## Tracking air pollution hotspots back to the source in real time

Environmental Defense Fund (EDF), in collaboration with technical and scientific partners, has developed an interactive, mobile-friendly website that allows the public to see air pollution hotspots in real-time, and trace them back to potential sources.

The capabilities of this tool combine and build on the scientific advancements EDF and partners have accomplished in the past 5 years of hyper-local air pollution research. Through multiple campaigns, EDF learned how to identify and characterize air pollution hotspots captured by mobile measurements. Our most recent campaign in Salt Lake City tested the science behind hyper-local source apportionment, the foundation for this tool, and the key to eliminating these hotspots.

To reduce air pollution, you first have to know what is causing it.

### Components

Air Tracker uses publicly available continental scale maps of the U.S. as the foundation for the interactive visualization. The tool currently supports three cities: Houston, Texas, Salt Lake City, Utah and Pittsburgh, Pennsylvania. These locations are identified on the main page of Air Tracker. Clicking on a location zooms in to the active domain for the city, outlined using a dashed box. Added to each city are real time ambient air pollution measurements of $PM_{2.5}$ from networks including EPA's AirNow network, PurpleAir low-cost sensor network, Clarity monitors in Houston, and TRAX in Salt Lake City.

### AirNow

AirNow air quality data represents a partnership between several federal, state, and local air quality agencies to provide real-time, quality assured ambient air pollution data from regulatory monitors across the U.S. and throughout the world. AirNow makes their data available via a public API. Air Tracker uses that API to continuously grab and map real-time air pollution concentrations for the highlighted cities. External link to the AirNow site is HERE. While air quality data on the AirNow site is typically reported as an air quality index (representing the cumulative health impacts of all regulated air pollutants), Air Tracker maps and reports the ambient concentration of $PM_{2.5}$ from the AirNow monitors in $ug/m^3$ units.

## PurpleAir & Clarity Low-Cost Sensors

PurpleAir and Clarity monitors are two common low-cost air quality sensors.

PurpleAir low-cost $PM_{2.5}$ sensors are common world-wide, and the company that developed these sensors makes their data public HERE. PurpleAir sensors use lasers to count suspended atmospheric particles within specific size ranges. PurpleAir sensors are used by the U.S. EPA to help track smoke plumes from wildfires HERE.

Clarity monitors are another common low-cost sensor. The owners of the Clarity monitors own their data, and so it is not typically available publicly, however, some community groups who own Clarity monitors in Houston neighborhoods agreed to share their data with Air Tracker. By adding real-time air pollution measurements taken from locations in their neighborhood, communities can identify times and locations with high pollution, and track those events back to potential sources. Neighborhood monitors literally bring Air Tracker close to home. More information about Clarity monitors is found HERE.

As the number of cities supported by the Air Tracker grows, we expect that the number of low-cost sensor technologies mapped on the Air Tracker will also grow.

## TRAX

In Salt Lake City, the TRAX is a light rail system that spans east and west and north and south across the SLC valley connecting neighborhoods and providing public transit. The TRAX trains are electric and three of these trains have air quality monitors installed on the roofs. When those three trains are running, they will measure and report to the Air Tracker site, real time $PM_{2.5}$ concentrations from along the light rail route.

## Weather Data

Air Tracker pulls real time wind direction and wind speed data from the following sources: National Weather Service monitors, Utah's Department of Transportation monitors, EPA's AirNow monitors, Texas Commission on Environmental Quality monitors, and low-cost Davis instruments. The wind direction is mapped using "wind arrows" that point in the direction the wind is blowing towards. (If the wind arrow is pointing north, then the wind is blowing TO the north FROM the south.) When the user clicks on any location with a wind arrow, the most recently measured wind speed and wind direction at that location will pop up on the informational column on the left side of the screen. While many aspects of weather will affect how air pollution is transported and mixed in the atmosphere, wind direction and wind speed are key to the formulations behind Air Tracker source areas.

The Air Tracker uses real-time measured weather data to evaluate its own performance. By comparing the measured weather data to the modeled weather data, the Air Tracker can tell the user in real time how good the model performance is, and therefore if the source areas are generally correct.

