Projecting wildfire-related toxic air pollution impacts at multiple scales

MIT Portugal Program Annual Report, October 2025

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Mercury (Hg) and Polycyclic Aromatic Hydrocarbons (PAHs) are toxic environmental pollutants that are emitted by both natural and anthropogenic sources. While human activities have historically played a dominant role in determining exposure to these pollutants, national and international policies have lowered the magnitude of anthropogenic sources, enhancing the relative contribution of natural sources such as biomass burning. Our project focuses on understanding how these toxic plumes travel and impact people, by characterizing potential exposure to air toxics from wildfires. Our work focuses on improving tools for modeling atmospheric fine particulate matter, carcinogenic air pollutants (polycyclic aromatic hydrocarbons) and a neurotoxic metal (mercury) from wildfires. Focusing on fires in Portugal and the Iberian Peninsula, we are assessing the relative impacts of toxic fires near to and far away from sources. We are also exploring trends in wildfire-related toxic risk, including consideration of how climate change could impact wildfire-related toxic air pollution.

Our annual report summarizes progress to date. First, we summarize work towards our three scientific objectives. Second, we highlight our collaborations with Portuguese investigators and impact on Portugal. Finally, we list collaborative presentations and publications.

Progress on Scientific Objectives

We have successfully completed our objective to ***develop an improved global-scale model of wildfire toxics, and apply it in international policy-focused assessments.*** We have completed work on this first objective, making several improvements to our global-scale model of wildfire toxics. The result of Objective 1 is an improved global-scale model of long-range transport of Hg and PAHs from wildfire sources (Cicone et al., under review), which will be applied in international assessment activities. Our work has been incorporated into the international Multi-Compartment Hg Modeling and Analysis Project (MCHgMAP), which is part of a collaborative international activity aimed to inform both regional and global policies on Hg (Dastoor et al., 2025). We are also participating in a model intercomparison activity assessing the impact of wildfires through the Hemispheric Transport of Air Pollutants (HTAP) effort, informing the international Convention on Long-Range Transboundary Air Pollution.

We continue to improve our global-scale model, in particular to facilitate work on Objectives 2 and 3. Work is currently under way to ***quantify toxic air pollution risks for selected large wildfire event case studies, and compare its impact to the aggregate effect of small wildfires.*** We identified limitations of MIT's existing modeling tools, which provide broad estimates but spatially resolved impacts of toxics relevant to localized areas like Portugal. Models typically used by the team in Portugal are higher resolution, but do not incorporate Hg and PAHs. In order to address the shortcoming of our models, we are actively developing a version of the GEOS-Chem High-Performance (GCHP) model that can simulate the atmospheric processing of Hg and PAHs. While typical GEOS-Chem simulations have a maximum global resolution of 2° latitude by 2.5°

longitude and nested resolutions as high as 0.5° latitude and 0.625° longitude, GCHP uses a more flexible gridding structure that has the capability enhance model resolution over the region of interest and degrade the resolution elsewhere. With this capability, we will be able to configure simulations that approach the resolution of the input emission datasets required to drive these global simulations. We will also be able to compare results for atmospheric particulate matter directly with those produced by the team in Portugal, allowing us to identify the influence of model resolution on our results. The development of this model is supported by advances made in our projects that focus on other regions of the globe, where we can leverage existing observations to validate model processes.

