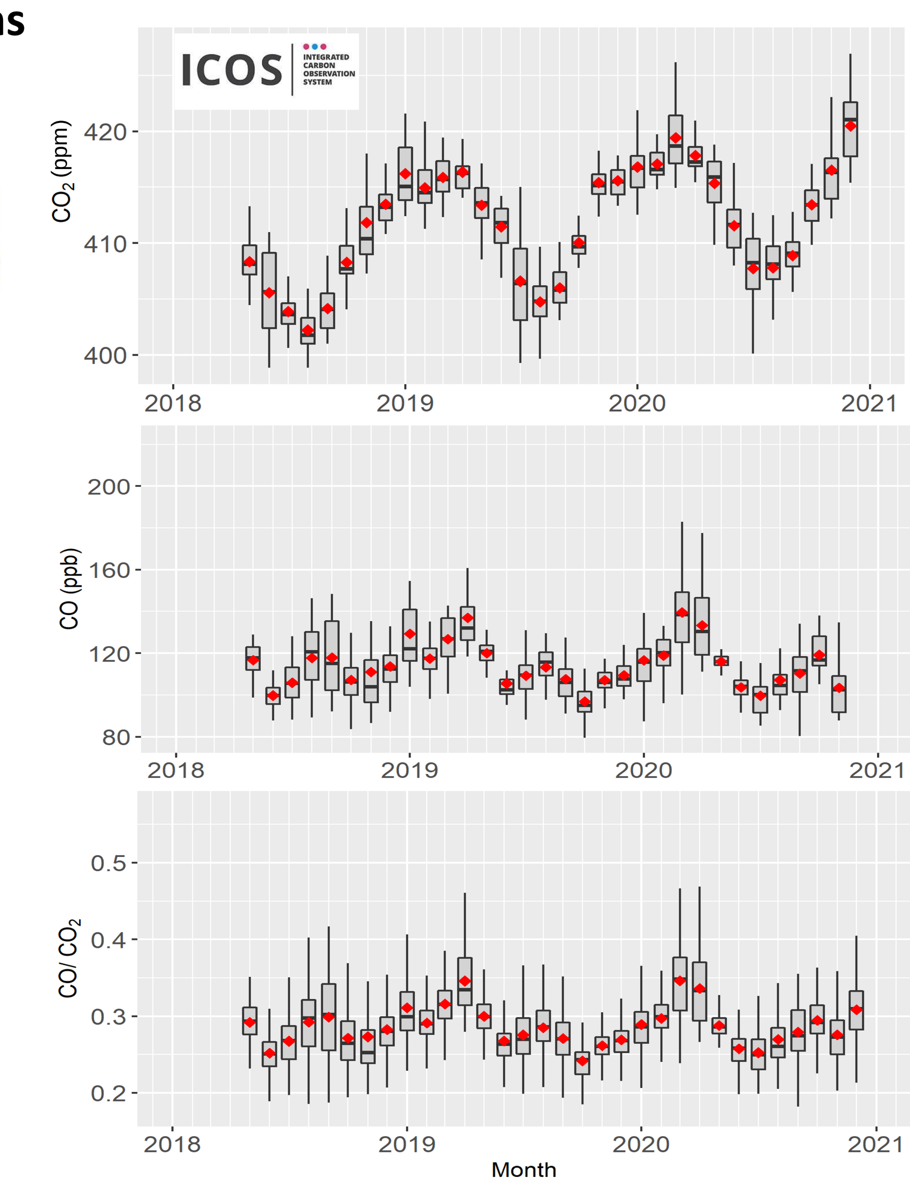
Mt. Cimone (CMN, 44°12' N, 10°42' E,) is the highest peak of the northern Italian Apennines and overlooks the Po basin (towards NW-SE) and northern Tuscany (towards S-NW). Within several kilometers from the site, human activity is very limited. Especially from April to September, the measurement site can be affected by thermal wind circulation (slope and valley winds, diurnal PBL growth) and convective vertical transport of air masses.

