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LETTER

Community-based participatory research for low-cost air pollution monitoring in the wake of unconventional oil and gas development in the Ohio River Valley: Empowering impacted residents through community science

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Abstract

Belmont County, Ohio is heavily dominated by unconventional oil and gas development that results in high levels of ambient air pollution. Residents here chose to work with a national volunteer network to develop a method of participatory science to answer questions about the association between impact on the health of their community and pollution exposure from the many industrial point sources in the county and surrounding area and river valley. After first directing their questions to the government agencies responsible for permitting and protecting public health, residents noted the lack of detailed data and understanding of the impact of these industries. These residents and environmental advocates are using the resulting science to open a dialogue with the EPA in hopes to ultimately collaboratively develop air quality standards that better protect public health. Results from comparing measurements from a citizen-led participatory low-cost, high-density air pollution sensor network of 35 particulate matter and 25 volatile organic compound sensors against regulatory monitors show low correlations (consistently $R^2 < 0.55$). This network analysis combined with complementary models of emission plumes are revealing the inadequacy of the sparse regulatory air pollution monitoring network in the area, and opening many avenues for public health officials to further verify people's experiences and act in the interest of residents' health with enforcement and informed permitting practices. Further, the collaborative best practices developed by this study serve as a launchpad for other community science efforts looking to monitor local air quality in response to industrial growth.

1. Background

Belmont County (BC), nestled in Eastern Ohio in the Ohio River Valley, takes its name from the French words for 'beautiful mountain.' Appalachia, once a pristine mountainous ecosystem, became the backbone of the U.S. fossil fuel system, first being reshaped by the coal industry, and more recently becoming a hotbed for unconventional oil and gas development (UOGD). Decades of environmental regulation, such as the Clean Air Act of 1970 [1], the Clean Water Act of 1972 [1], and the Safe Drinking

Water Act of 1974 [2], have been established to protect people's health by regulating air and water pollution, but gaps in the regulatory structure such as the 'Halliburton Loophole' have reduced the barriers UOGD faces in permitting structures [3].

Previous work has found that infrastructure associated with this industry emits air pollutants, including particulate matter ($PM_{2.5}$), radioactive particulate matter and volatile organic compounds such as benzene, toluene, and ethylbenzene [4, 5]. These pollutants have been linked to adverse respiratory and cardiovascular health effects [6]. For every Ohio River county where the Ohio Environmental Protection Agency (EPA) had a volatile organic compounds (VOCs) or heavy metal monitoring station, the agency found a cancer risk from ambient air pollution that exceeds 1 in 10,000—EPA's upper limit for 'acceptable risk' [7]. These counties are all located in Appalachian Ohio, designated as either 'at-risk' or 'transitional' counties by the Appalachian Regional Commission [8]. Beyond elevated baseline ambient concentrations, BC residents have also had to adapt to frequent large-scale disasters. The Statoil Well-pad Fire in 2014 burned $25 million of equipment, and industrial waste that flowed into the Ohio River killed at least 70,000 fish [9, 10]. In 2018, a well pad operated by XTO Energy, an ExxonMobil subsidiary, exploded at Powhatan Point leading to one of the nation's largest methane releases [11].

Additionally, House Bill 278 [12], which gives the Ohio Department of Natural Resources (ODNR) full control over the rapidly expanding placement of oil and gas drilling operations, further removed local communities from the decision-making process. This is a national environmental injustice crisis [13] where low-income and marginalized communities are disproportionately impacted by large industries where externalities are not fully taken into account in their activities. In a November 2020 webinar [14], Leatra Harper, Managing Director of the Freshwater Accountability Project (FAP), shared a clip of the Williams Salem Compressor Station in Jefferson County [14]. Pointing to it as a source of the community's ailments, she stated 'Local residents there have suffered headaches, fatigue, and burning sensations in their throats and noses' [15]. Steinzor [16] detailed Ohio's deficiencies in regulations and responsiveness to community concerns, and documented many cases of community concerns being inadequately handled or willfully downplayed by regulators. BC residents have long called for transparent tracking of cumulative permitted emissions, but have yet to receive substantial results. In this way, we refer to community members as marginalized, understanding that this marginalization is due to systemic under-serving and deplatforming of their voices and concerns.

The proliferation of fracking, increasing evidence of its detrimental environmental and public health impacts [17–19], and failure in regulatory oversight have necessitated community science, community-based knowledge production, and health advocacy network-building [20].

This paper describes the ongoing community-led project, and aims to provide an example of continued and active engagement between scientists and community members. We explore the collection of baseline air quality data through a community monitor network, engage with simple plume models to validate documented experiences of pollution, and describe the benefits of this type of approach to science. Note that, in the scope of this community science paper, we are not aiming to classify the specific health and air quality outcomes of the region.

2. Study development

2.1. Identifying local issues and concerns

Concerned Ohio River Residents (CORR), founded in 2018, is a grassroots advocacy organization dealing directly with the harmful impacts of fracking. In 2015, permitting of the PTT Global Chemical (PTTGC) Ethane Cracker Plant in BC raised serious concerns about the large amounts of volatile VOCs, hazardous air pollutants and greenhouse gas emissions. Harper explained: 'With BC already being the most heavily fracked county in Ohio [21], with all the infrastructure and waste handling facilities like Austin Masters and 4 K, with the many injection wells that take frack waste that are not regulated for air emissions, we can see that the cumulative toxic air emissions could be a big problem, even before a huge ethane cracker plant is built to produce 1.5 million tons of polyethylene for plastic we do not need.' Adding a highly polluting facility like the proposed PTTGC Ethane Cracker Plant to the high existing toxic load created by UOGD could be especially detrimental in a Valley that already carries a legacy of high industrial pollution [22].

