Cascadia Action maps industrial air pollution by gathering samples on rentable electric scooters. Right before a sample, we search the Spin app for scooters with a full battery near study routes. In order to gather the best particulate data, we ride in neighborhoods when industrial truck traffic is heaviest. While a ride itself is two hours or less, these trips require substantial effort to plan. Our goal is to ride and collect data during the specific atmospheric conditions that concentrate air pollution at ground level.

The Equipment

We measure diesel particulate with thick, twenty-pound, metal briefcase-sized air monitor called the MiniWRAS, short for Wide Range Aerosol Spectrometer. This is a regulatory-grade $38,000 mobile monitor manufactured by Grimm-Durag in Germany. This monitor can detect and record airborne particles along 41 size channels as small as .01 microns and as large as 10 microns. For reference, a human hair is about 60 microns wide, dust and pollen are about 10 microns wide, and woodsmoke particles are about .2 microns. Diesel particulate is first emitted as .01 microns particles. Once airborne it quickly aggregates with other fresh diesel particles into clumps that average .2 microns. Most particulate monitors use a laser to measure particles .3 microns and larger, and cannot reliably measure diesel particulate or wood smoke.

On a monitor scooter ride Greg, our lead researcher, wears the MiniWRAS strapped to the front of his body attached to a mountaineering backpack. A small air intake hole on the front on the monitor is thus always pointed forward in the direction he is moving.

We wrote our own software that accepts MiniWRAS data, converts particle counts to mass, and creates color-coded maps of where we ride.

Our lead researcher during a sample ride.

The grey box above is the MiniWRAS. The two small green boxes are PocketLab Airs -- each is paired with an iPhone for data collection. Phones and PocketLabs are attached to a plastic pipe with Quadlock handlebar phone mounts. A strap loops though the pipe and the whole array attaches to the backpack with carabineers.

Greg also carries an Anker 20,000mAh portable charger Quadlocked to the pipe that connects to the PocketLabs and phones with charging cables. One of the phones is pointed upward and uses Google navigation. The route is premade in Google maps and emailed to the rider who follows the directions using a Bluetooth headset. Greg wears an N100 particulate mask that can safely filter 100% of diesel particulate and a bicycle helmet.
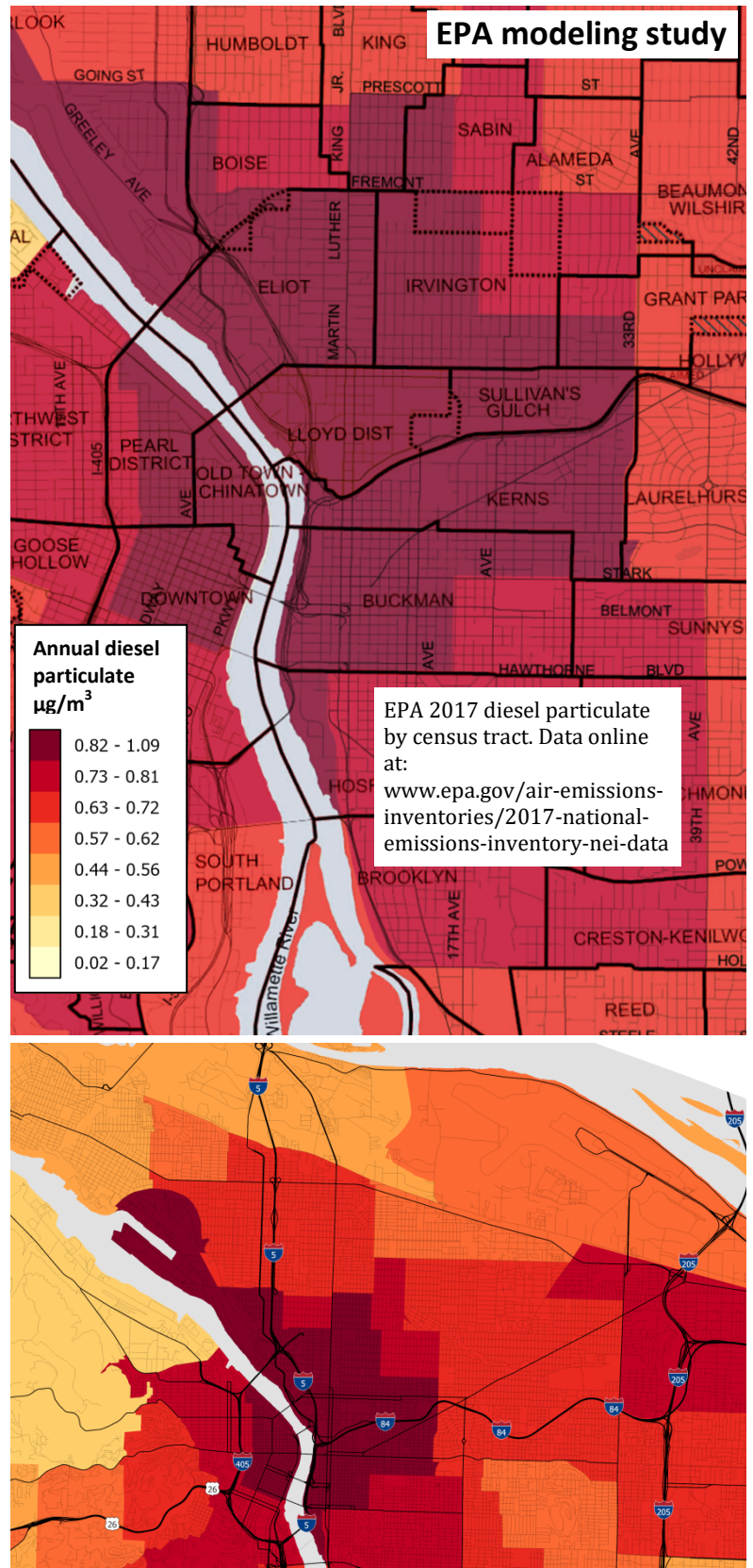
The PocketLab Airs cost $300 each and record PM 2.5 and humidity, GPS, carbon dioxide, ozone, dew point, temperature, and barometer data. Humidity is important to measure because it grows particle size, making particulate monitors a little less accurate. Stationary monitors address this through heated air inlets. We take humidity into account when analyzing our results.

The study area
Ideally, we sample during times of high diesel particulate pollution. This is due to both the number of unfiltered trucks and busses nearby and also wind which can move the pollution around. A phenomenon known as atmospheric inversion can concentrate the pollution at ground level where it is most dangerous to people.

In Portland, the majority of diesel particulate pollution comes from the interstate highways that are used as a hub by unfiltered short-haul diesel trucks AKA "box trucks." These trucks pace back and forth making deliveries within the city. We worked with Mason Levitt from Beyond Toxics who used ARCGIS to map the most recent EPA model of airborne Portland diesel particulate -- the 2017 National Emissions Inventory released in 2020. We call the area the EPA reported to be the highest risk of pollution exposure "the Blob." It looks like a blob on the map and is super dangerous, like the creature in the 1958 horror movie. Our MiniWRAS samples within the Blob closely matched the EPA model.

The two maps below is the most recent EPA diesel particulate model made in ARCGIS, layered with a map of Portland neighborhood associations. The "Blob" of highest health risk in the center, color coded in purple, where I-5, I-84, and I-405 converge spread across 12 Portland neighborhoods.

EPA 2017 diesel particulate by census tract. Data online at: www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data

Annual diesel particulate μg/m³

	0.82 - 1.09
	0.73 - 0.81
	0.63 - 0.72
	0.57 - 0.62
	0.44 - 0.56
	0.32 - 0.43
	0.18 - 0.31
	0.02 - 0.17

Mapping and graphing wind direction

Hourly, daily, and seasonal changes in wind direction decide neighborhood exposure to diesel particulate. We calculated predominant wind direction using Portland wind monitor data. We found diesel particulate in winter was opposite of the predominant wind direction. It appears that graphing hourly and daily wind explained why the Blob was located east of I-5 in winter.
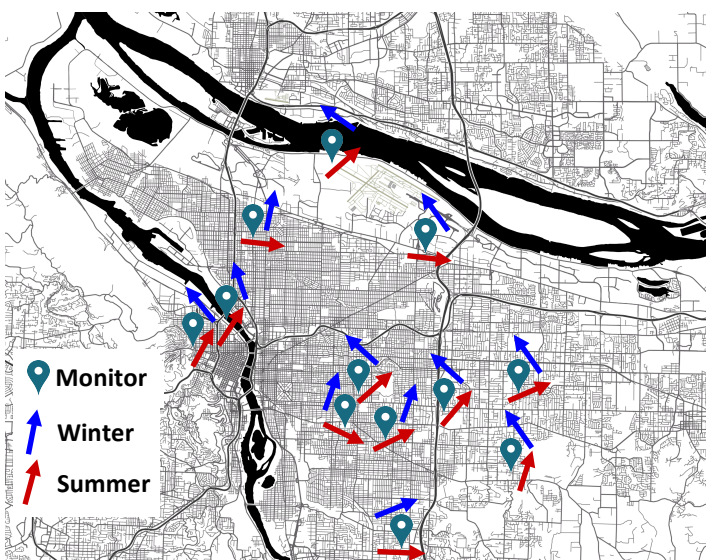
Teddy and Jenn downloaded and analyzed all Portland 2022 and 2023 data from the MesoWest database. MesoWest is operated by the University of Utah and consists of privately owned wind sensors which are called anemometers. We found that 12 of the 21 anemometers on their website had at least a year of data in the time period we are researching and did not appear to be malfunctioning. Since these sensors are privately owned, unsurpringly, some appear to not be maintained or sited properly. For example, some of these sensors were only capable of tracking certain wind directions, while others would have large gaps in their data.