As shown by the footprint calculated by the Stochastic Time Inverted Lagrangian Transport (STILT, Lin et al., 2003) model, CMN atmospheric observations are strongly sensitive to emissions occurring over northern Italy but they can still retain signals of emissions occurring over a large fraction of the European domain. It is also interesting to note that according to STILT analysis, the highest surface sensitivity is related to the surface covered by forest, suggesting that atmospheric observation at this measurement site can be profitably used to investigate the impact of wildfires on atmospheric composition variability.

Metodology – Atmospheric observations



Hourly CO_2 values observed at Mt. Cimone from 2018 to 2020. **Green**: original data. **Yellow**: trend component of the CO_2 time series as deduced by the application of ccgrv methodology. **Green**: detrended values. **Grey**: de-trended and de-seasonalised (according with ccgrv) values.

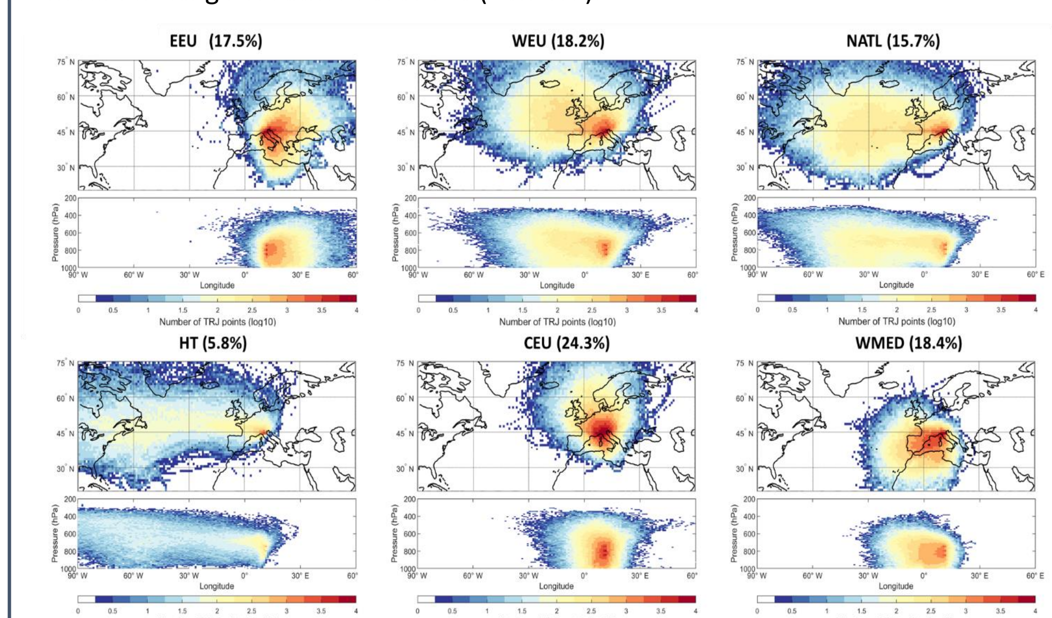


The atmospheric observations of CO and CO_2 are carried out in a standardized way for measurement set-up, used materials, quality assurance strategy and data creation workflow (see Hazan et al., 2016; Yver-Kwok et al., 2021).

The dataset considered in this work is part of the ICOS level-2 data release (1-hourly time averaged data that underwent the final quality check by site PIs). Starting from the hourly mean values of CO and CO_2 , a time series of CO/ CO_2 ratio was calculated to help in identifying the occurrence of open fire plumes to the measurement site.