Previous work has shown local and regional spatial heterogeneity of air pollutants within urban and often rural industrial regions [23–25], pointing out the inadequacy of the sparse monitoring network in the area for determining attainment in a highly heterogeneous region. The US Environmental Protection Agency's (USEPA) current monitoring infrastructure in the region relies largely on three reference-grade monitors in Ohio and West Virginia (blue 'E'symbols, Figure 1). Given the diverse experiences of residents living near fracking operations, CORR/FAP raised concerns about this network's inadequacy to capture differential exposures within the community. BC has been designated as 'in attainment' for the $PM_{2.5}$ National Ambient Air Quality Standards (NAAQS) since 2013 and 8-hour ozone NAAQS since 2007 [26]. However, air pollutants have

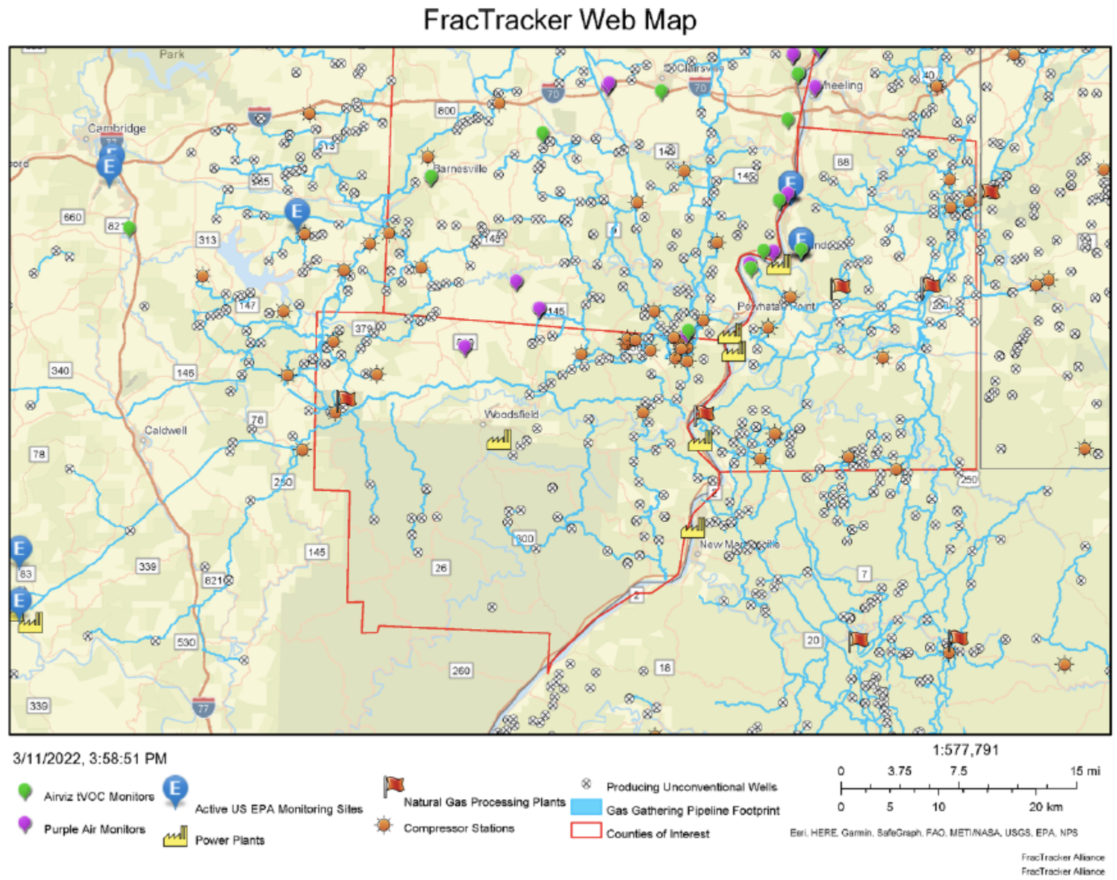

Figure 1. Map of BC with EPA, PurpleAir, and Airviz monitors shown, on top of UOGD infrastructure. Note that symbols for monitors in close proximity sometimes overlap. The interactive version of this map can be accessed at [53]. Some locations have been edited slightly to protect participant privacy. Developed by FracTracker Alliance.

been shown to be harmful to human health even at levels below NAAQS [23, 27, 28], and the World Health Organization recommends daily guidelines far lower than the USEPA NAAQS [29].

Interest in pollution data from residents experiencing health concerns led to community leaders applying for and receiving a $40,000 grant from the Community Foundation for the Alleghenies to better understand the baseline ambient air quality in this highly industrial area with high density, low-cost sensor networks, and make data available to the public and regulators. However, an urgent need for external technical assistance in conducting the modeling studies and utilizing the sensor network became clear.

2.2. Defining the project and building a team with the AGU Thriving Earth Exchange

Since its launch in 2013, American Geophysical Union Thriving Earth Exchange (AGU TEX) has provided support, resources, and forums for nearly 200 volunteer community science collaborations as they work together to tackle local challenges related to climate change. TEX is organized around the premise that community-centered science enhances the ability for science to both serve and be informed by wider society, particularly communities that have been historically marginalized and underserved.

While 'citizen science' is sometimes co-opted by traditional academic institutions as the process of academic experts defining a study, recruiting local volunteers for collecting material inputs, and then publishing the study without tangible benefit to the local communities, there has been a significant amount of research into best practices for community science, which emphasizes putting scientists and community members on equal footing, drawing from their pertinent expertises [30–34]. Within this context, TEX strives to bring scientists and community members together, working jointly towards a common goal [35]. While there are challenges to deploying this methodology in different community contexts, the premise is that community leaders identify problems, then seek out volunteer scientists to address technical barriers [36]. Unity goals are prioritized in the narrative and execution of the work. TEX provides support in the form of a four-phase project milestone process [37] which can help frame a productive and collaborative process.

CORR applied to the TEX program in November 2019, identifying a need for external assistance towards two goals [38]:

(a) Understanding current cumulative emissions: 'We would like to be able to take all the air permits and study the cumulative effects of small particulate matter, VOCs and greenhouse gas emissions that have been already approved in the region, and overlay that with the expected emissions from the ethane cracker plant.'
(b) Establishing baseline measurements and installing a high-density monitoring network: 'There is an immediate need to do baseline monitoring above and below prevailing winds of the proposed ethane cracker plant.'