Buildings and topography redirect wind. One example of this we saw was a sensor which showed the wind coming from the same direction all year. In order to ensure accuracy, we also left out any sensors that had suspicious data. Allison contacted the site owners of five of the most reliable anemometers so far to ensure they were properly sited.
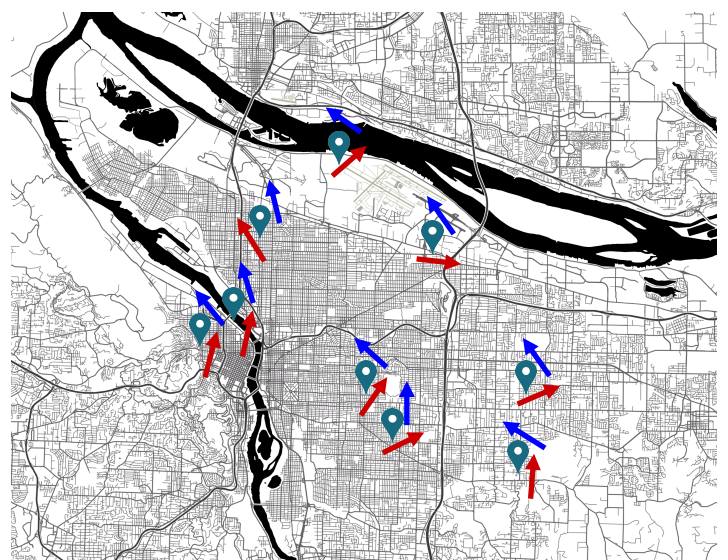
We downloaded all 2022 and 2023 wind direction data from the 12 reliable monitors on MesoWest. We compiled all measurements in a spreadsheet and then the graphed the results in Excel. We found that wind direction changes frequently. In a given month the wind can come from any of the four cardinal directions, but each month will have one or two predominant wind directions. We sorted the months into seasons: June, July, and August for summer and December, January, and February for winter. Next we calculated the average wind direction for summer and winter in Excel, shown in the two maps below. The average wind direction shifts, or nearly reverses in winter vs. summer. These maps of predominant seasonal wind direction are the first ever made for Portland for locations other than the Portland Airport.
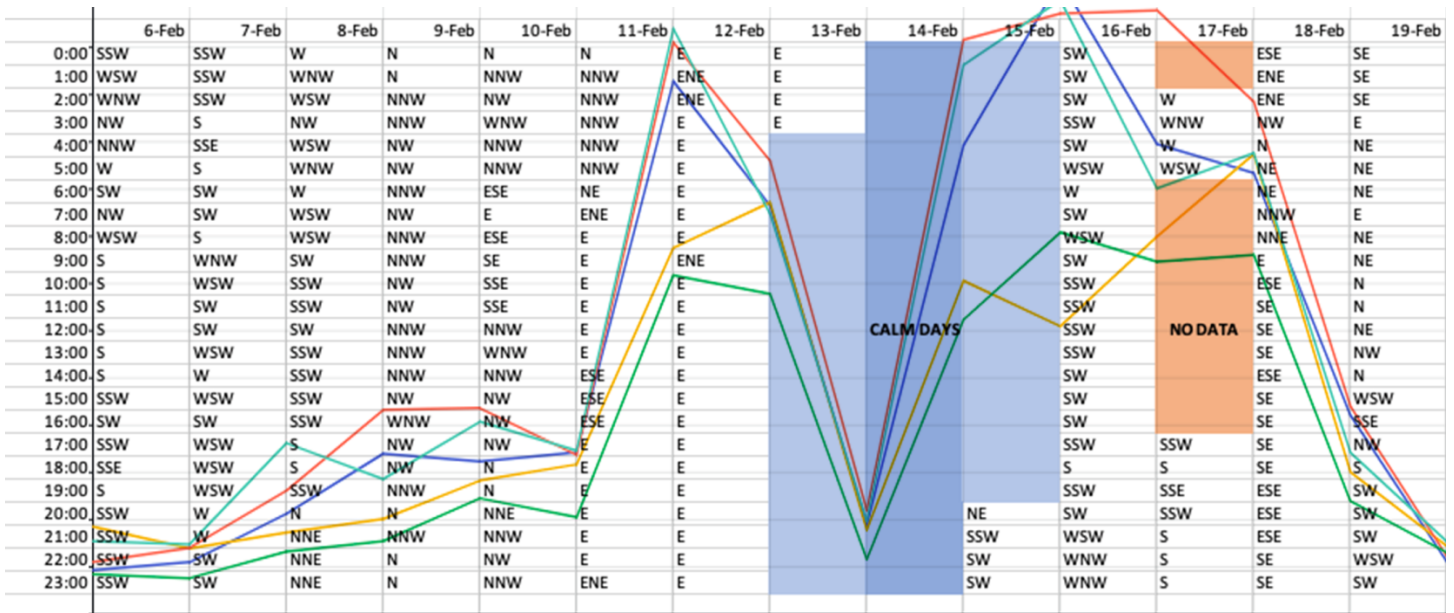
We wanted to determine which side of the highway is going to get the majority of the diesel particulate. All of our winter samples showed diesel particulate in the I-5 corridor as being east of the I-5, which is nearly opposite of the predominant wind for winter. To solve this mystery, we graphed two weeks of hourly wind data from February 2023. That graph is on the next page, showing the wind changing direction to the east, and an inversion forming causing air pollution to spike. This made us realize that predominant wind direction could not help us predict air pollution events, and that we would need to rely on hourly and daily wind data to determine which side of the highway the pollution would blow.

2022 Predominant seasonal wind direction

2023 Predominant seasonal wind direction

	6-Feb	7-Feb	8-Feb	9-Feb	10-Feb	11-Feb	12-Feb	13-Feb	14-Feb	15-Feb	16-Feb	17-Feb	18-Feb	19-Feb
0:00	SSW	SSW	W	N	N	N	E	E			SW		ESE	SE
1:00	WSW	SSW	WNW	N	NNW	NNW	ENE	E			SW		ENE	SE
2:00	WNW	SSW	WSW	NNW	NW	NNW	ENE	E			SW	W	ENE	SE
3:00	NW	S	NW	NNW	WNW	NNW	E	E			SSW	WNW	NW	E
4:00	NNW	SSE	WSW	NW	NNW	NNW	E				SW	W	N	NE
5:00	W	S	WNW	NW	NNW	NNW	E				WSW	WSW	NE	NE
6:00	SW	SW	W	NNW	ESE	NE	E				W		NE	NE
7:00	NW	SW	WSW	NW	E	ENE	E				SW		NNW	E
8:00	WSW	S	WSW	NNW	ESE	E	E				WSW		NNE	NE
9:00	S	WNW	SW	NNW	SE	E	ENE				SW	E	NE	NE
10:00	S	WSW	SSW	NW	SSE	E	E				SSW		ESE	N
11:00	S	SW	SSW	NW	SSE	E	E				SSW		SE	N
12:00	S	SW	SW	NNW	NNW	E	E		CALM DAYS		SSW	NO DATA	SE	NE
13:00	S	WSW	SSW	NNW	WNW	E	E				SSW		SE	NW
14:00	S	W	SSW	NNW	NNW	ESE	E				SW		ESE	N
15:00	SSW	WSW	SSW	NW	NW	ESE	E				SW		SE	WSW
16:00	SW	SW	SSW	WNW	NW	ESE	E				SW		SE	SSE
17:00	SSW	WSW	S	NW	NW	E	E				SSW	SSW	SE	NW
18:00	SSE	WSW	S	NW	N	E	E				S	S	SE	S
19:00	S	WSW	SSW	NNW	N	E	E				SSW	SSE	ESE	SW
20:00	SSW	W	N		NNE	E	E		NE		SW	SSW	ESE	SW
21:00	SSW	W	NNE	NNW	NNW	E	E			SSW	WSW	S	ESE	SW
22:00	SSW	SW	NNE	N	NW	E	E			SW	WNW	S	SE	WSW
23:00	SSW	SW	NNE	N	NNW	ENE	E			SW	WNW	S	SE	SW

The graph above is hourly MesoWest wind direction anemometer data near the study area. The colored lines show PM2.5 measured by five PurpleAir monitors spaced throughout Portland. The calm days are an inversion concentrating the air pollution which spikes up to 25 µg/m³.
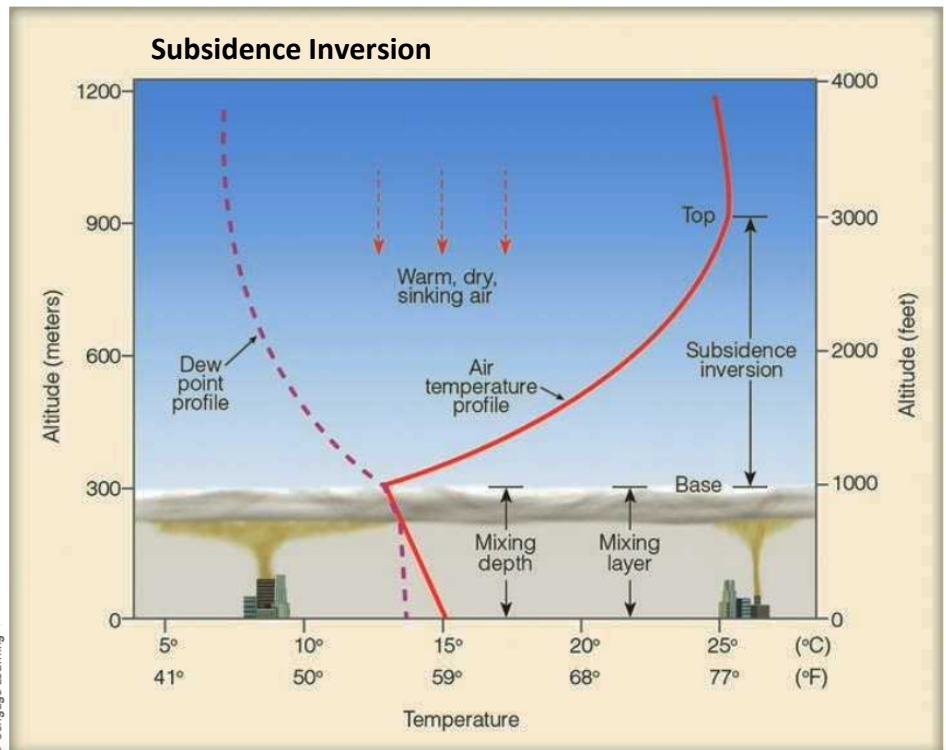
Graphing inversions