## STILT Source Areas

The Stochastic Time-Inverted Lagrangian Transport Model (STILT) was developed by Professor John Lin from the University of Utah (Lin et al., 2003). STILT is based on the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model developed and supported by NOAA (Stein et al., 2015). STILT has recently been incorporated into the HYSPLIT programming and is now also maintained by NOAA. STILT and HYSPLIT are part of a group of air dispersion models called Lagrangian models. Lagrangian air dispersion models follow single parcels of air in space and estimate at each time step the forces on the parcel, and thus, the movement of that parcel in response to those forces. Each model builds in a component of random motion (so no two parcels are going to behave the same). This means that the model can estimate an entire plume of air parcels by tracking many individual parcels and combining the results. You can think of a parcel of air as an individual $PM_{2.5}$ molecule, or as a tiny volume of the gases that make up the air.

**Contact EDF at AirTracker@edf.org to request copies of relevant peer-reviewed literature*

What is unique about STILT is that it does this Lagrangian process in reverse. STILT tracks parcels backwards in time by estimating where the particle likely came from given the weather metrics according to the weather model, at each time and location of the parcel as the model steps backwards in time. Similar to the forward trajectory model, there is an added random component to the forces on the air parcel which again means that no two parcels will follow the exact same path. However, that random component will be quite small relative to the influences of winds and known turbulence so the parcels path will stay generally in the same direction and same speed. The collection of the backward trajectory paths of several thousand air parcels is mapped as the source area in Air Tracker.

While no two parcels will follow the exact same back trajectory, they may move through the same place in space. If several individual parcels all move across the same location, it makes that location more likely to be important. If you would like to see the relative importance of a particular location within the source area, you can click on the three dots to the right of the title “Source Area:” in the information panel on the left. This will give you the “Source Area Settings” pop-up, and the option to turn on the “Show Contributions Likelihood” option. When that option is turned on, the map changes to show the likelihood function. In the case of Air Tracker, the locations with several air parcels crossing over them are colored darker blue when mapping the likelihood function. And if you start your source area at a location with a high pollution measurement, it means that these darker locations within the source area are the most likely locations where the source of that high pollution measurement is located because so many parcels passed over that location. This doesn't rule out the locations under the lighter color blue as source locations, it just makes them less likely.

STILT also accounts for vertical mixing. However, if a particle travels outside of the well-mixed atmospheric layer closest to the surface (also called the atmospheric boundary layer) then it no longer shows up on the map. This is because the air above the boundary layer is not going to impact humans at that moment (it can always mix down later if the conditions are right). While the particles that escape above the boundary layer don't show up in the source areas, STILT will still follow them in case they come back into the boundary layer later. But all this means that if a source is emitting air pollution above the boundary layer (this can sometimes happen with larger emissions stacks, like those associated with big industrial facilities, and especially at night when the mixed layer is lower), then Air Tracker will not be able to trace air pollution back to that source.

Average daytime and nighttime planetary boundary layer (PBL) heights (the mixed layer) change by location and time of year. Nighttime PBL heights can be as low as a few hundred meters, while daytime PBL heights can be as high as a few kilometers. Temperature, cloud cover, wind speed, land use cover and several other factors influence PBL height.

### High Resolution Rapid Refresh (HRRR) Weather Model

The High Resolution Rapid Refresh (HRRR) weather was developed by NOAA for the purpose of weather forecasting. The HRRR model used by the Air Tracker is run every hour in the forecast mode to predict future weather patterns across the US. The model domain is a 3km x 3km grid that covers the continental United States. The time resolution is one hour. More information about the HRRR model can be found HERE.

### HRRR Model Performance Evaluation, Salt Lake City, Utah

EDF, with meteorologists at the University of Utah, conducted a systematic evaluation of HRRR model performance in Salt Lake City. The goal of this analysis was to quantify average HRRR model performance in SLC and identify any biases that may impact Air Tracker applications. While seasonal statistics as presented here are important, an hourly evaluation is still necessary to confirm that individual source areas are correct and meaningful. The seasonal model performance evaluation used measured weather data from two key sources: stationary ground-level weather monitoring stations, and twice daily meteorological soundings. Data from the weather monitoring stations include surface wind direction, wind speed, temperature, humidity, and solar radiation (monitor locations shown in the bias figure below). The soundings use a weather balloon to measure and report vertical profiles of wind speed, wind direction, temperature, and humidity from the Airport in SLC at 5AM and 5PM Mountain time. Measured values were compared to HRRR. Evaluations were conducted by season to identify trends in model performance by season. The figure below shows the seasonal averaged wind speed error at monitor locations throughout Salt Lake City for summer (left map) and fall (right map) 2019. Locations in the central valley show errors close to 1 meter/second (m/s) while locations closer to the mountains show larger errors.