Once accepted, CORR was connected with Garima Raheja as the Community Science Fellow, which began a collaborative process to articulate the two goals in detail. Then Raheja advertised the project to a broad network and recruited graduate student Lyssa Freese as the Volunteer Scientist for Part (A). Local resident-activist and former Rensselaer Polytechnic Institute Professor Yuri Gorby joined as Scientist Part (B). Due to the geographic spread of the project team, as well as the COVID-19 pandemic, project meetings were held weekly over Zoom. As will be seen in this work, the goals and priorities of the project evolved over time, shifting to an emphasis on baseline monitoring and plume modeling in response to the lived experiences of community members.

3. Methods

3.1. Public participation network building

Inclusive public participation networks to authentically drive the project were developed through two main strategies.

(a) First, develop public awareness through regional marketing, with advertising billboards, websites [39], social media pages [40], and outdoor rallies [41] featuring chants and posters [42] to share information about environmental issues and related health impacts. This was made more challenging as safe, socially-distant modes of communicating information were necessitated due to the COVID-19 lockdown which halted traditional indoor organizing meetings.
(b) The true power of the public outreach efforts was built through personal, long-term, word-of-mouth organizing. CORR/FAP responded to requests for help from neighboring Salem Township residents; faith leaders including Pastor Bill Myers and Father Michael engaged parish members in installing a PurpleAir monitor at a local church, and encouraged residents to host air pollution monitors at their homes. Contacts at a local high school helped with setting up a sensor at the location and engaged student involvement. This word-of-mouth organizing serves a two-fold purpose. First, involved community organizers spread the word about upcoming advocacy and air quality monitoring using low-cost sensors. In the reverse direction, organizers listened to community member concerns and suggestions, bringing to the wider organizing effort [41]. This intentionally includes deplatformed marginalized community members (often these are community members who are the most burdened, elderly, low-income, or immobile) in the organizing efforts, broadening the sources of input into the project's goals. Such distributed organizing networks blur the lines between 'leader' and 'participant,' thus encouraging all community members to be co-creators.

Table 1. Cumulative pollutants permitted by Ohio EPA for BC Jurisdiction (January 2019–June 2019 permits).

Pollutant	Amount permitted (tons/month)
Carbon Monoxide	27.73
NO_x	6.68
PM	3.1
SO_2	3.09
VOCs	112.35

3.2. Assessment of cumulative emissions from oil and gas development

Based on community concerns about cumulative emissions due to rampant permitting of UOGD, the group conducted, to our knowledge, the first manual review of all operations permitted from January to June 2019 in order to estimate cumulative permitted pollutant levels. The permit review for the first half of 2019 is summarized in table 1.

This work is building evidence for more formal study to determine if the region is in attainment with NAAQS, and create more transparent regulatory permitting schemes.

3.3. Sensor network building

CORR/FAP, working with the AGU TEX, and advised by Volunteer Scientists, created a network and budget plan of high-priority deployment locations based on proximity to point source polluters and prevalence of health concerns associated with air pollution and selected two types of low-cost sensors:

- 35 PurpleAir $PM_{2.5}$ sensors (with tVOC module retrofitting) manufactured by PurpleAir Inc. (Draper, UT) which use PMS5003 and PMS1003 laser particle counters to measure concentrations of $PM_{2.5}$, ESP8266 chips to sync real-time data over WiFi, and one Bosch BME 280 sensor to estimate pressure, relative humidity and temperature [43]. The Plantower sensors sample at approximately 1 min frequency. PurpleAir sensors were chosen for their low cost, ease of real-time data upload to a pre-established global network, and relative accuracy.

When correction factors are applied to raw PurpleAir data, $PM_{2.5}$ concentrations reported by PMS5003 sensors have been known to correlate strongly with $PM_{2.5}$ concentrations reported by reference-grade monitors [44–48]. Therefore, we correct the raw PurpleAir outputs using the Gaussian Mixture Regression model-based correction [49, 50] trained on four datasets of nearby colocations of low-cost sensors with reference-grade monitors (3 in Pittsburgh, PA and 1 in Columbus, OH), and then average the corrected output to hourly, daily and annual timescales for qualitative and semi-quantitative analysis. Figures S1–S4 (available online at stacks.iop.org/ERL/17/065006/mmedia) show the performance of this correction; Figure S5 shows an example of the correction on data from Purple Air #43972 located in Barnesville, OH.

- 25 Airviz Duo tVOC + $PM_{2.5}$ monitors, manufactured in collaboration with the Carnegie Mellon University CREATE Lab (Pittsburgh, PA), which use the Sensirion SPG30 multi-pixel gas sensor platform to measure tVOCs and the Sharp1014 infrared (IR) dust sensor module for $PM_{2.5}$. These monitors have been evaluated by initial studies and have been found to have some accuracy, but future work should investigate sensor performance more thoroughly [51, 52]. Here we use raw sensor output only for qualitative conclusions. Acting as a liaison between sensor developers and users, Ana Hoffman from the CREATE Lab integrated community members' suggestions, advice, and insight into online real-time visualization software.

Through a public participation network, CORR/FAP recruited and trained 35 households who agreed to install and maintain a sensor and pay for WiFi connection.

4. Study results

4.1. Air pollution modeling and monitoring results

4.1.1. $PM_{2.5}$

Figure 2 shows the monthly-averaged plot of GMR-corrected PurpleAir $PM_{2.5}$ concentrations for the duration of the study period. Each node is displayed using a light colored line; the average of all nodes is marked using the dark red dotted line, and the $PM_{2.5}$ measurements from the Wheeling, WV EPA monitor are shown in dark green dotted line. The relative agreement in trends between the low-cost network and the EPA site demonstrates that, on a seasonal scale, the two types of monitoring track well. This is helpful for establishing a regional baseline, and identifying areas of concern when one node spikes above the agreement of the others. Note also that monthly average values remain consistently above the World Health Organization (WHO) Annual $PM_{2.5}$ Guideline (5 μg m^{-3}), and during the winter and summer, hit the WHO Daily $PM_{2.5}$ Guideline (15 μg m^{-3}).