On average, pollution tends to be worse during winter due to a phenomenon called atmospheric inversions. Citywide air pollution is heavily influenced by inversions.
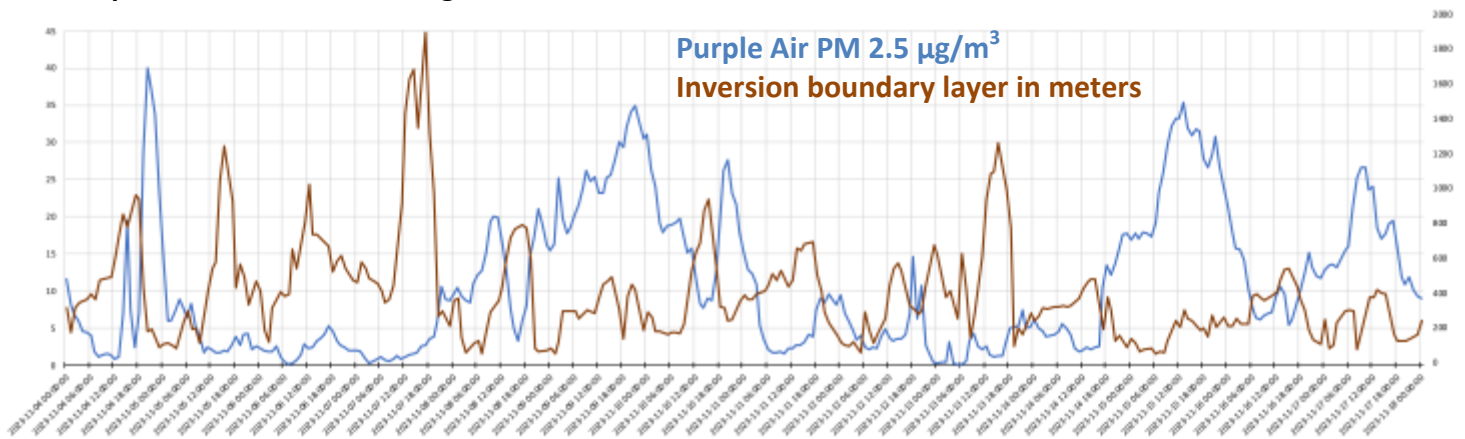
On most days, rising air carries urban air pollution upward where it can mix with the cooler air above and disperse away from the city.

In the evening, the ground cools faster than the air above. Cool air near the ground settles out and doesn't rise. The atmosphere stabilizes and a blanket of warm air sits on top of a stable layer of cool, effectively trapping the denser pollution-laden air near the ground and keeping it at ground level. This is the nightly inversion that causes more air pollution in the evening.

On cold windless nights the pollution can get trapped in a sinking or downward movement of air over a wide area within a region of high pressure. This is known in meteorology as "subsidence." Subsidence inversions bring stable conditions in an area of high pressure causing dangerous spikes in air pollution. Since it's colder in winter, subsidence inversions are more common.

We use free online NOAA software that reports inversion for any point in the past, current, or up to two days in the future. This is a model, not measurements from monitors, yet we have found it to be remarkably predictive of PM2.5 measured in real time by PurpleAir monitors.

Subsidence Inversion

4

Air pollution increases during inversions Portland November 4th 2023 to November 18th

Purple Air PM 2.5 µg/m^3
Inversion boundary layer in meters

Graphing PM2.5

The graph above shows PM 2.5 using Portland purple air data and Portland inversions using NOAA software data. As you can see when the inversion ceiling is lower the ground, then PM2.5 air pollution gets worse.

Our research has demonstrated that PM2.5 monitors cannot see diesel particulate accurately and consistently. We use PM2.5 as a faster way to gauge the amount of inversion. There is a delay between the start of an inversions and when pollution accumulates. Real-time spikes in PM2.5 are the best way to know that diesel particulate is concentrating at ground level.

The way that we graph PM2.5 these days is through purple air data. The software we wrote has downloaded all the purple air data that has ever been collected in Portland. This software can automatically graph PM2.5 hourly, daily, or annually for individual or groups of PurpleAir monitors. It can tell the difference between indoor and outdoor PurpleAirs. Therefore, our custom software is super convenient unless the data that we need is for today or yesterday. It takes about a week to download the new data. If we need more current information then we go to the Purple Air website and we look at the data in real time. When we're planning a ride, we look at the forming inversion and the PM2.5. We want to go and collect data when PM2.5 is spiking because that suggests that an inversion has formed and pollution is being held at ground level.

Rain forecasts

Our equipment isn't waterproof, so if the chance of precipitation isn't dropping to zero by the time we are ready to go, the ride must be rescheduled.

For a rain forecast for the next two hours, we use accuweather.com. For a rain weather forecast from two hours to six days in the future we use weather.gov. Details rain forecast instructions are included in the procedures section of this report.

Diesel monitoring results

The complete results of our diesel mapping of Portland neighborhoods are online at:

portlandcleanair.org/files/reports/Mini WRAS%20report.pdf

Our procedures for using the MiniWRAS to map neighborhoods is online at:

portlandcleanair.org/files/reports/Mini WRAS%20procedures.pdf

All of our procedures for graphing wind direction, inversion, and PM2.5 are on the following pages of this report.

Cascadia Action MiniWRAS and PocketLab Procedures

1.   How to carry MiniWRAS and two sets of PocketLab/smartphones

The MiniWRAS is required to point towards where we walk according to Durag. So this requires mounting a 19 pound device on the chest of the user. It has a handle but this requires carrying a heavy device one on side, which gets tiring quickly.

We use a Dana Designs "Overkill" Alpine mountaineering backpack designed to carry heavy loads. We use two loops made of tubular webbing tied with a water knot. These are anchored to the backpack shoulder strap loops above the chest strap. We use locking carabiners on the end of each webbing loop, pass it through the handle of the MiniWRAS, and clip it to the backpack shoulder strap.

The phones and PocketLabs each have a quad lock adaptor attached with 3M adhesive and locked to a plastic pipe with four quadlock bicycle mounts. Tubular webbing passes through the pipe and there is a water knot loop at each end with a locking carabiner.

We found Bluetooth was less reliable when the smartphone was in a jacket pocket near the device. A see through mesh pocket worked. The procedure above has no physical interference between the PocketLab and the smartphone, and the phone is positioned as close as possible.

2.   Collect humidity data PocketLab PM2.5 comparison data with PocketLab

We carry two PocketLabs connected to two Iphone 7 or above. This allows us to compare PM2.5 data from two PocketLabs and a MiniWRAS on a graph automatically generated by the auto-grapher software we wrote.

 How to connect to with the iOS App:
1.   Open the Apple App store.
2.   Search PocketLab. Download the PocketLab App.
3.   Make sure Bluetooth is turned on in your settings.
4.   Open the PocketLab App.
5.   Turn the PocketLab Air on. It should then automatically connect.
6.   You'll default to a view of all sensor graphs. You can switch to view graphs on their own using the switch graph icon in the upper left corner of the screen.

How to export your data:
1. After recording a data trial, click the "Export Data" button in the lower right corner. 2. You will then be given the option to save locally (directly download the .csv file to their computer/phone) or save to Google Drive. I would probably recommend saving to Google Drive as it will then be easier to share. 3. Next, have them either email their .csv file or share it directly with you via Google Drive.

Preferred export method:
Save data to Pocketlab cloud software, "CloudLab". by clicking "Upload to CloudLab" after a data recording. Then you are asked to either login or create an account. It requires an internet connection to save the data to CloudLab, so keep that in mind. Then save their data to a "Timeline" in CloudLab. After saving to CloudLab, you can then go back and view the graphs at anytime from other computers/devices. The graphs will look as they do in the web app. From CloudLab, we can still download the data as .csv files. Always download a .csv file of the recorded data. "CloudLab" is beta software right now and Pocketlab is doing a major overhaul of it this summer

These are attached to the backpack shoulder strap facing forward, in front of the person as you walk.

3.   Converting from particle count to mass:
We wrote software that converts particle counts to mass expressed as micrograms per cubic meter (µg/m3) and plots the sum of the mass of 13 MiniWRAS channels less than .5 microns. The software plots colored dots on an online MapBox map showing the concentration of airborne particles .01 to .449 microns.

"The accumulation mode of diesel engine particulates is made of sub-micron particles of diameters typically ranging from 30 to 500 nm (0.03-0.5 nm)" https://dieselnet.com/tech/dpm_size.php
The nucleation mode of diesel is as small as 10 nm. This converts to .01 to .5 microns.

California risk assessments, and DEQ particle monitors use mass expressed as µg/m3 for diesel particulate. The MiniWRASA and the Grimm software provide µg/m3 only for PM2.5; diesel particulate (.5 microns and smaller) is reported as particle counts.

The conversion equation from particle count to particle mass provided by Durag by request is shown below:

$$m_i = \frac{1}{6}\pi D_i^3 \rho$$

The mass of an individual particle can be calculated given its diameter (D_i) and density (ρ); multiply this by the number of particles to calculate the total mass of particles of a specific diameter or in a specific size bin. To convert this total mass of particles to a particle density (µg/m³), you then need to divide by the total volume sampled (ρ = mass/volume).

This total volume can be calculated from the duration of the sample (one minute, etc.) and the sample flowrate of the instrument (1.2 lpm), i.e., in one minute the device samples a total volume of 1.2 liters (1.2 liters = 0.0012 m³). Particle density in units of µg/m³ would then be equal to the total mass of particles sampled in one minute divided by the total volume sampled in one minute, 0.0012 cubic meters.

We received a sample MiniWRAS spreadsheet from Durag and calculated total diesel particulate mass in the following spreadsheet: "1371_aaar_tuesday.dat.xls"

The conversion requires a value for the density of soot, which we used 1800kg per cubic meter.
"Usually, the true density of freshly emitted soot particles is assumed to be close to 1800-1900 kg/m3 (Bond et al., 2013; Dobbins, Mulholland, & Bryner, 1994"
https://www.sciencedirect.com/science/article/am/pii/S0021850219300114

Our Excel conversion equation we wrote from the information above:

= PI() / 6 * POWER(nm / 1000000000,3) * rho_true * D2 / v_air / 1000000000

Here are the values used in the equation:

Value	Name	Unit	Description
1800	rho_true	kg / m^3	diesel particulate density
3.141592654	pi	1	spherical particle volume
0.0012	v_air	m^3	MiniWRAS volume air/min.

Here are the variables used in the equation:

nm = (column header + next column header)/2
rho_true = 1800 (kg / m / m / m)
pi = 3.14159265359 (unitless)
D_i = particle_bucket_nm / 1000000000 (meters)
v_air = 0.0012 (m * m * m)
m_i = pi / 6 * D_i * D_i * D_i * rho_true (kg)
rho_total = m_i / v_air (kg / m / m / m)
rho_microg = rho_total / 1000000000 (micrograms per cubic meter)

Upon review by Durag, we were told our conversion was correct. MiniWRAS data contains 41 evenly spaced channels from .01 to 35 microns. Row headers in MiniWRAS data are the bin low boundary size. That column reports all the particles from the low boundary size up to the size of the next channel's low boundary. We use the calculated midpoint of each channel.