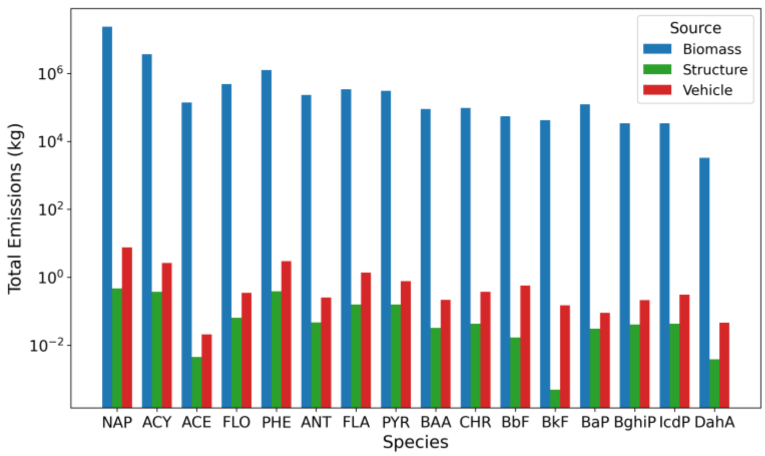

Figure 1. 2019 WUI emissions in the Iberian Peninsula from burned biomass (blue), structure (green), and vehicle (red) sources. Emissions are shown for the 16 EPA priority pollutants. Note the use of a log scale for the y-axis.

In exploring wildfire events for consideration, we identified that a particular concern for air pollution in Portugal are wildland urban interface (WUI) fires, which are increasingly occurring both in Portugal and globally as urban development expands into fire-prone landscapes. The WUI is defined as “the line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetation fuels” (Harries et al., 2022). Fires at the WUI are of notable concern to public health due to their proximity to people and the burning of human-made materials that emit toxic pollutants like PAHs and Hg. We have now developed a global inventory of WUI PAH emissions from biomass, structures, and vehicles by leveraging case studies of fires in California. These case studies provided estimates of the proportion of structures and vehicles typically destroyed in WUI fires, based on known fire perimeters and associated damage. We combined this information with high-resolution infrastructure data, FINN fire data, and structure- and vehicle-specific emission factors to estimate emissions on a global scale. The estimates for 2019 for the Iberian Peninsula are shown in Figure 1. These emissions will be used as input into the updated GEOS-Chem model to investigate the health impacts of PAHs as a result of WUI fires. Due to the lack of known emission factors for Hg, this analysis will be constrained to PAHs.

The development of the GCHP simulation will enable us to achieve our third objective, to **quantify the relative importance of projected future anthropogenic vs. climate-driven changes on wildfire-related toxic impacts.** To assess how climate changes impact these air pollutants, we need to be running GCHP to be able to leverage prior work at MIT that enables running ensembles of the GEOS-Chem atmospheric model for a variety of future climate scenarios (Eastham et al., 2023). We have also identified collaborators for projecting anthropogenic air pollutants, building on our previous work projecting air pollutant emissions (Atkinson et al., 2022), which will enable future anthropogenic emissions inventories consistent with climate policy projections to drive global scale models. We anticipate continuing work on this objective in the coming year.

Collaborations with and impacts on Portugal

Our work has involved running new model simulations and analysis at MIT focused on wildfire impacts of Hg and PAHs, and comparing to existing data sources provided by colleagues in Portugal. Facilitated by regular zoom meetings and in-person meetings associated with key scientific conferences, we have to date produced five coauthored conference presentations with members of both teams. These are listed in the next section, "Publications and Presentations to date."

This project addresses a topic of great interest in and relevance to Portugal, the impact of wildfires. We aim to provide better understanding of the toxic impact of these fires, which leads to quantifiable health impacts in the Portuguese population (Duarte et al., 2023). Our initial estimates, derived from inputs to the GEOS-Chem global chemical transport model, show that biomass burning contributed over 90% of annual Hg emissions and over 50% of annual PAH emissions in central Portugal during the extreme 2017 Portuguese biomass burning events (Figure 2). These estimates will be further refined as our scientific work progresses.