In contrast, Table 2 shows the highly-variable correlation between the EPA monitors and PurpleAir network, when the correlation is assessed using daily-averaged data. The R^2 values of the ordinary least squares regression (OLS) between the reference- and PurpleAirs range from 0.01 to 0.55 (Figures S6 and S7 show the OLS and joint density plots from the one higher R^2 and one low R^2 correlation). The varied but generally low R^2 values indicate that the EPA measurement is insufficient for understanding heterogeneous air quality trends throughout the region. Table 2 also gives the number of days measured by each PurpleAir, the number of measured days above the WHO Daily $PM_{2.5}$ guideline (15 μg m^{-3}), and the slope and intercepts of site-specific OLS.

4.1.2. VOC

Residents recorded, by hand, air pollution events and associated health effects. On 16 October 2020, there were particularly numerous poor health experiences recorded by many in the community. Volunteer scientists used NOAA Hybrid Single-Particle Lagrangian Integrated Trajectory [54], High-Resolution Rapid Refresh (HRRR) [55] and CMU CREATE Lab PlumePGH to model plumes of emissions from the Dominion Compressor Station at Powhatan Point, Ohio (Figure 3, yellow) and the Williams Compressor station in Salem Township of Jefferson County, Ohio. (Figure 3, green). This model was used to understand potential sources of spikes in tVOC sensors seen near Powhatan Point between 5AM and 7AM. In Figure 3, the top right panel shows that emissions from Dominion Compressor Station were over Powhatan Point at this time. Variations in wind patterns carry pollutants to all quadrants of the surrounding residential area based on topography, wind speed and mixing height, which change hourly. Elevated raw tVOC values were measured on multiple Airviz monitors in the community network up to 12 miles from Dominion on 16 October 2020. Figure 3, as well as the Video Abstract, show that the modeled plumes show variability in pollution direction of modeled plumes on this day.

The correlations of these independent data sources provides insight into regions and communities most at-risk, and emissions spike patterns helped identify specific, concerning industrial operations. This has allowed community leaders to submit targeted public records requests about these operations and the validity of attainment compliance.

On a separate occasion, organizers also observed correlations of natural gas processing operations like pipeline pigging and compressor station blowdown operations with downstream ambient air pollution

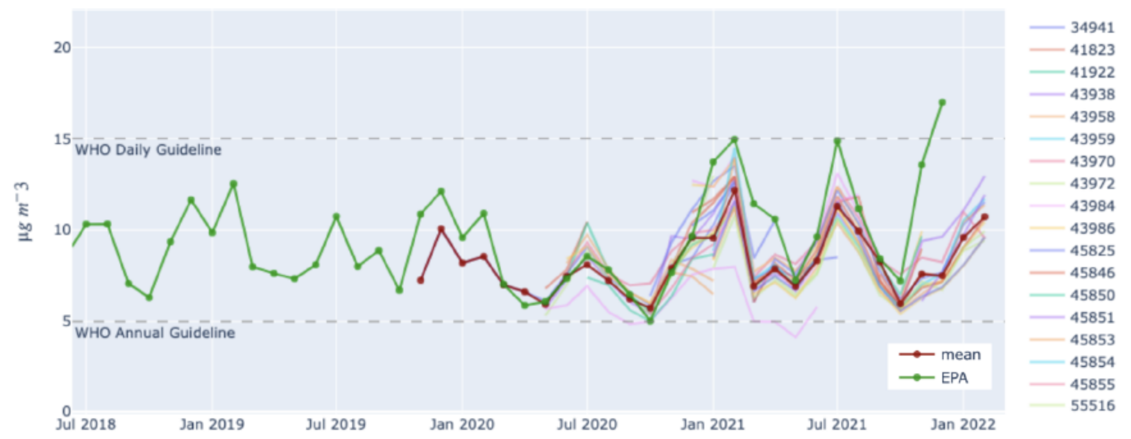

Figure 2. Monthly average plot of GMR-corrected PurpleAir $PM_{2.5}$ over study period. Each light colored line represents one node. The dark red dotted line represents the mean of all PurpleAir nodes. The dark green dotted line represents the EPA Wheeling, WV $PM_{2.5}$ measurement.

Table 2. Summary of PurpleAir Data, with PurpleAir Node ID number, total number of days measured by node, number of measured days above 15 μg m^{-3} (World Health Organization Daily $PM_{2.5}$ Standard), slope, intercept and R^2 values of ordinary least squares regression of daily-averaged node data against Wheeling, WV EPA monitor. The table is sorted by highest to lowest R^2 values. Node data is publicly available at environmentaldata.org.

Node	# of days measured	# of days above WHO guideline	Slope	Intercept	R^2
55516	57	6	0.93	2.77	0.55
57427	336	50	0.69	4.86	0.44
57428	336	42	0.73	4.61	0.43
65171	206	20	0.73	5.73	0.43
62336	19	1	0.86	9.01	0.37
45855	156	11	0.76	6.39	0.36
41922	377	19	0.78	4.39	0.33
43984	379	2	1.12	3.97	0.32
45853	68	0	0.76	2.32	0.29
45825	169	25	0.48	6.63	0.28
34941	576	28	0.71	4.74	0.28
43986	597	30	0.78	5.22	0.26
43972	635	29	0.68	5.71	0.23
65170	382	17	0.70	6.77	0.22
45846	434	36	0.51	6.95	0.21
65522	387	20	0.57	7.44	0.19
45850	146	0	0.65	3.44	0.19
43938	590	48	0.43	7.56	0.18
65523	387	20	0.53	7.63	0.17
43970	590	46	0.40	7.45	0.15
64823	398	31	0.43	8.25	0.15
64822	398	26	0.42	8.40	0.15
58263	422	42	0.34	8.68	0.12
58264	422	40	0.30	9.10	0.11
88437	49	2	0.27	6.59	0.11
43958	166	3	0.27	5.16	0.08
94104	86	8	0.23	15.49	0.01
41823	73	2	0.02	7.28	0.00

spike events picked up by their monitor (Figure 4) and correlated with headaches and nausea (Figure 5).