4.   Determine the percentage of diesel particulate for samples .5 microns and smaller:

All particles .5 microns and smaller are diesel particulate minus the percentages of woodsmoke and brake dust:

TBD% woodsmoke - during similar inversions, we will sample highway exposed areas to areas not highway exposed to determine the expected percentage of woodsmoke near highways. EPA NATA also reports modeled annual averages of woodsmoke and diesel particulate for Portland.

Ultrafine particles near highways are less than 12.5% brake dust - based on citations below, all roadside particulate is 58.5% of is ultrafine diesel particulate and 8.4% brake dust. 8.4 / (58.5 + 8.4) = 12.5%. This includes ultrafine brake dust particles larger than our cutoff of .5 microns, which is why I include "less than" - it looks like brake dust is 10% or less of particles .5 microns or less.

Works cited:

Diesel powered vehicles are only 6% of Oregon vehicles on the road, they emit 60 - 70% of all particulate emissions from all on-road vehicles combined.
Oregon DEQ
www.oregon.gov/deq/FilterDocs/DieselEffectsReport.pdf

More than 90% of DPM is less than 1 µm in diameter
CARB
https://ww2.arb.ca.gov/resources/overview-diesel-exhaust-and-health

Brake dust is up to 20% of traffic-related particles.
Liza Selley, a postdoctoral research fellow at the University of Cambridge
https://airqualitynews.com/2020/04/16/air-pollution-from-brake-dust-may-be-as-harmful-as-diesel-exhaust-on-immune-cells/
citing Air Quality Expert Group to the Department for Environment, Food and Rural Affairs; Scottish Government

https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1907101151_20190709_Non_Exhaust_Emissions_typeset_Final.pdf

ultrafine dust particles of less than 2.5 μm account for about 42% of brake dust
Zhang et al. Enclosure Design for Brake Wear Particle Measurement Using Computational Fluid Dynamics
https://www.mdpi.com/1996-1073/14/9/2356

5.   Grimm MiniWRAS & Pocket Lab deployment procedure for mobile mapping / graphing of diesel particulate.

Pre- Deployment:
- Charge all devices: MiniWRAS, two phones, and two pocket labs.
- Insert USB device (flash drive with Grimm formatting/calibration folder) into the MiniWRAS BEFORE START.
- Disable auto-lock for GPS collection on the collection phones. (under "display and brightness" for iPhone). Having another navigation app giving directions will have the same effect.
- For evening collection have a flashlight / headlamp ready.

Start Deployment:
1. Launch Strava GPS application and press START.
2. Start Pocket Lab by pressing button (light quickly flashes red and green). Launch Pocket Lab application, pair device (Light slowly blinks magenta), PRESS RECORD. Repeat for each redundant device.
3. Press ON switch on MiniWRAS, wait 3 mins or until the battery indicator lights up and beeps. Remove aircover, then press START (Start light should turn solid and fans will begin to run).

Rig the miniWRAS to a backpack or carrying apparatus along with the pocket lab / phone array.

During Sampling:
Face collection ports straight ahead and begin walking. Careful not to press any buttons.

End Deployment:
1. Press STOP on pocket lab app, export file.
2. Stop MiniWRAS, wait 3 mins or until light stops flashing, power down by pressing the off switch, take out the USB device with the collected data on it.
3. Stop GPS recording and export the .gpx file.

Sample Data Processing:
After each sample there should be three files. A .dat file from the MiniWRAS, a .csv file from one of the Pocket Labs, and a .gpx file from the Strava app.
1. Paste only these three files into the Airmap here: https://cdaringe.github.io/airmap/
2. Then click "Submit". One the next page DO NOT CHANGE the reference numbers at the top. Click "Continue".
3. The color-coded map shows the MiniWRAS sample. Select the particle size you wish to graph. For our latest report we used option 1: PM 0.5 ug/m3 (derived) and option 3: PM 2.5 ug/m3.
4. Adjust the map zoom as needed and screenshot the map. For PC use WINDOWS+SHIFT+S and crop out the browser window to get a clean map image. On mac this is done with SHIFT+COMMAND+5 which opens the screen capture window. Find the file where the image is sent and name it to keep track.
5. Clicking "Show Charts" opens the MiniWRAS PM 2.5 / PocketLab PM 2.5 / PocketLab Humidity Graph. This chart let you compare the PM 2.5 readings from the MiniWRAS and the PocketLab as well as humidity data which affects particle size. Screenshot this graph using the same method above.
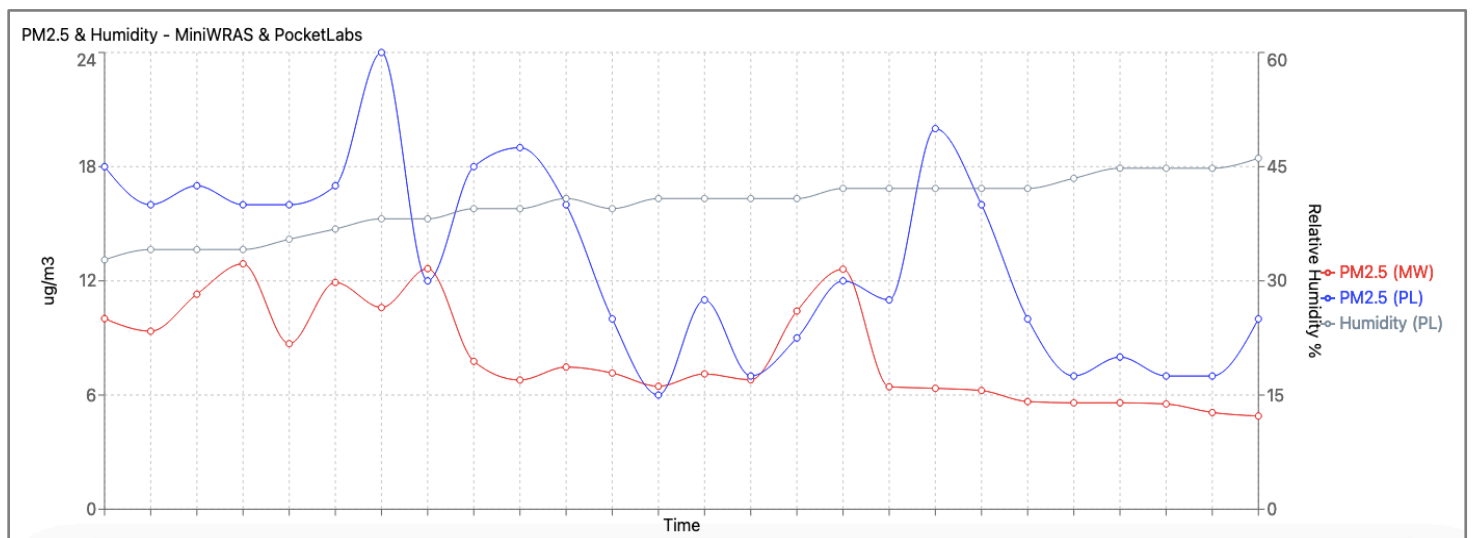
Cascadia Action Wind Graphing Procedures

ROUND 1 PROCEDURES – Monthly Comparison

Compiled by Teadoro Holt on 11 October 2023
Data from https://mesowest.utah.edu/

MesoWest Procedures:
Accessing Data: Log into Mesowest, select your region from the map. Change the network to "All Networks" and refresh. We noticed some sensors are not always visible on the map, which must be an error. Once you found your sensor, click it and select "download" data.

At this point you will only be able to download one day at a time unless you are logged in. Once logged in you can select the number of days you wish to graph, and then set the end date and hour. We used 365 days with an end date of January 1 2023, and selected "Local" for the timezone, this gave us a data set for all of 2022. Make sure to select "All Variables" and then "Retrieve Data". NOTE: some sensors will give you data in standard vs daylight time, this one hour difference is not a large enough error to consider, but the difference between UTC and PST should be converted.

Organizing Data:
Once downloaded, organize the file into a folder with a nickname for the sensor. The file will have an alphanumerical code and come as a .csv file. Immediately open the file in excel and save as an .xlsx file to prevent data loss. Rename the file to help you identify the sensor. Now we suggest you carefully look at the data.

Some sensors will not give wind data, others may give wind speed but not direction, some will give the speed and the direction as degrees, but won't give the cardinal direction code (e.g. NNW or North by Northwest). The method we used to graph wind direction requires only the timestamp and the cardinal direction columns of the data. Wind speed is also useful to analyze the data. If you see a gap in direction readings, it may be because there was no wind at that time. *NOTE: Timestamps are not universal. Some sensors record readings every 5 minutes, others every hour. Correcting this is explained below. We graphed all sensors using the same 100% stacked bar graph method.

Preparing Data to be Graphed:
On a new sheet in the same workbook, copy and paste the timestamp, wind speed, wind degrees, and wind direction for the entire year. On the side, we listed the 12 months down a column and then listed the cardinal directions across the top. The order here is important, we wanted our graphs to closely resemble the wind direction graph from weatherspark.com. In this graph, the directions are color coded from top to bottom North, East, South, West. To achieve this, we actually had to list the directions across the top in the opposite direction starting with Northwest, West, Southwest etc. The codes looked more like this, NW, WNW, W, WSW, SW, SSW, S etc.

Once the directions were all labeled along the top columns, we picked the first NW column and used "=COUNTIF($ Range start: $ Range end, $ Criteria)" The range was the beginning and end of January. The $ fixes the reference to a cell. For the range of dates, place the $ before the cell ID. e.g $B3:$B299. The Criteria was the NW column label we just created. Note the $ must be after the Column letter but before the row number e.g. H$3 and not $H3. Clicking and dragging this down for each month just repeated the readings for January. It was necessary to change the range individually for each month. Then we simply selected the entire NW column of formulas and dragged it out for every column of direction codes.

Graphing the Data:
Now you should have a table with the months down the side, and the directions along the top. Each cell is the number of times in a given month that the anemometer recorded wind from that direction. Typically, one mph or higher is recorded. Next select the entire table and insert a "100% stacked graph". You will now have a graph with very colorful thin columns. Make sure the x axis is your months and the y axis the precent.

Formatting the Graph:
Format the chart area and turn off the gridlines then format the data series and reduce the gap width to 10%. Next all you need to do is change the colors and spruce up the charts size and text font to your liking.