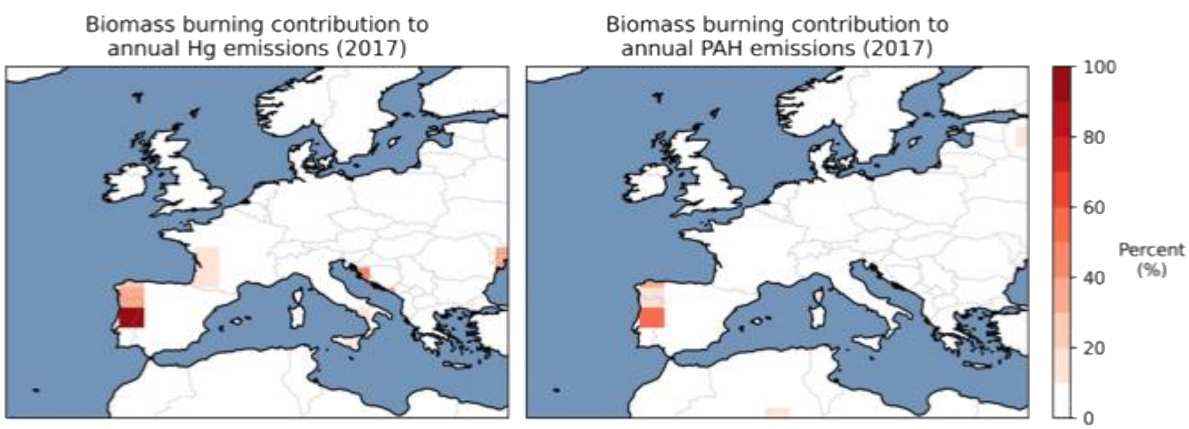

Figure 2: The percentage contribution of biomass burning emissions to total emissions of Hg (left) and 16 EPA priority PAH (right).

Publications and Presentations to date

Cicone, L., Gama, C., Miranda, A., Osswald, T., Monteiro, A., Wong, A., Selin, N. E. Emissions and Chemistry of PAHs from Wildland-Urban Interface Fires: Implications for Human Health. American Meteorological Society (AMS). *TBD*. 2026.

Cicone, L., Roy, E., Monteiro, A., Miranda, A., Gama, C., Osswald, T., Selin, N.E. Global and regional wildfire emissions of toxic pollutants contribute to health risks. MIT Portugal Program Annual Conference. *Talk and Poster*. 2024.

Cicone, L., Roy, E., Monteiro, A., Miranda, A., Gama, C., Osswald, T., Selin, N. E. Global and regional wildfire emissions of toxic pollutants contribute to health risks. International Technical Meeting on Air Pollution Modeling and Its Application (ITM). *Talk*. 2024.

Cicone, L., Gama, C., Miranda, A., Osswald, T., Monteiro, A., Wong, A., Selin, N. Quantifying the wildfire contribution to polycyclic aromatic hydrocarbon exposure and health effects. International Global Atmospheric Chemistry Conference (IGAC). *Talk*. 2024.

Cicone, L., Wong, A., Selin, N. Quantifying the wildfire contribution to polycyclic aromatic hydrocarbon concentrations and health effects, submitted to *Environmental Research Letters*.

Cicone, L., Gama, C., Miranda, A., Osswald, T., Monteiro, A., Wong, A., Selin, N. Emissions and Chemistry of PAHs from Wildland-Urban Interface Fires: Implications for Human Health. International Global Atmospheric Chemistry Early Career Researcher Conference (IGAC ECR). *Poster*. 2025.

Roy EM et al., Spatially and temporally dense measurements reveal meteorological driver of atmospheric mercury variability, *In preparation for submission to Environmental Science and Technology.*

Roy EM et al., Variability-based constraints on regional gaseous elemental mercury fluxes, *In preparation for submission to Atmospheric Chemistry and Physics.*

Roy EM, Selin NE, Spatially and temporally dense measurements reveal meteorological driver of atmospheric mercury variability MIT Department of Earth, Atmospheric, and Planetary Sciences Annual Research Showcase, Cambridge MA, USA, September 2025

Roy EM, Gay DA, Selin NE, Regional drivers of Hg loadings informed by spatially and temporally dense observations. European Geophysical Union General Assembly 2025, Vienna, AT, May 2025

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