Methodology – Modelling tools and satellite fire data

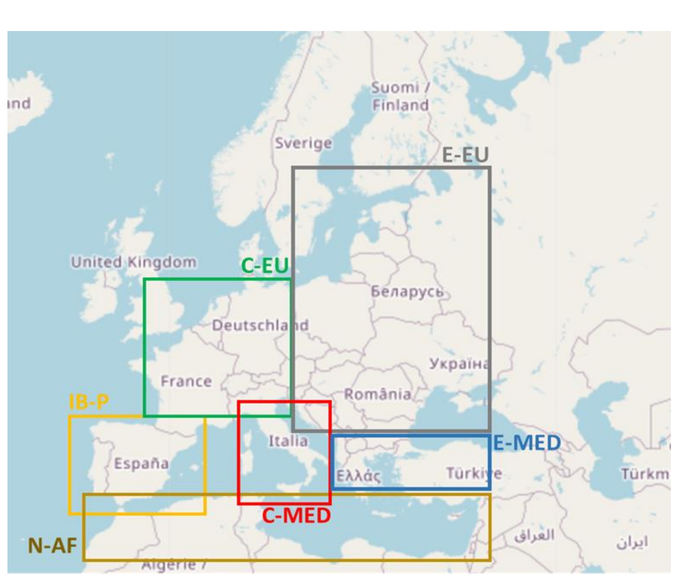
To determine the synoptic origin of the air masses reaching CMN and to assess the possibility that air masses underwent impact of open fire emissions during travelling towards the sites, 5-days 3D back-trajectories were calculated based on six-hourly meteorological data (00, 06, 12, and 18 UTC) with the Lagrangian Analysis Tool LAGRANTO (Sprenger and Wernli, 2015) over the period 2018 - 2020. For each set, three back-trajectories were computed, with starting points shifted by a vertical range of ± 50 hPa with respect to the station location (i.e., at 840, 790, and 740 hPa). The trajectory calculations were based on the ERA5 reanalysis dataset of the European Centre for Medium-Range Weather Forecasts (ECMWF).



Back-trajectory cluster identified for CMN. The colored scale reports the number of back-trajectory points over a 1°x1° horizontal grid and over 81 pressure levels. The number over each cluster plot denotes the percentage of occurrence to CMN during May 2018 - December 2020.

Eastern Europe (EEU): air-masses mostly following a westward advection path to CMN, with evident transport at relatively high pressure levels
Western Europe (WEU): air-masses mostly following south/eastward and downward advection path to CMN
North-Atlantic (NATL): air-masses originating over northern Atlantic Ocean and advected easterly towards the measurement site
Hemispheric transport (HT): air-masses originating over (or farther) the West coast of North America, typically in the free troposphere and easterly advected towards the measurement sites.
Central Europe (CEU): air-masses originating mostly over central Europe and central Mediterranean basin that mostly undergone to upward transport toward CMN
Western Mediterranean (WMED): air-masses mostly following north/eastward advection path to CMN

With the purpose of interpreting and attributing the variability of CO_2 at CMN, we considered the STILT model (https://www.icos-cp.eu/data-services/tools/stilt-footprint). STILT provided the simulated time series of CO_2 at CMN as resulting from the integration of contributions from different natural fluxes (split up into uptake of CO_2 by photosynthesis and release of CO_2 by respiration), anthropogenic emissions (split into emissions from different source categories: energy production, industrial processes, transportation, residential heating, and other processes), contributions from sources and sinks outside the model domain (i.e. the so-called background). No contributions from wildfire emissions are considered.



With the aim of identifying the occurrence of vegetation fires over Europe, the Global Fire Emission Dataset - Version 4 (GFED4) was considered. By using the online GFED Analysis Tool (http://www.globalfiredata.org/analysis.html), the number of fire counts over 6 emission regions (see left) were obtained on a daily basis.