4.1.3. Plume modeling

The dispersed network provides the ability to investigate specific sources of emissions, particularly as UOGD continues to expand in the area. As seen in figure 6, we used the CREATE lab's python version of the NOAA Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT) [54, 56, 57] to evaluate the highest receptor areas for a primary pollutant from the Dominion Transmission site, a plant located right outside of Powhatan Point. This version of HYSPLIT uses the forward dispersion simulation, and emissions are at a height of 50 meters. Integrated over 26 months, the trajectory of pollution from one

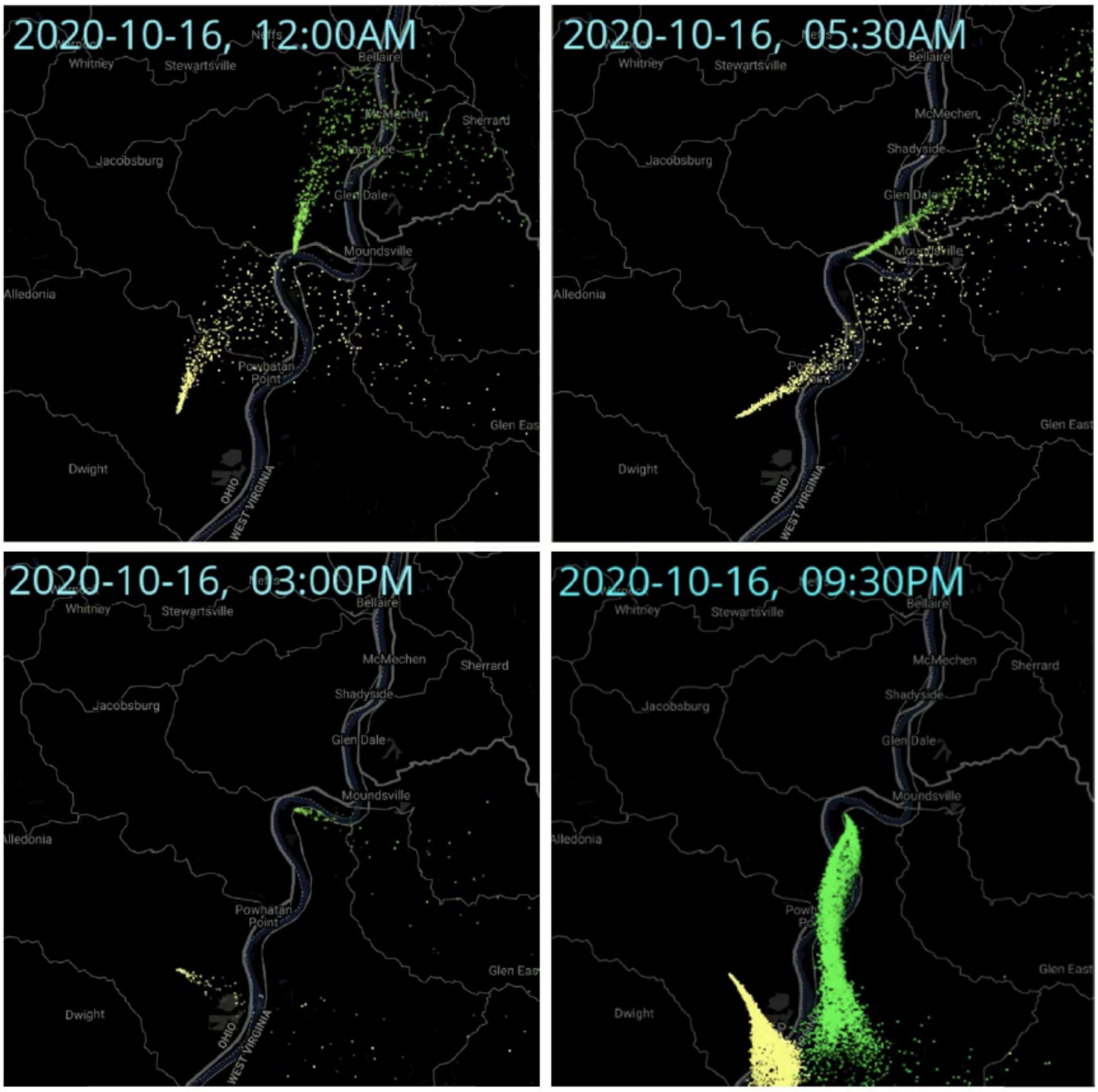

Figure 3. Modeled plumes of emissions from the Dominion Compressor Station at Powhatan Point, Ohio (yellow) and the Williams compressor station near Dillies bottom, Ohio (green).