We chose to color our graph to resemble the weatherspark wind graph. There are 16 wind directions. The main four each got a color, blue, green, red, and brown. We made the main four darker colors than the others. We also darkened the cardinal directions either side of east and west to highlight the seasonal shift in wind patterns in Portland OR. So WNW, W, and WSW, were all dark but NW and SW were lighter to show the intermediate directions. This meant that N and S were darkened and NNW, NNE and SSW and SSE were lighter. This is not ideal if you wish to highlight the seasonal change of wind from north to south. All this is just to decide whether NW, SW, SE, or NE are color coded to match N-S or E-W.

Lastly, insert a legend on the right and delete the intermediate directions so N, S, E, W are clearly differentiated.

Rinse and Repeat:
Download another sensor and organize its data. Making sure to use the same cells, copy and paste the timestamp, wind speed, wind degrees, and wind direction for the entire year. Now all you should need to do is copy and paste the table from the first sensor, it should autofill with the new data! Then when you paste the graph, right-click "select data", on the top for the data series click the white and red icon and highlight the table. Now the graph is specific to the new sensor.

*NOTE: Each sensor may use a specific interval of measurements. For example, if two sensors take readings hourly then the above "Rinse and Repeat" method will work. However, when one or more sensors use a different interval such as 15 or 5 minutes, you will need to adjust the range of the

COUNTIF formula for each month. In other words, there are a lot more 5 minute measurements for each month, than there are 1 hour measurements, so your graph will not match up with the months unless the monthly formulas are corrected. Of course, you can then click and drag each months formula to fill for all of the directional columns. To confirm you did it correctly, click on a cell for a month and look at the highlighted box, it should encompass all the measurements for that month from midnight on the 1st to 23:00 on the 31st (If hourly data).
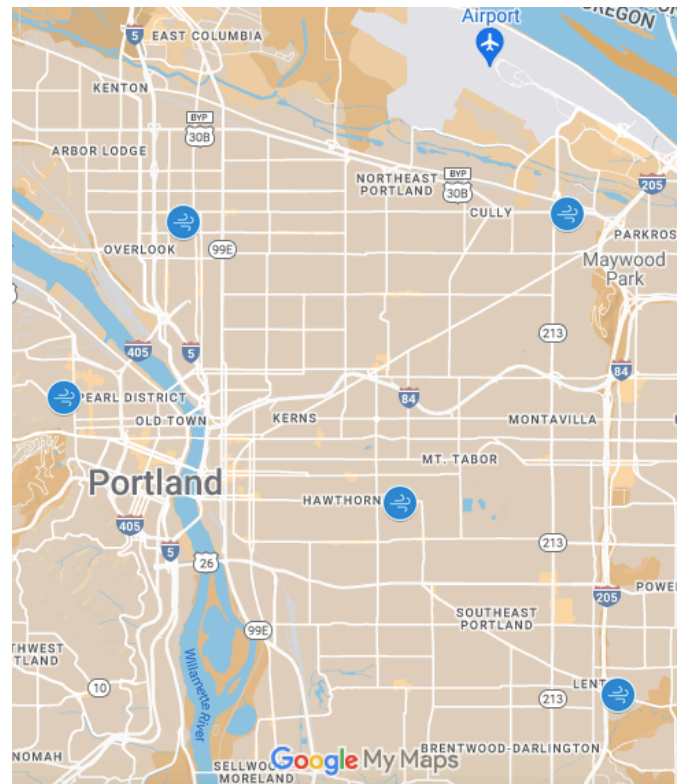

Other sensors that would fill in the gaps in this map either did not record wind direction data (Overlook), or had errors in their data (NE Broadway). Other sensors are available near the SW hills but these were not graphed due to their proximity to hills. Most of these locations are relatively flat except for NW which boarders the west hills that make up Forest Park.

Humbolt Neighborhood Wind Direction 2022
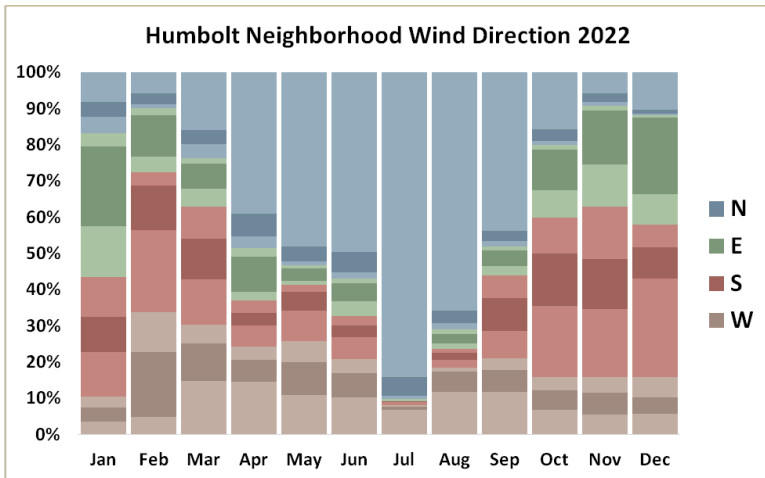
Jefferson High School in Humboldt Neighborhood in NE Portland:
Winter wind comes from the South and East.
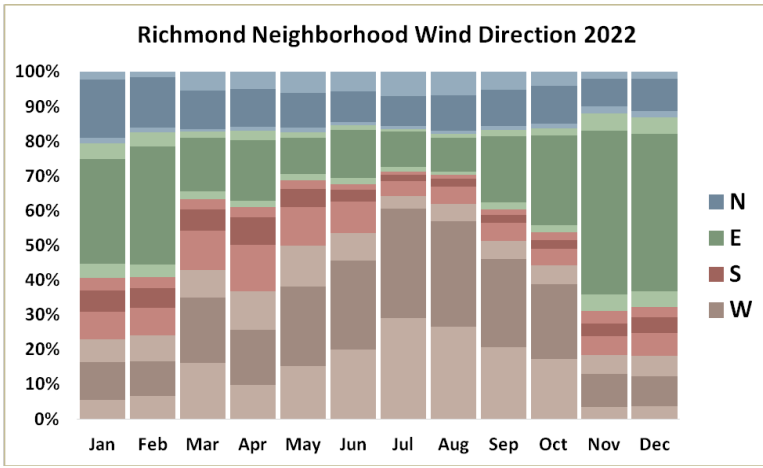Summer wind comes from the North and West

Cully Neighborhood Wind Direction 2022
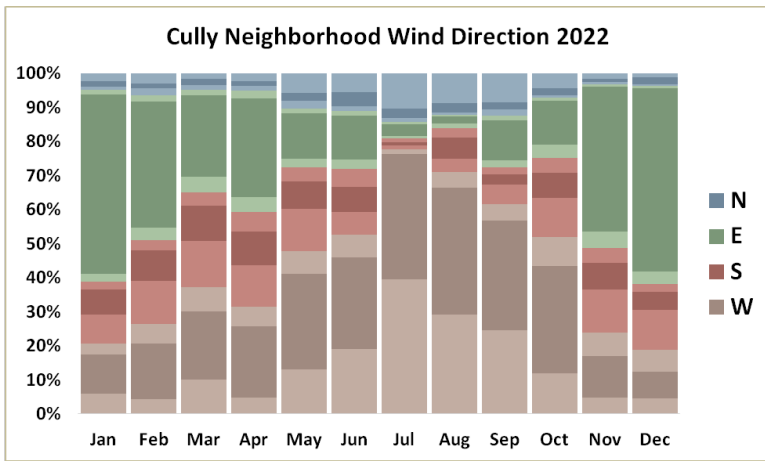
Cully Neighborhood in NE Portland:
Winter wind comes from the East.
Summer wind comes from the West.

Northwest District Wind Direction 2022
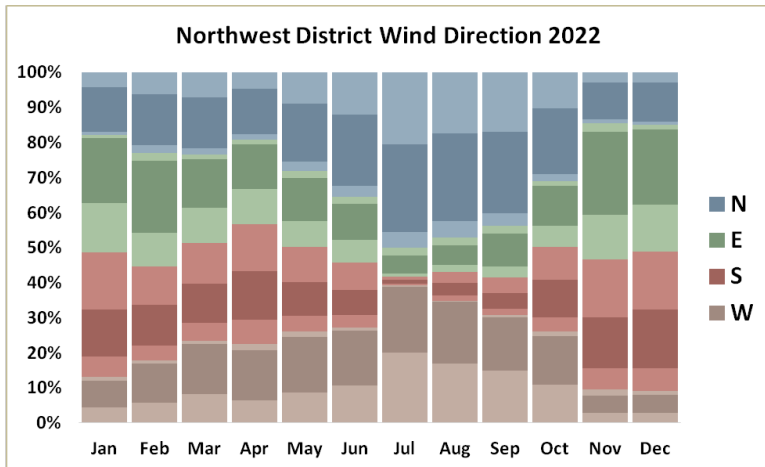
Northwest District Neighborhood in NW Portland:
Winter wind comes from the East and South.
Summer wind comes from the North and West.

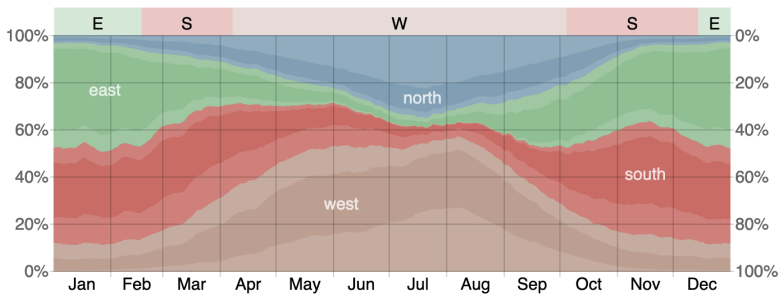**Lents Neighborhood Wind Direction 2022**
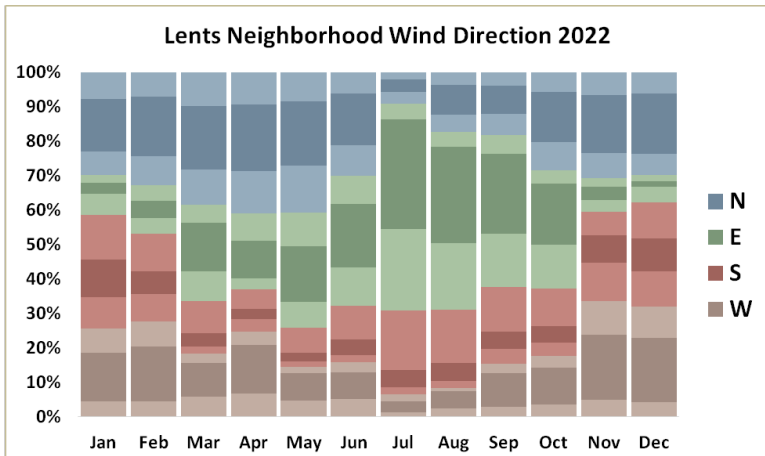
Lents Neighborhood in SE Portland:
Winter wind comes from the South, North, and West.
Summer wind comes from the East.