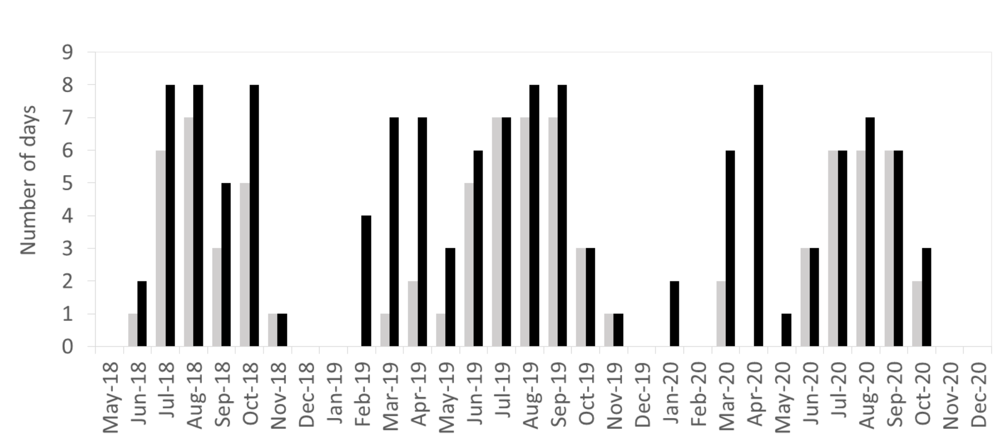
Fire count data were derived by the MODIS (Moderate Resolution Imaging Spectroradiometer) L2 fire product (Giglio et al., 2020). In the GFED Analysis Tool the original data with 1-km data resolution (at the NADIR) were considered. The 6 source regions (Eastern Europe; Central Europe; Iberian Peninsula; Central Mediterranean; Eastern Mediterranean, Northern Africa) were selected also considering the feature of the atmospheric circulation at CMN as diagnosed by the cluster analysis

Event selection methodology

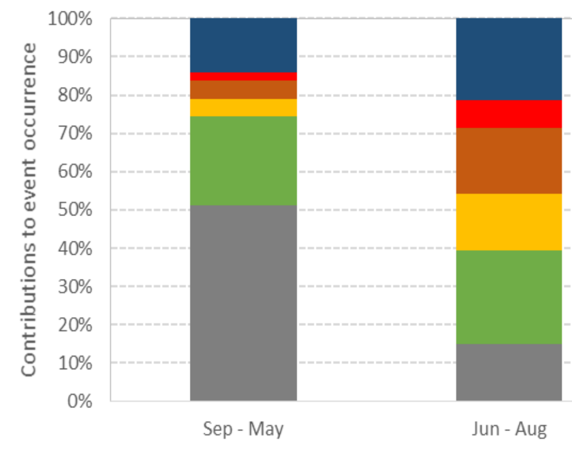
We defined an approach combining in-situ observations of CO/CO_2, satellite fire detections, LAGRANTO air mass back-trajectories and STILT CO_2 simulations to identify the possible days in which open fire plumes affected CMN during the timeframe 2018 - 2020.

The following conditions had to be satisfied to mark a day as potentially influenced by open vegetation fires from eastern Europe at the representative ICOS sites:
1) Observed daily CO/ CO_2 average value higher than the monthly 75th percentile;
2) At least 25% of daily back-trajectories within clusters related to origin or passage over one of the 6 source regions with a robust (i.e. daily number of active fires higher than the 75th percentile over the investigated period) presence of active fires over the same source region;
3) Observed daily CO_2 average value exceeding the STILT daily CO_2 values by more than 1 ppm.

Monthly number of days possibly affected by wildfire emissions at CMN. Black bars denoted results when the constraint by STILT was removed (“no-stilt”).