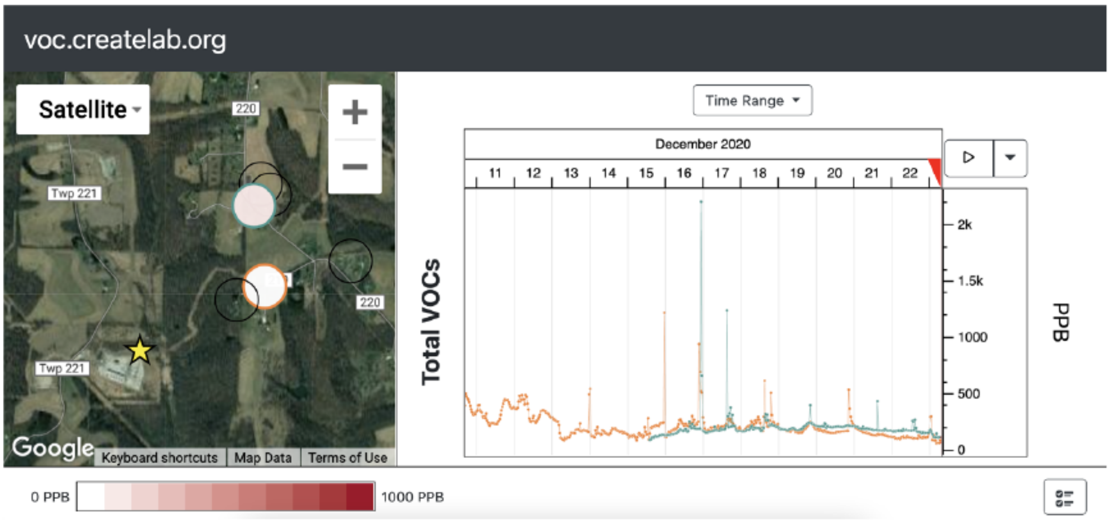

Figure 4. Screenshot from voc.createlab.org, demonstrating the uncorrected low-cost observed total VOC concentrations recorded by 2 outdoor sensors (green, orange) located near the Williams Salem Compressor Station (yellow star), noting elevated raw VOC concentrations spiking above 1000 parts per billion multiple times from 15 December to 18 December (same period as noted in figure 5). Non-shaded circles indicate indoor sensors.

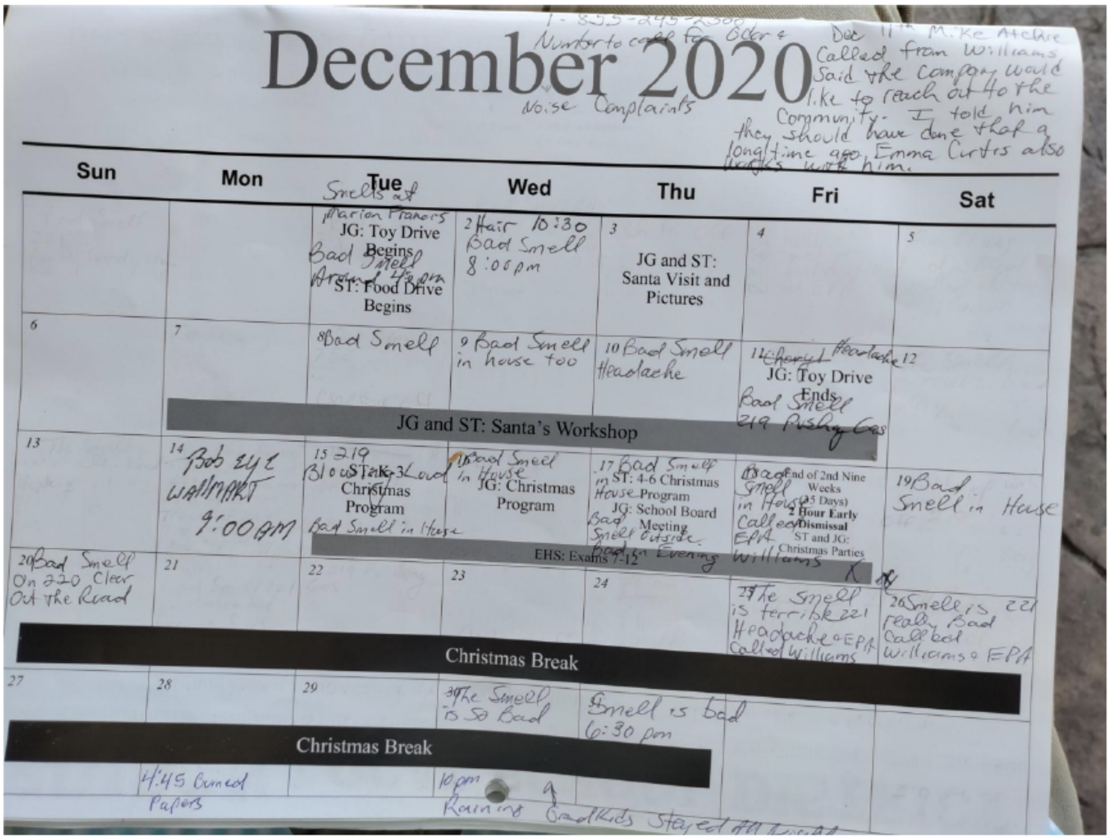

Figure 5. Top: month-long log of health conditions and observed operations recorded by a Salem Township, OH resident, noting that elevated periods of bad smells from 15 December to 18 December prompted a call to the EPA.

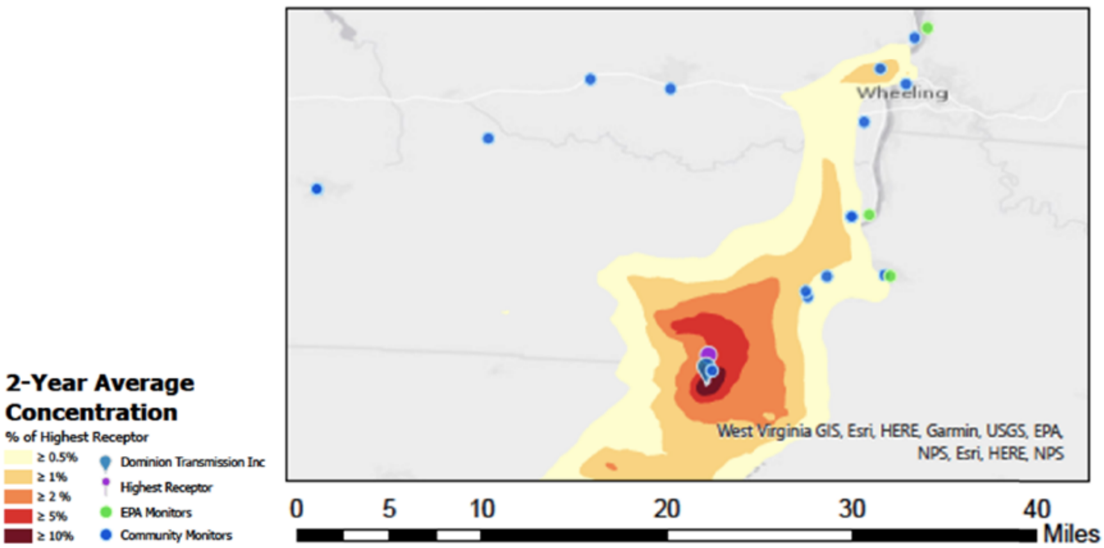

Figure 6. Modeled average concentration of primary air pollutants from the Dominion Transmission site outside Powhatan Point, OH. The meteorological data used covered 3 January 2019–5 January 2021 . Blue circles denote low-cost monitors set up by community members, and green dots denote regulatory monitors. (Note: some monitor locations are excluded due to residents' privacy concerns). The highest receptor of primary pollutants from this source over the 26 month time-period is marked in purple, and areas with above a 10%, 5%, 2%, 1%, and 0.5% of the pollution that is transported to the highest receptor are shaded in a gradient.