Richmond Neighborhood Wind Direction 2022

Legend: N, E, S, W

Hawthorne Street in Richmond Neighborhood in SE Portland:
Winter wind comes from the East.
Summer wind comes from the West.

KPDX Intl. Airport from weatherspark.com

Notes: This graph closely matches wind graphs from Northwest and Cully. Does not match up with Lents, topography or sensor placement may be responsible. **Sensors must be physically sighted to confirm their placement.**

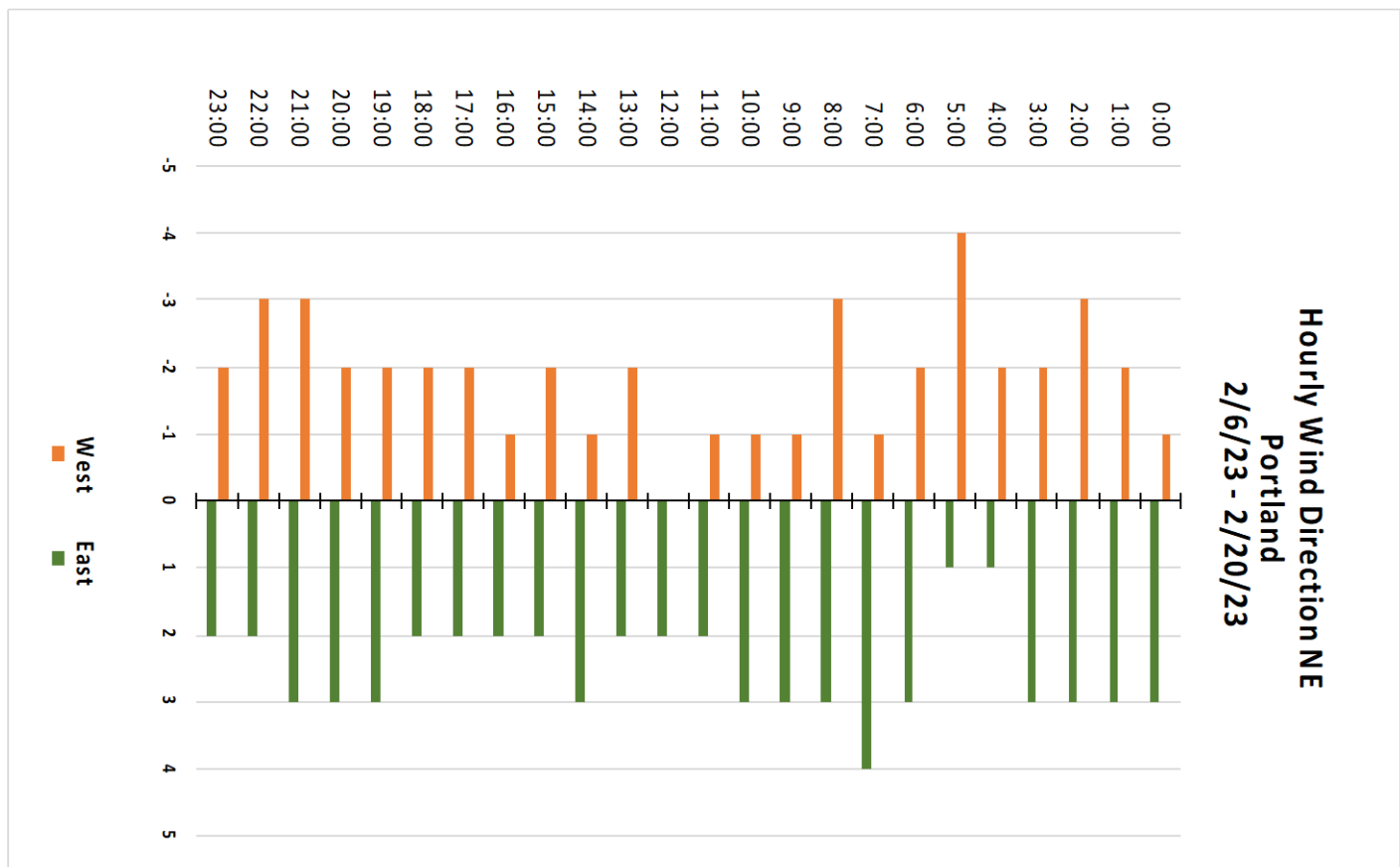# ROUND 2 PROCEDURES – Hourly Comparison

Compiled 8/11/23
Teadoro Holt, Cascadia Action.
NE Portland Hourly Wind Data
2/6/23 – 2/20/23

The following graph was made using anemometer data from the MesoWest network. Two weeks of wind direction data in February of 2023 from 2/6 – 2/20 were compiled and graphed in Excel. The goal was to highlight the alternating East and West winds, as such only ENE, E, ESE WNW, W, and WSW cardinal directions were mapped. The data included almost 48 hours of calm readings and several hours of missing data highlighted below.

		6-Feb	7-Feb	8-Feb	9-Feb	10-Feb	11-Feb	12-Feb	13-Feb	14-Feb	15-Feb	16-Feb	17-Feb	18-Feb	19-Feb	20-Feb
	0:00	SSW	SSW	W	N	N	N	E	E			SW		ESE	SE	S
	1:00	WSW	SSW	WNW	N	NNW	NNW	ENE	E			SW		ENE	SE	SSE
	2:00	WNW	SSW	WSW	NNW	NW	NNW	ENE	E			SW	W	ENE	SE	S
	3:00	NW	S	NW	NNW	WNW	NNW	E	E			SSW	WNW	NW	E	S
	4:00	NNW	SSE	WSW	NW	NNW	NNW	E				SW	W	N	NE	SSE
	5:00	W	S	WNW	NW	NNW	NNW	E				WSW	WSW	NE	NE	SSE
	6:00	SW	SW	W	NNW	ESE	NE	E				W		NE	NE	ESE
	7:00	NW	SW	WSW	NW	E	ENE	E				SW		NNW	E	SE
	8:00	WSW	S	WSW	NNW	ESE	E	E				WSW		NNE	NE	SW
	9:00	S	WNW	SW	NNW	SE	E	ENE				SW		E	NE	N
	10:00	S	WSW	SSW	NW	SSE	E	E				SSW		ESE	N	N
	11:00	S	SW	SSW	NW	SSE	E	E				SSW		SE	N	WNW
	12:00	S	SW	SW	NNW	NNW	E	E		CALM DAYS		SSW	NO DATA	SE	NE	NW
	13:00	S	WSW	SSW	NNW	WNW	E	E				SSW		SE	NW	NW
	14:00	S	W	SSW	NNW	NNW	ESE	E				SW		ESE	N	SW
	15:00	SSW	WSW	SSW	NW	NW	ESE	E				SW		SE	WSW	SSW
	16:00	SW	SW	SSW	WNW	NW	ESE	E				SW		SE	SSE	SW
	17:00	SSW	WSW	S	NW	NW	E	E				SSW	SSW	SE	NW	WSW
	18:00	SSE	WSW	S	NW	N	E	E				S	S	SE	S	W
	19:00	S	WSW	SSW	NNW	N	E	E				SSW	SSE	ESE	SW	WNW
	20:00	SSW	W	N	N	NNW	E	E			NE	SW	SSW	ESE	SW	W
	21:00	SSW	W	NNE	NNW	NNW	E	E			SSW	WSW	S	ESE	SW	W
	22:00	SSW	SW	NNE	N	NW	E	E				SW	WNW	S	SE	WSW
	23:00	SSW	SW	NNE	N	NNW	ENE	E				SW	WNW	S	SE	WSW
East	ENE	0	0	0	0	0	2	3	0	0	0	0	0	2	0	0
120	E	0	0	0	0	1	12	21	4	0	0	0	0	1	2	0
	ESE	0	0	0	0	2	3	0	0	0	0	0	0	6	0	1
		0	0	0	0	3	17	24	4	0	0	0	0	9	2	1
West	WNW	1	1	2	1	2	0	0	0	0	0	2	1	0	0	2
90	W	1	3	2	0	0	0	0	0	0	0	1	2	0	0	3
	WSW	2	6	4	0	0	0	0	0	0	0	3	1	0	2	3
		4	10	8	1	2	0	0	0	0	0	6	4	0	2	8

Hourly Wind Direction NE Portland 2/6/23 - 2/20/23

West
East

(times: 0:00, 1:00, 2:00, 3:00, 4:00, 5:00, 6:00, 7:00, 8:00, 9:00, 10:00, 11:00, 12:00, 13:00, 14:00, 15:00, 16:00, 17:00, 18:00, 19:00, 20:00, 21:00, 22:00, 23:00)

ROUND 3 PROCEDURES – Mapping Seasonal Direction

Graphing Wind Data 2023
(Using degrees instead of cardinal direction)
Compiled by Teadoro Holt on 6 January 2024
Data from https://mesowest.utah.edu/

MesoWest Procedures:
Accessing Data: Log into mesowest, select your region from the map. Change the network to "All Networks" and refresh. We noticed some sensors are not always visible on the map. This must be an error. Once you found your sensor, click it and select "download" data.

At this point you will only be able to download one day at a time unless you are logged in. Once logged in you can select the number of days you wish to graph and then set the end date and hour. We used 365 days with an end date of January 1 2023, and selected "Local" for the timezone. This gave us a data set for all of 2022. Make sure to select "All Variables" and then "Retrieve Data". NOTE: some sensors will give you data in standard vs daylight time, this one hour difference is not a large enough error to consider, but the difference between UTC and PST should be converted.

At this point it is best to make a spreadsheet with the sensor names and coordinates with separate columns for latitude and longitude. We will need this spreadsheet to make a google map.

Organizing Data:
Once downloaded, organize the file into a folder with a nickname for the sensor. The file will have an alphanumerical code and come as a .csv file. Immediately open the file in excel and save as an .xlsx file to prevent data loss. Rename the file to help you identify the sensor. Now we suggest you carefully look at the data.