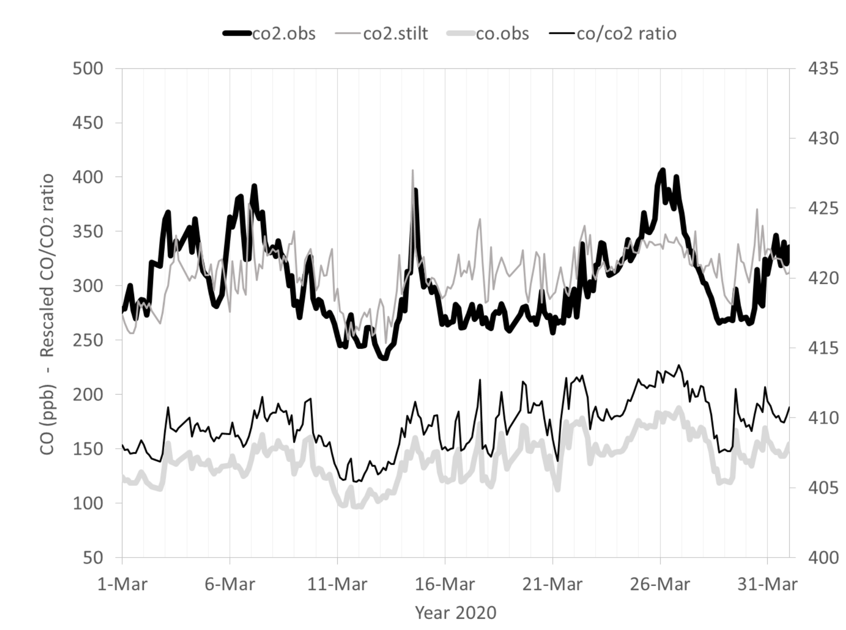


Percentage contribution of the different source regions to the event occurrence during not summer (Sep - May) and summer (Jun - Aug) periods.



A not negligible number of days potentially affected by transport of open fire plumes were detected: they ranged from 35 during the “not summer” period to 43 during June – August (5.5% and the 17.6%). The seasonality of the events showed an evident cycle with a peak from late spring to early autumn and a minimum in winter. Looking at the potential source regions of wildfire plumes, we found a prevalence of **E-EU (51%) and CW-EU (23%) during the not summer period**, while during **June - August the prevalence were related to CW-EU (24%) and to Mediterranean regions (E-MED: 21%; IB-P: 15% and N-AF: 17%)**.

Results – Case study March 2020



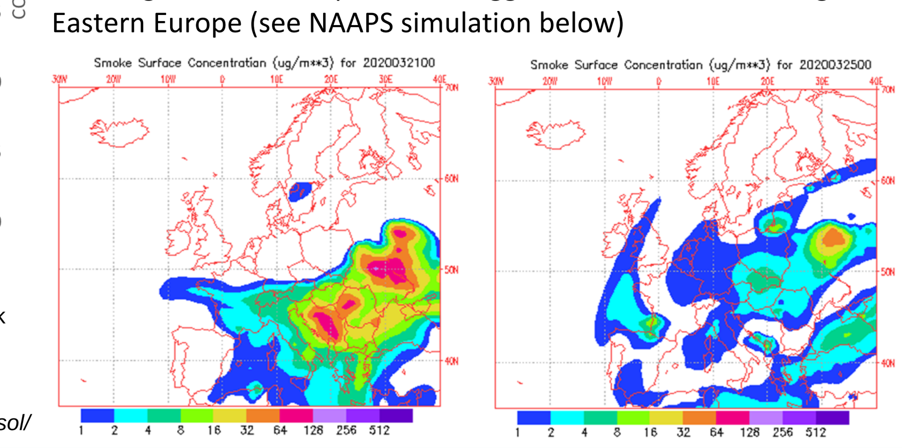
Hourly mean values of CO_2 (black tick line), CO (grey tick line) and CO/CO_2 (black tin line) and CO2.stilt (grey thin line) at CMN during March 2020. Please note that the CO/CO_2 values were scaled x 500.

https://www.nrlmry.navy.mil/aerosol/

A notable increase in CO_2 was observed on 22 - 27 March 2020. On 26 March (2:00 UTC) a peak of 428 ppm was observed, +13 ppm increase with respect to the previous period (i.e. 16-20 March 2020).

The high CO_2 values were accompanied by an increase in CO which was also reflected in the increase of the CO/ CO2 ratio. CO2.stilt provided a good description of the day-to-day CO_2 variability observed at CMN but was not able to represent the observed CO_2 peak on 25 - 26 March 2020.