source in the area varies widely, and it is useful to have a larger array of monitors (which serve as receptors) to understand source contributions. Already it can be observed that at least seven of the monitors from the high-density network facilitated by residents intersect with areas of highest receptors (yellow/red zones), but none of the regulatory monitors fall within the range.

In our further work, we hope to analyze individual source contributions to monitor data; this will be an important next step in this partnership, particularly as new emissions sources are built.

4.2. Social results: public participation benefits in the community

4.2.1. Community solidarity

Recognition and acknowledgement of shared experience or injustice build collective confidence. Residents feel validated when their neighbors also cite similar, sometimes obscure health issues with data correlating health impacts to spikes in air pollutants nearby. Community member Kevin Young states, "Before CORR/FAP, there was no one to help us. None of the Ohio regulators would come to witness the extreme air pollution events that made my wife and me very sick. Just knowing someone cares and validates our serious complaints has been so helpful. Now that we have data to substantiate the harmful amounts of the air pollutants, it seems the regulators are taking us more seriously. Before I got involved, I felt alone, hopeless and victimized. But once I started organizing with the group, I had hope we could get the help we needed."

4.2.2. Technical capacity

Residents became familiar with maintaining and interpreting monitors, checking them every morning, and, noticing patterns, began to make decisions using monitor information.

4.2.3. Personal health protection

Community members used local sensor data to know when to close windows, wear masks, or update indoor air purification systems, with some members observing high levels of air pollution personally phone calling up to 50 neighbors to provide evacuation warnings and guidance [58]. For example, the Williamsons and Hamlins evacuate their homes after reading values on their monitors, and on days where scheduled pigging operations were expected to create hazardous air conditions, Darlene Williamson discouraged their out-of-town grandchildren from visiting and secured alternative childcare [58].

4.2.4. Crowdsourced data builds regional advocacy, which benefits local communities

Community data collection relies heavily on community contribution, where the crowdsourced knowledge is greater than the sum of its parts. Multiple monitors in an area show the spatial relation and movement of pollution events, therein providing validation throughout the network. To supplement the low-cost sensor data, many households took copious notes, including hourly logs of air quality, weather conditions, personal health effects, and sensor performance (Figure 3 shows one of the many community handwritten logs). Further, community knowledge is vital in mapping current fracking operations, pipelines, and infrastructure, with many longtime residents providing detailed information and photos of fracking-related infrastructure. BC community members' collaboration with the FracTracker Alliance has led to the National Energy and Petrochemical Map [59]. Crowdsourced data collection in these many forms resulted in a more constructive way to engage with EPA, ODNR, the Ohio Department of Health, and industrial operators. Data offered the community a shared language with regulators to articulate complaints. For instance, in the Salem Township case, residents complained and the media published those complaints [60], but the regulatory agencies did not acknowledge complaints or visit homes for inspection until after significant crowdsourced regional air monitoring results and personal health logs were publicized.

4.2.5. Broader community education

In contrast to traditional scientific practice of sharing after project completion, the group instead chose to share throughout the process. Results were informally communicated frequently to community stakeholders; residents were encouraged to provide guidance, direction, opinions and insight into future steps. In November 2020, CORR/FAP and TEX teamed with the Southwestern Pennsylvania Environmental Health Project, Halt the Harm Network, and FrackTracker Alliance to produce two formal Community Education webinars. About 50+ attendees from around the region attended the webinars, and 350+ have watched the recorded livestream, which is available on Youtube [14]. The webinars focused on:

(a) Introducing local issues and the extent of the industry
(b) Explaining air quality basics: vocabulary, types of pollutants, and health effects
(c) Identifying regulatory deficiencies and opportunities for improvement
(d) Demonstrating current modeling and monitoring activities (with a call for volunteers and monitor host sites)
(e) Sharing insights and best practices for environmental activists in nearby regions hoping to launch similar advocacy efforts
(f) Hosting a forum for community members to discuss issues and freely ask questions to experts from host organizations
(g) Providing methods for allyship for attendees from outside the community (financial donations, materials, technical assistance).

4.3. Broader social results

CORR/FAP efforts in the region have garnered national attention. Local activist Jill Hunkler was invited to testify to the US House of Representatives Subcommittee on the Environment [61]. The CORR/FAP/TEX collaborative group has also been invited to present at scientific conferences, including the 2020 American Geophysical Union Fall Meeting and Shale Network Conference. FAP was also asked to present results and collaboration advice at the AGU TEX New Fellows Orientation [62, 63]. Regional officials have invited activists to share insights and give presentations to regulatory groups.

4.4. Collaboration results: best practices developed

The CORR—FAP—TEX—CREATE Lab collaboration started in December 2019, and continued through the COVID19 pandemic, and continues to grow to date. Over the course of the two years, the team has developed the following best practices:

4.4.1. Virtual meetings

Regularly, weekly meetings on Zoom video conferencing allowed participation from around the world, provided a safe method of gathering during the COVID-19 pandemic, and included vital tools such as screen sharing and file transfer. One participant took notes on a shared Google Drive document.

- Despite the benefits of virtual meetings, one of the hardships in navigating this type of relationship is that some non-local collaborators have not been to BC, Ohio. This also creates partnerships that can potentially rely on non-local collaborators, leaving a gap in capacity when they leave if there is not a proper plan in place.