Some sensors will not give wind data, others may give wind speed but not direction, some will give the speed and the direction as degrees, but won't give the cardinal direction code (e.g. NNW or North by Northwest). The method we used to map wind direction requires only the **timestamp and the wind direction in degrees**. Wind speed is also useful to analyze the data. If you see a gap in

13

direction readings, it may be because there was no wind at that time. *NOTE: Timestamps are not universal. Some sensors record readings every 5 minutes, others every hour. This method will use the average direction of each month so time interval is not an issue.

Preparing Data to be Graphed:
On a new sheet in the same workbook copy and paste the timestamp, wind speed, wind degrees, and wind direction for the entire year. On the side, list the 12 months down a column. On the next column use the =AVG formula and select all the direction readings for that month, then repeat for all 12 months. The number should be between 0 and 360 degrees.

The goal is to have one map that shows the wind direction at each sensor in winter vs summer. Now you should have a table for each sensor with the months down the left side, and the prevailing wind directions down the right side. For our purposes April through September is Summer, and October through March is winter. If you notice that the wind change occurs at a different time of year, communicate with the team so we can adjust.

the direction in degrees is the direction that the wind is blowing from. Now find the average wind direction for summer and again for winter. repeat for each sensor you have downloaded.

Mapping the Data:
Using "Google My Maps", create a map of the city and import your coordinates spreadsheet to put dots at every sensor position. You may need to manually tweak the spreadsheet or make adjustments on google to make sure each dot is displayed correctly. This map doesn't have to be perfect as we will make a new high resolution map at a later stage.

Next use a photo editor or word processor to insert two arrows, one above and one below each sensor **pointing in the direction of the wind flow**. For example, if your average wind direction is coming from the West , the arrow will point to the right towards the East. The compass has 360 degrees with 0 or 360 as North, 90 East, 180 South, 270

West, etc. We used a compass rose to compare the arrow with the compass. *The blue dial is magnetic north, use the black dial.
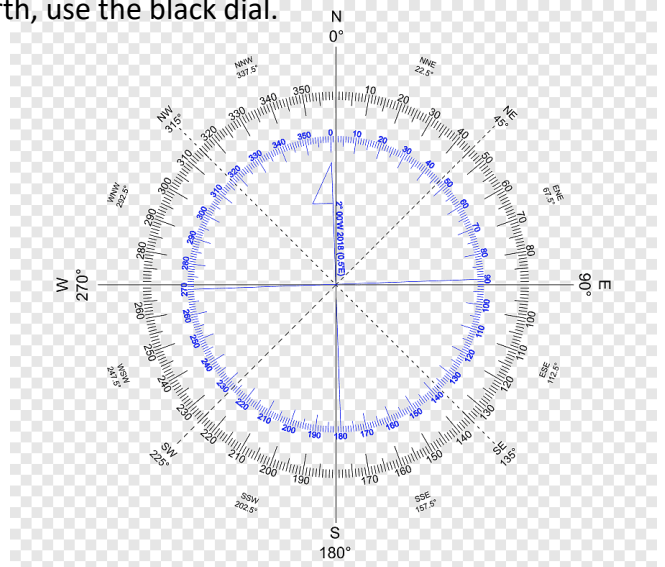
The top arrow above each sensor is the wind flow direction in winter, in blue. The bottom arrow below each sensor will be the wind flow in summer, in red.

Here is a results with a low resolution base map.
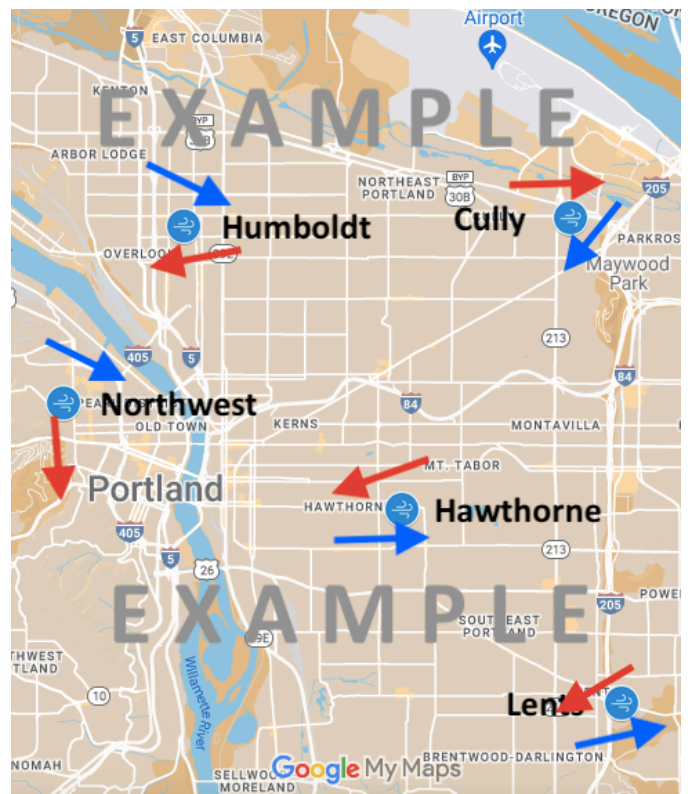
The report has the final with a high resolution map made with Unversal Map Downloader, map combiner, a paid app at https://www.allmapsoft.com/umd/:

# MiniWRAS Sample Forecasting Procedures

Teadoro Holt, Cascadia Action 18 November, 2023

Rain forecast

For a rain forecast for the next two hours, we use Accuweather at accuweather.com. Enter your zip code and choose the "Minutecast" tab. Choose "close" to any popup dialog box. Below the forecast is a weather radar with a map of Portland. Zoom in four times on the map. There is a slider on the bottom of the map that you can move to the right which shows radar projections.

For a rain weather forecast from two hours to six days in the future, go to weather.gov. Enter your zip code in the top right box. At the bottom under "Additional Forecasts and Information" choose "hourly weather forecast. The rain row on the graph has total inches of predicted rain.
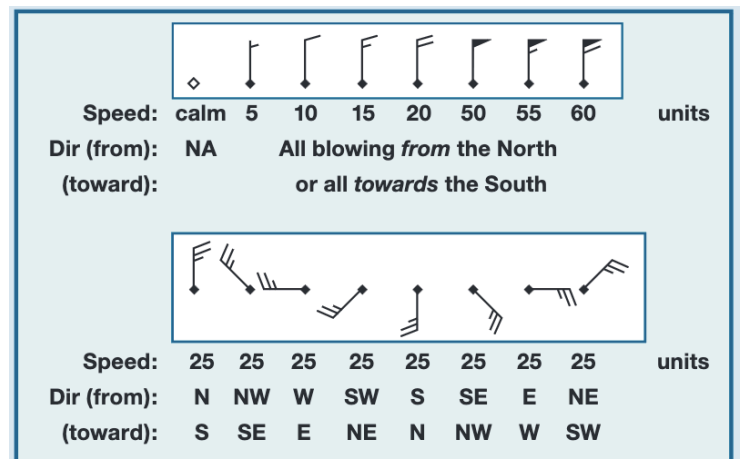
Detailed NWS Forecast:

1. Go to weather.gov and enter city name "Portland, OR". This will show you a detailed forecast for the next several days. Select "Hourly Weather Forecast". https://www.weather.gov/
   - (Note: You can also select "Forecast Discussion" for a detailed overview of the atmospheric conditions.)

2. Once at the hourly weather forecast, chose your starting time. The forecast will show 48 hours from this start time. Then Hit "Submit".
   - (Note: If you only see numbers and not graphs, go back a page and start again. Avoid clicking on the graphs as this will display the raw data.)

3. See legend below for how to read the forecast.
   - From top down, the graphs are ordered: Temperature & Dewpoint, Wind Speed & Direction, Clouds and Moisture, and then the types of Precipitation.

The grey areas of the graph represent dark hours.
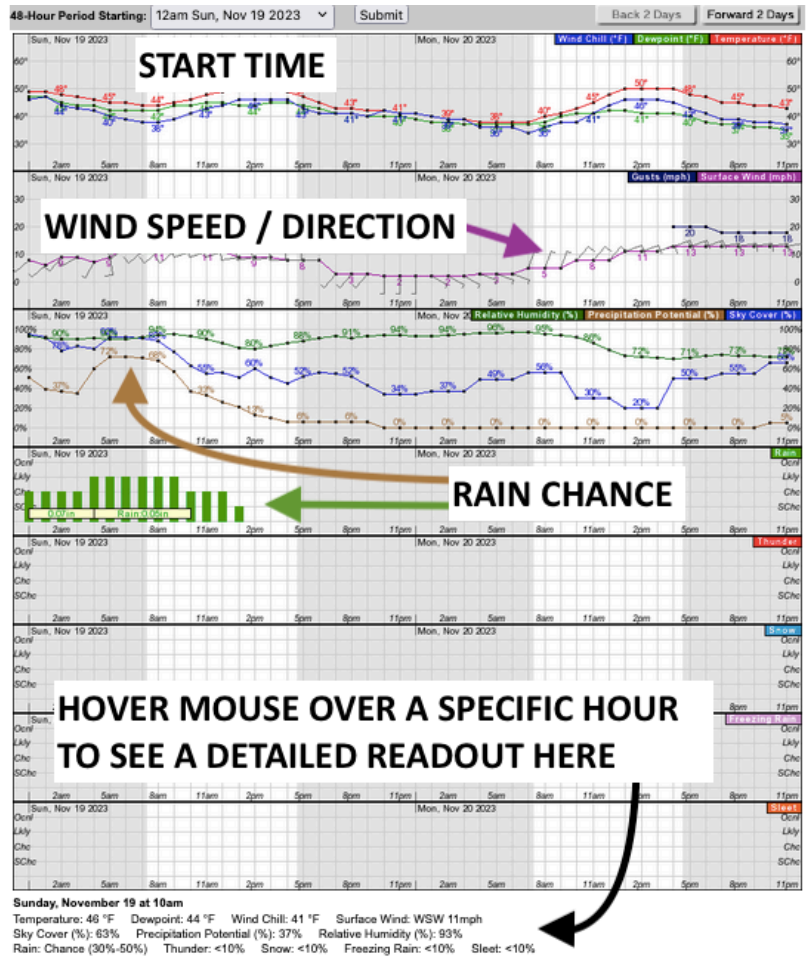
4. Wind barbs point in the direct the wind is coming from. See description below: Here you can hover your mouse over a specific hour and on the bottom of the screen you can see a detailed readout of the prediction conditions, including wind (from) direction and speed. (See black arrow)

- Here you can hover your mouse over a specific hour and on the bottom of the screen you can see a detailed readout of the prediction conditions, including wind (from) direction and speed. (See black arrow)

5. Use the "Forward 2 days" button to see advanced forecasts. We double check this webpage a few hours before sampling to **confirm absence of rain**.
   - When there is a slight chance of precipitation in a forecast, that chance usually drops to zero as you approach the sample time, if it does not come close to zero, we call off the sample.