The origin of the CO_2 peak was tagged to wildfires occurring over Eastern Europe (see NAAPS simulation below)

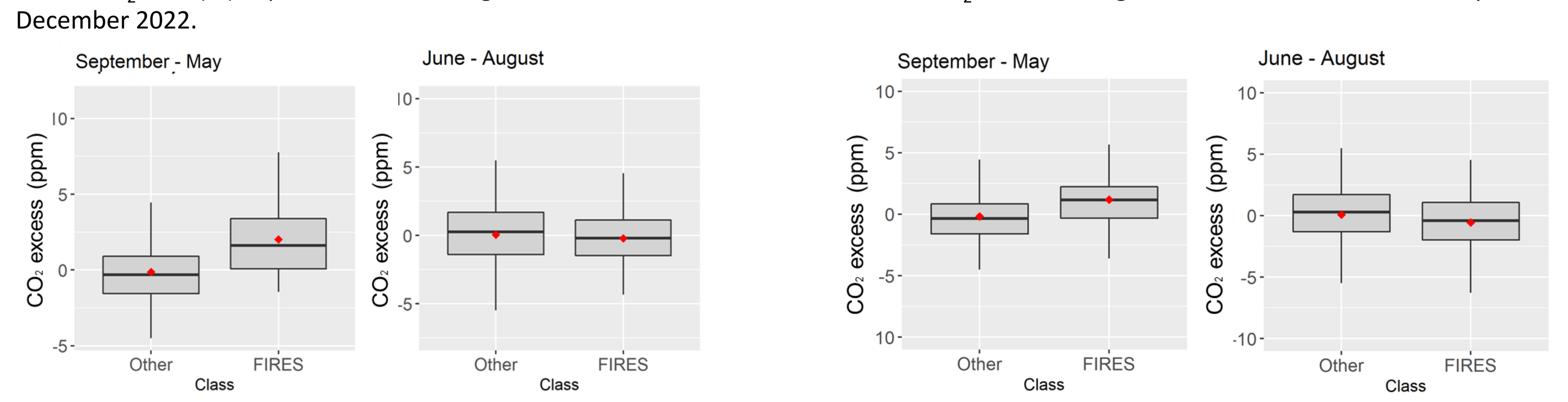


Results – Multi-annual assessment of wildfire emissions

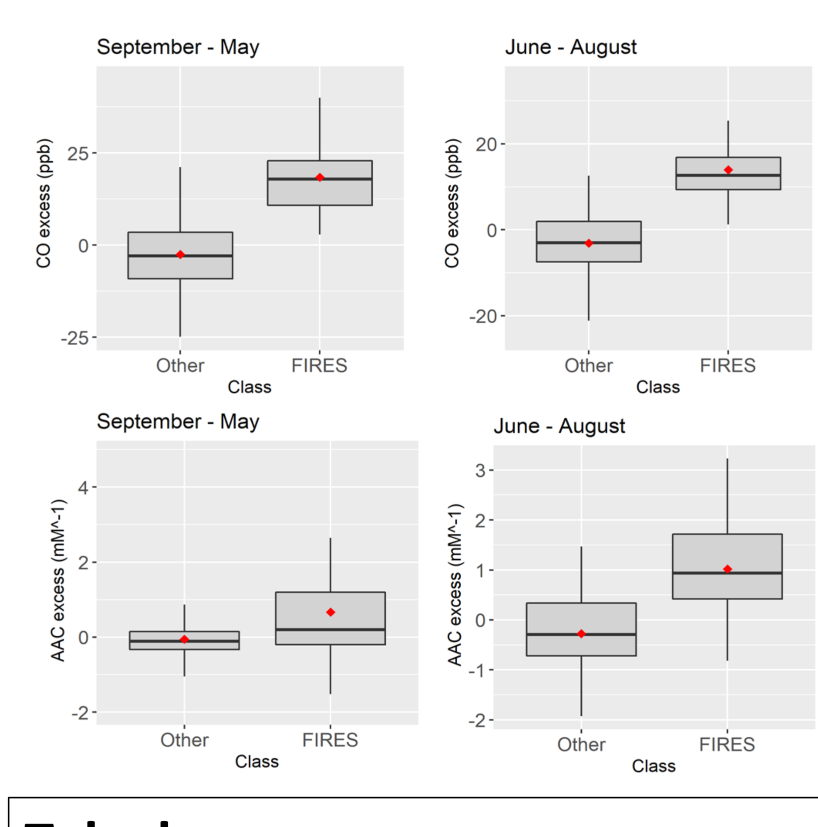
To assess the possible impact of wildfire plumes to the CO_2 at CMN, we have calculated the excess of detrended and deseasonalized CO_2 (CO_2^{excess}) by subtracting from the 3-hour averages the actual monthly means, *i.e.,* for each i^{th} 3-hour values $CO_2(i)$, the excess of CO_2 is calculated as:

$$CO_2^{excess}(i) = CO_2(i) - CO_2^{monthly}(m)$$

where $CO_2^{monthly}(m)$ represents the average values of detrended/deseasonalized CO_2 for each single calendar month *m* from May 2018 to December 2022.



For each period, we reported the mean average value (red points), the median (bold lines) and the 5th, 25th, 75th and 95th percentiles (box and whiskers) of the excess of deseasonalized and detrended CO_2 for days possibly affected by wildfire plumes (“Fires”). For comparison, the daily CO_2 values for remaining periods (“Other”) are reported. **Left: results with STILT constraint. Right: results without STILT constraint**.



A sensitivity test was implemented (see “Event selection methodology”) by relaxing the constraint imposed by the use of STILT output in the selection methodology: **the number of detected events increased to 56 days during June - August (20.2%) and to 74 days (i.e. 11.7% of the period) during May - September, suggesting a high sensitivity on May - September detections.**

While the seasonality of the detected events was maintained, neglecting the STILT constraint increased the number of detection during late winter and early spring. The results of the impact analysis on CO_2 showed the same tendency as for the base case (see above)

Similarly than for CO_2 , we calculated excess of CO and Aerosol Absorbing Coefficient (AAC). During summer, both CO_{excess} and AAC_{excess} showed higher values for days possibly affected by wildfires: since both CO and AAC can be considered tracers for combustion emissions and they do not have a strong vegetation sink like the CO_2 , these results would support the actual presence of wildfire plumes at the measurements site and a possible role of the biospheric sink in partially hindering the wildfire impact in summer.

Take home messages

- Observations at CMN can represent, if supported by adequate diagnostic tools, a powerful dataset to evaluate the impact of open fires to CO_2 variability
- The obtained results suggested that CMN could be affected for a not-negligible fraction of time by wildfire plumes. We found a potential important contribution of wildfires from Eastern Europe during September - May (51% of events), while during summer there was a prevalence from the Mediterranean sector (53% of events).
- Looking at the possible impact of these events to the observed CO_2, we detected an increase during September - May (+3.4 ppm, on average), while we did not find any significant variations during summer months (role of biospheric uptake?).
- These estimates should be treated with caution due to (i) the relatively short considered study period, and (ii) the sensitivity of results as a function of the set-up of the selection methodology.

Ministero dell'Università e della Ricerca
FSC Fondo per lo Sviluppo e la Coesione
Cosimo Fratticioli’s and Pamela Trisolino’s grants are funded by the National Project Rafforzamento del Capitale Umano CIR01_00019 – PRO-ICOS_MED “Potenziamento della rete di osservazione ICOS-Italia nel Mediterraneo – Rafforzamento del Capitale Umano”

ICOS activities at the CMN class-2 atmospheric sites are partially supported by the JRU ICOS-Italy

ICOS National Network Italy