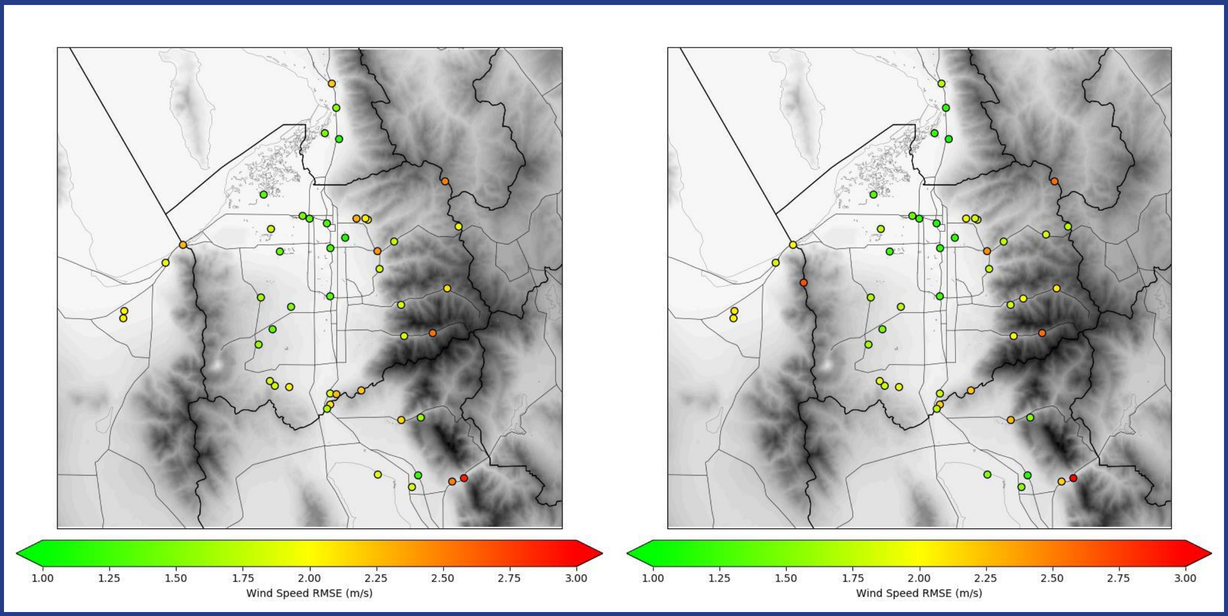


Figure. Left image shows summer, right image shows fall, average wind speed bias at weather monitoring stations throughout Salt Lake City Valley

For the purposes of the Air Tracker, hourly surface wind direction and wind speed are the most important metrics for performance evaluation. However, additional surface level metrics including temperature, humidity and solar radiation, and the evaluation of these metrics in the upper levels of the atmosphere, are also important to increase confidence in the model's ability to represent turbulence and atmospheric mixing of air particles (these forces are important to represent all relevant influences on atmospheric particles at any given time).

### General Findings of HRRR weather forecast model performance in Salt Lake City:

1. Average wind speed error was just above 1 m/s during summer and fall months with a positive bias between 0.5 m/s and 1 m/s. This means the model more often predicted wind speeds that were higher than what the local weather stations measured.

2. Model performance was better in the heart of SLC valley away from complex terrain. The areas closer to and within complex terrain performed worse. This is expected! The model resolution is not fine enough to capture detailed changes in

terrain features and as a result, it may not be able to model air flows influenced by those finer scale features.

3. Model performance stayed fairly constant across seasons and across times of the day.

## For which air pollution species is Air Tracker most appropriate?

$PM_{2.5}$: Air Tracker currently maps real-time measured concentrations of fine particulate matter smaller than 2.5 micrometers ($PM_{2.5}$). These measurements are taken from EPA AirNow regulatory monitors, and several low-cost sensor networks. $PM_{2.5}$ was selected as an initial focus for Air Tracker because it is strongly linked to negative health outcomes. When we breathe in particles of $PM_{2.5}$, these particles are small enough to travel deep into our lungs affecting a number of systems in our body, including cardiovascular and respiratory systems (Bell et al., 2012). $PM_{2.5}$ exposure can cause premature mortality, heart and lung disease, and diabetes. The United State Environmental Protection Agency (US EPA) has set limits for atmospheric concentrations of seven species of air pollution together called "criteria pollutants". These limits are called National Ambient Air Quality Standards (NAAQS) and $PM_{2.5}$ is one of these criteria pollutants controlled through the NAAQS because of these important health outcomes.