6. We recommend looking at the "Surface Maps" section of the NWS website https://www.weather.gov/zid/surface as these will indicant approaching weather fronts. Weather fronts and rapid changes in atmospheric pressure result in higher winds, precipitation, and vertical mixing which is not ideal for sampling. At any time, 4 maps are available, the current map, 6 hour map, 12 hour map, and 18 hour map. You can compare these maps to estimate when a temperature or pressure shift will occur.

Consulting the Purple Air Map:

1. Go to purpleair.com and select real-time map from the dropdown. Or follow the link below:

https://map.purpleair.com/1/m/i/mAQI/a60/p604800/cC0#10.95/45.5212/-122.6702

2. Select a sensor near the sample area, Indoor sensors are marked with a black ring, avoid these sensors, or disable them in the settings menu (cog wheel in top left).
   - In the settings menu, you can also change the metric you wish to observe, the default metric is the US EPA Air Quality Index also shown at the bottom-left of the map.

3. A graph appears on the left that shows the recent readings from that sensor. Notice the pattern of highs and lows to confirm the validity of your chosen sample time.

Advanced Inversion Forecasting With NOAA:

Below are procedures for forecasting inversion events. NOAA uses supercomputers that generate 3D models of the atmosphere, the results are publicly available here: https://www.ready.noaa.gov/READYcmet.php
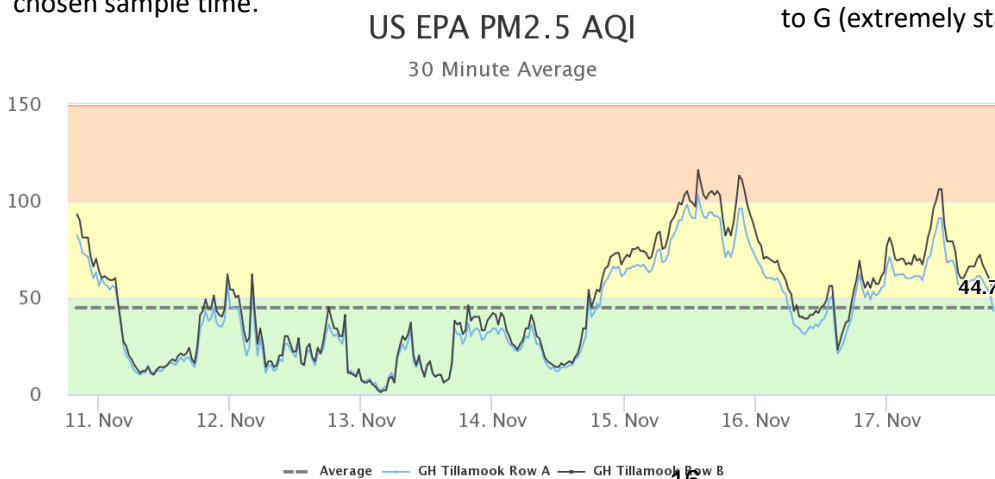
48 Hour advanced planning is less accurate but still allows you to visualize when an inversion will occur. The cycle refreshes every day at 00:00 UTC (5pm PDT, or 4pm PST). For more current results access the data base after this time.

1. Access the database and add the latitude and longitude coordinates to the nearest hundredths place (for example 45.56 -122.67) this is sufficient precision for inversion data. You may also enter just the city name and state. Click "Continue"

2. Under "STABILITY TIME SERIES" select "NAM Model (3km, 48h, 1hrly, CONUS, pressure-sigma hybrid)" then click "Go".

3. Select the most recent meteorological forecast cycle (top of the drop-down list) and click "Next".

4. For "Starting date/time" Select the earliest (current) start time at the top of the list. Then enter the access code at the bottom of the page and click "Get Stability".

5. Please note that NOAA lists their data using Universal Time Coordinated UTC, and 24 hour military time. Be sure to convert your sample time to UTC. The clock app on most smartphones has a world clock, there is also a chart on the previous NOAA page labeled "what is UTC, GMT, Z time?", or a helpful website here: https://www.worldtimebuddy.com/. Be sure to account for daylight savings time changes.

6. The resulting chart shows the next 48 hours of stability calculations. The Pasquill stability class is listed at the top of the chart A (extremely unstable) to G (extremely stable). The red line shows the inversion ceiling. Stable air and low ceilings typically mean bad urban air quality as the inversion concentrates air pollution at ground level.

US EPA PM2.5 AQI

30 Minute Average

Average — GH Tillamook Row A — GH Tillamook Row B

PurpleAir.com

18 Hour forecasts are more accurate, and allow you to narrow down when an inversion is the most likely. Since it only shows 18 hours ahead, you may wish to access this type of forecast late the evening before, or early morning on that day. The steps are the same as above just select the following:

1. Under "STABILITY TIME SERIES" select "HRRR Model (3km, 18h, 1hrly, CONUS, pressure)" then click "Go".
2. Follow the same steps listed above, but make sure to select "Forecast duration from start time, 18h" the chart will be in the same format as before just with a zoomed-in view of the next 18 hours.
3. Please note that the graphs will be different as they are generated using different models.

Documenting Past PM2.5 with PurpleAir

Purple Air Data Processing:
The graph above shows how we compare mobile sample readings to stationary Purple Air readings from nearby.

1. Compare the MiniWRAS sample route to the purple air map here: https://map.purpleair.com/1/mAQI/a10/p604800/cC0#11/45.4972/-122.6937 and select a sensor near the center of the sample area or along the route. Open the PCA Purple Air Auto-Grapher here: https://observablehq.com/d/da04a12af18af536 and look for the sensor you wish to graph. If it is not there then it may be a new sensor or one that is not added to the Auto-Grapher yet. Find the closest graphable outdoor sensor.
2. The date and time of the sample should be in your local timezone, as is the purple air data. Your sample timestamps can be found in the Pocketlab .csv file. For the purple air graph, select a date range that centers the sample time. We chose a 3 day range with the day of the sample in the middle of the graph. You may wish to "zoom in" and select a shorter date range.
3. Group by "Hourly" and adjust the "Tick multiplier" to show enough time stamps to make your graph easy to read, then screenshot here or select the three dots on the top left corner, "download svg" and open the file in a new tab. Then use CTRL++ to zoom in and then screenshot for a big HD graph. Repeat for multiple sensors. In the example below, we edited the image to include a black arrow at the time of sampling.
4. We use Photoshop to overlay PurpleAir with Inversion data.
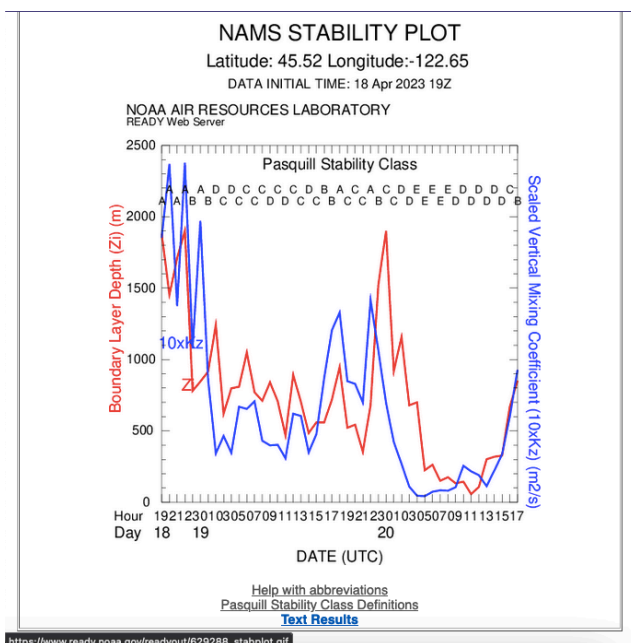
Acknowledgements

Cascadia Action would like to thank the boards of the Bridgeton, Downtown, Eliot, Kenton, Linnton, Lloyd, Overlook, and Sullivan's Gulch Neighborhood Associations for planning and monitoring with us.

Alexandra Ruhf is our researcher and a board member. She has a Master's degree in Neuroscience from University of Washington and ten years of health care employment experience helping patients with heart and vascular imaging. She currently works at the neuroscience department of Oregon Health Sciences University as a study coordinator. Alexandra's report citing the health effects of diesel particulate is here: http://portlandcleanair.org/files/reports/new%20PCA%20diesel%2012.pdf

Christopher Dieringer is our software writer. He has a BS in Industrial Engineering and BS Manufacturing Engineering from Oregon State University and a MS Computer Science from Georgia State University. He has worked in semiconductors, software security, brain research, and commerce firms. Chris automates our data visualizations with web design, replacing the need for GIS and Excel.

Greg Bourget is our executive director and lead researcher. He has a BA in political science from Humboldt State University and has been employed in mass outreach with 18 nonprofit environmental protection organizations since 1991. Greg works to connect 82 participating Portland organizations, staff, and volunteers working with this monitor project. Greg's report on diesel particulate monitoring options is here: http://portlandcleanair.org/files/reports/Diesel%20particulate%20monitoring.pdf

Mason Leavitt works as a GIS technician at Beyond Toxics, a Eugene, Oregon nonprofit addressing industrial air pollution. He has a BA in Geography as well as Spatial Data Science from the University of Oregon and has three years experience with data analysis and cartographic design. Mason created the EPA diesel particulate model maps on pages four and six.

Robert Wright is our meteorology advisor. He has a Master's degree in meteorology from University of Utah, over 25 years of experience as a meteorologist in the United States Air Force and 11 years of meteorological applications development for a Washington DC company. Robert advises us on the effect of atmospheric conditions on pollution concentration to determine when measurements are collected.

Seth Woolley is our data expert and board member. He has over 20 total years of professional software engineering experience including 14 years with geospatial data analysis systems and six years in digital security auditing. He is currently employed as a senior programmer working on Doppler-radar-collected moisture and airborne particulate data. Seth solves our math and physics needs with software code.

Teadoro (Teddy) Holt is our data analyst and a board member. He has an AS in Natural Science from Sierra College and two years of hands-on chemistry experience at Sierra and Portland Community Colleges. He is working towards a Bachelor's degree in Environmental Science from Portland State University with a minor in Climate Change Science. Teadoro provides data management and analysis, map and graph making, atmospheric forecasting, and procedure writing for this diesel particulate monitoring effort.