4.4.2. Inclusion

Local residents, out-of-town allies, scientific experts, and other colleagues of the organization were invited to join weekly calls. Team members would listen to concerns, identify ways to work together, and often develop long-term symbiotic relationships.

4.4.3. Flexibility and distributed leadership

The team's 'come as you are, come when you can' approach recognized that community activists are often volunteering on organizing efforts on top of full-time jobs, school, or caretaking responsibilities. Participants were invited to give what they had bandwidth to contribute, with members frequently stepping in and out for events or urgent emergencies. Consistent notetaking and email communication allowed those who stepped out to easily rejoin. This flexibility, especially during the COVID-19 pandemic, helped create a culture of care that pervaded advocacy efforts, and allowed participants to develop healthy, supportive relationships. Despite best efforts, there were periods of volunteer burnout as activists involved in multiple advocacy efforts felt stretched thin by organizing in many spaces.

4.4.4. Networks of networks

Group members attended meetings and participated in efforts at other environmental networks, thus webbing together a broader regional network of networks.

- The Breathe Collaborative is a coalition of citizens, environmental advocates, public health professionals and academics working to improve air quality, eliminate climate pollution and make the Southwest Pennsylvania region a healthy and prosperous place to live. The Collaborative powers the Breathe Project through science-based work and a community outreach platform.
- The Air Emissions Environmental Justice Working Group was developed to bring together CORR/FAP and anti-fracking activists in Louisiana, to build upon both networks' body of knowledge and create a broader regional sharing of lessons and best practices
- AGU Thriving Earth Exchange Community Science Network: CORR/FAP leaders, the Project Fellow and Volunteer Scientists attended regular video conferences hosted by AGU, to learn about other community science efforts, solicit recommendations and ideas for project study, hear about newly launched products and services, and join in celebrating successful community efforts.

4.4.5. Community relationships

CORR/FAP leaders fostered trust and a sense of being cared about, and supported new community members who wanted to start speaking out and participating in the research. Community trust is vital: many residents' complaints have been downplayed or ignored by the regulatory agencies. In an environment where there is already so much mistrust, it is vital for residents to know that they have safety and support for their concerns.

4.4.6. Science powered by local knowledge

While scientific study and measurements are vital to understanding a region, often local knowledge is discounted. This study emphasized that local knowledge is central to understanding the history, dynamics, and future of a region. By involving a broad public participation network in the scientific study, this work brought together quantitative and qualitative knowledge that was greater than the sum of its parts. Impacted community members are empowered as their own advocates through documentation of ongoing health complaints that were associated with monitor spikes, overcoming blind spots in knowledge and data related to air pollution from UOGD.

- Paired with deepening knowledge about air quality data and corresponding health impact came awareness and stress from worrying about and advocating for the health of the community.

4.4.7. Transitions

This collaboration shifted from its initial goal of permit research and analysis of cumulative impact of existing polluters into data analysis and broad communication.

- As capacities and concerns change, and communities become more knowledgeable about air pollution impacts, the collaboration will assess strategies that ensure that the local community members have the resources and infrastructure to continue the work.

5. Future work

Additional VOC monitoring with Summa passivated stainless steel canisters would be beneficial for measuring actual levels of harmful pollutants and help identify the source. Automatically-triggered canisters would allow sampling on rapid timelines and odd hours, which can be challenging manually. Additionally, given the levels of VOCs measured inside residential homes, there is a concern about vapor intrusion contributing towards the total VOC indoor concentrations. Vapor intrusion is the migration of vapor-forming chemicals from a subsurface source into a building and is considered the pathway with the greatest potential to result in human exposure at sites impacted by volatile organic compounds in groundwater [64]. Understanding groundwater flow and soil gas concentrations surrounding and beneath places where people live, work and attend school is needed to calculate potential contributions of subsurface volatile pollutants to indoor air quality. Efforts are ongoing to detect possible mechanisms of vapor intrusion into some homes that show high levels of contamination inside versus outside.

Further, there is interest in potentially developing collaborative tools that can correlate personal health experiences and sensor data on both hyperlocal and regional levels, in near real-time, to facilitate communication inside the affected communities as well as between the communities and industry, academia, and government. Crowd-sourced data from low-cost monitors are important to obtain the attention and remedial action needed to better protect public health, especially in the face of the proliferation of a highly polluting industry like fracking in a region.

Broadly, in order to truly advance community-based science, there is an urgent need to revise or create grant processes that allow for community groups to receive necessary funds, in a method that removes overhead costs and reporting burdens, and truly allows community leaders the long-term agency and the ability to procure the necessary equipment, scientific analysis, and regulatory attention, validation and partnerships over the course of the project.

6. Conclusion

The high-density sensor network deployment and sustainment, the localized warning systems, and the detailed documentation and logging of health impacts associated with monitor spikes are the result of thousands of volunteer person-hours. The vital air quality heterogeneity assessment and the short-term mitigation of health impacts are direct results of public participation and community-based networking and establishment of community-based scientific resources. The AGU TEX program supports ongoing grassroots organizing and community empowerment, and CORR/FAP are established vital local and regional resources with scientists from around the country by their side. Initial monitoring and modeling results from BC have enlivened public engagement with the media, regulatory agencies and industry, providing evidentiary backing to residents' experience and helping to translate this experience into the language used by government representatives of public health after long-held practices of marginalization of community concerns. The social benefits and best practices developed are now being used as models for growing community science efforts and empowering marginalized residents facing environmental injustice around the country.

Data availability statement

The public access point for PurpleAir, Airviz, and EPA monitoring data is the Carnegie Mellon University CREATE Lab's Environmental Sensor Data Repository. NOAA HYSPLIT and all data necessary to run the model are available at ready.noaa.gov/HYSPLIT.php. Modifications have been made to the code from PlumePGH.org in order to produce the videos and visualizations seen here.

The data that support the findings of this study are openly available at: environmentaldata.org.

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