$PM_{2.5}$ is a general term for many different species of air pollution that form small particles in the atmosphere. When air pollution monitors report total concentrations of $PM_{2.5}$, that concentration is the total mass of all the unique particle species. Some component species of $PM_{2.5}$ are emitted directly from human related activities (primary species: black carbon is a key example of primary $PM_{2.5}$). Some $PM_{2.5}$ component species are formed in the atmosphere as a result of chemical reactions between "precursor" species (secondary species: sulfate and nitrate are two examples of secondary $PM_{2.5}$).

Air Tracker is better suited to track sources of primary species because the model we use to estimate air flow (transport or air parcels) doesn't include any atmospheric chemistry (chemistry is required to represent formation of secondary species). Air Tracker is also best suited for local sources because it doesn't include any physical loss processes (like settling). Since $PM_{2.5}$ is a mix of primary (better performance) and secondary species, (requires chemical formation) interpretation of sources requires another consideration: spatial variability.

If one monitor (or two monitors close together) measures concentrations of an air pollution species that are much higher than other monitors around, then those monitors measuring high concentrations are likely indicating an air pollution hot spot. Air pollution hot spots are ideal uses of the Air Tracker because they indicate a likely source nearby. When a measured air pollution concentration is higher than the surrounding area, it means that the air pollution "plume" has not had time to become well mixed in the atmosphere. And that means that there is probably a source nearby.

## Additional Air Pollution Species

*Nitrogen oxides:* NO & $NO_2$ cycle between each other in the atmosphere depending on local conditions (sunlight and other pollutants, namely atmospheric oxidants). Together they are referred to as $NO_x$. NO is emitted directly by any atmospheric burning (including internal combustion engines in vehicles), but it forms $NO_2$ so quickly (usually) that we can apply Air Tracker to $NO_2$ as a "primary" species. $NO_2$ is another air pollution species covered by EPA's NAAQS. While the source of much of urban $NO_2$ is from vehicles, large point sources (of which there are a lot in Houston and North Salt Lake City) are also a source of $NO_2$. Inhalation of $NO_2$ is mostly associated with asthma incidence and is a big problem with children.

*Hazardous Air Pollutants (Air Toxics):* EPA has a list of HAPs that it regulates. These species are known carcinogens, and cause issues with immune systems, endocrine systems, and can cause acute issues (headaches, shortness of breath, dizziness). There are fewer HAPs monitors in the US (there are close to 200 different species on the HAPS list, and they are difficult to measure). Air Tracker is well suited to identify sources of HAPS because they are primary species and have fewer individual sources than most criteria pollutants. The EDF team is actively working with community groups and city officials in Houston, Texas to add lower cost sensors to Air Tracker that measure a collection of volatile organic compounds (VOCs - most HAPs are VOCs) that can be used to indicate a potential plume of HAPs. These sensors, called S-pods, will report total VOC concentration, and more importantly, identify plumes above background with reasonable confidence as demonstrated by EPA and research partners in a recent publication (MacDonald et al., 2022).

Air Tracker does not perform well with identifying sources of ozone. Ozone is a secondary pollutant (formed in the atmosphere from reactions between $NO_x$ and VOCs), and sources are typically well mixed by the time ozone forms, so we can't just "look upwind" to find ozone sources. Additionally, sulfur dioxide, $PM_{10}$, lead, carbon monoxide are all criteria pollutants regulated by the USEPA, but are not really applicable to Air Tracker, mostly because few locations in the country are in non-attainment for these species and so there is less concern. But additional challenges exist unique to each species.

## Future Capabilities

Air Tracker demonstrates EDF's commitment to working with communities to bring data to action. In both Salt Lake City and Houston, EDF is working with community members and air quality regulators to identify air quality data needs and build capabilities into the tool based on that feedback.

We will highlight two examples of potential use cases for Air Tracker that have been identified in conversations with users. The first use case will add a visual of the source region to the city's benzene rapid awareness email warning system. When the RABITS email alerts are sent out, the inclusion of a source area will allow mitigation officers to more rapidly target potential sources of the Benzene leak to reduce time to control.

A second use case will be the automatic development and incorporation of a source area within a user developed nuisance report. When community members smell or see something suggesting environmental harm, they can report this to the city using a city-approved form. EDF is creating an app to automate the generation and submission of the correct format and will incorporate Air Tracker back trajectories from the location and time of the reported nuisance event to help both the community member and the regulator identify the likely cause of that event.

**For any questions, please contact us at AirTracker@edf.org.**