Comparing air quality forecasts with air quality data

During eruptions, air quality forecasts may be available which predict the concentrations of volcanic emissions - usually sulfur dioxide (SO_2) gas or particulate matter (PM) - at different locations downwind of the eruption. Sometimes there can be a difference in air pollution levels predicted by a forecast and those measured by local air quality monitoring stations (Figure 1). This briefing note explains reasons for these differences.

In this briefing note, the example of the 2022 Mauna Loa, Hawai'i eruption is used but the concepts are applicable to comparable eruptions in other places. The Vog Measurement and Prediction Program (VMAP) provides real-time vog (volcanic pollution) forecasts for the Hawaiian islands (http://mkwc.ifa.hawaii.edu/vmap/new/) and air quality is officially measured by the Hawaii State Department of Health (HDOH) (https://air.doh.hawaii.gov/home/map). There are also other non-regulatory-grade sensors deployed by research scientists and the public which may add information.

Key messages:

- All forecasts have uncertainty and will not always match real-time air quality measurements.
- Models for volcanic air pollution identify where and when pollution may occur more accurately than the exact amount of the pollutant.
- We recommend that air quality forecasts and real-time measurements be used in tandem. When a model forecasts pollution in your area, you should stay alert and check the air quality measurements (if available in your area).
- Sometimes the air can look hazy in the distance (e.g., looking across the ocean) but this doesn't mean the vog is at ground level or in your location.

What is the difference between air quality forecasts and air quality monitoring?

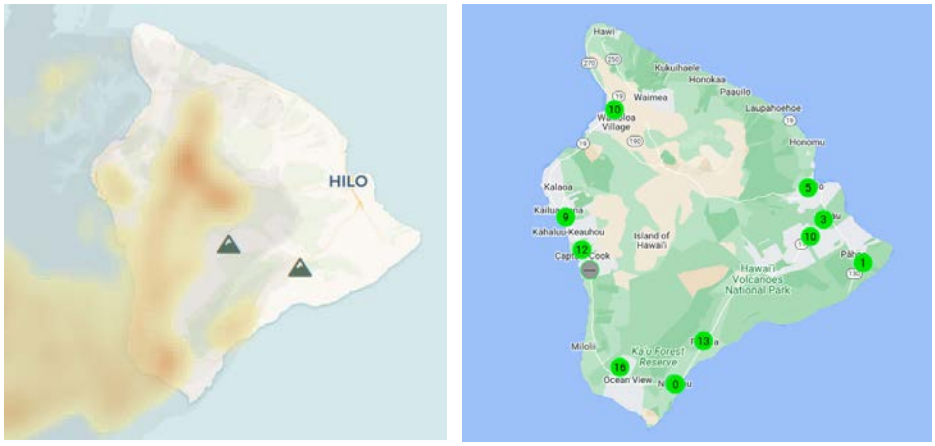

Figure 1. Left hand image: VMAP model for Hawai'i Island at 12pm 3 December 2022. Right hand image: HDOH monitoring stations at 12pm 3 December 2022 showing good air quality (green code) across the island.

- Regulatory-grade air quality monitors are very precise, providing real-time measurements of pollution concentrations such as SO_2 and PM. These measurements reliably inform people of the air quality at that moment in time, in that location, at ground level. Low-cost sensors can also be reliable if their data are calibrated to match the regulatory monitors.
- Models which forecast pollution from volcanic emissions (such as VMAP) use computer calculations to simulate the pollution, very much like a weather forecast. They will tell people

where and when pollution *might* be expected, but they are not real-time measurements, and have a high degree of uncertainty.

Why do forecasts predict different levels of pollution to those measured at the air quality stations?
It is very technically difficult to accurately forecast (i.e. predict in advance) when, where and in which concentrations volcanic pollutants are going to be, at ground level. There are many factors related to the environment and the eruption which limit the accuracy of the model. Some examples of these factors are below:

- As everyone knows, weather forecasts are never 100% accurate, and the smaller the meteorological event, the harder it is to forecast with high precision. For example, short-lived rain showers are extremely hard to pin-point exactly with respect to timing, location, and the rain intensity. Volcanic eruptions are also relatively small-scale events and are also difficult to simulate with high precision in a computer model.
- Although models may forecast air quality at 'ground level', the reality is that they are typically predicting air quality at heights at, and close to, ground level. The VMAP model displays the predicted vog concentrations between 0 and 100 meters above ground level. In other words, the predicted vog levels shown on the VMAP map could be anywhere between ground level and 100 meters in the air. The reason for this is the uncertainty in the model calculations. Data displays can vary between different models so the user should always check what is being displayed.
- Models have a set limit on spatial resolution (the size of the area they are predicting for) and this is defined by the model's uncertainty. Both weather and volcanic pollution models do not make predictions for a point location, but rather for an area. In the case of VMAP, the area used is approximately 1x1 km.
- The time periods displayed by air quality stations and forecasting models may vary. It is common for the models to display the pollutant concentrations as one-hour averages, while air quality stations may be set to display the measured concentrations in shorter time periods, for example, as 10-minute averages. Users are encouraged to check the time-resolution settings when reviewing model or monitor information.
- When a volcano starts a new eruption, there may not have been an opportunity to test and tune the model for that exact location. Scientists setting up volcanic pollution models use real-time observations (such as from air quality monitoring stations) to tune their models, meaning that as an eruption continues, the accuracy of the model is likely to improve. In the case of the 2022 Mauna Loa eruption on Hawai'i Island, the VMAP model already existed for Kīlauea volcano but had to be adapted for the new eruption (pollution source) due to the different location, elevation and topography and it will take time for its accuracy to improve.
- The amount of sulfur dioxide (SO_2) gas released from the volcano, also called emission rate or flux, is one of the main controls on the pollution levels downwind. There are several factors causing uncertainty in the model related to SO2 flux.
    - *Uncertainty in field measurements of SO_2 flux*. The main source of uncertainty is that the processing of SO_2 flux data relies on forecasts of wind speed and direction.
    - *SO_2 flux variability versus availability of measurements*. The flux is highly dynamic and can vary a lot and rapidly during eruptions, sometimes within a few minutes. Even under good conditions, measurements of SO_2 flux are typically only made once a day so the model has to assume that the emissions will stay exactly the same until a new measurement is available. In many cases, measurements may not be possible for many days in a row if, for example, the weather conditions are not right.
    - *Time lag between field measurements and forecast update*. Processing of SO_2 measurements is typically not automated and there is some time lag between field data being collected and the forecast being updated.

- The so-called 'injection height' of the pollutant is another important factor which also changes frequently, making it difficult to feed accurately into the model. The injection height refers to how high the pollutant is lifted above the eruption vent before it is transported away by the wind. This depends on the intensity of the eruption and can also fluctuate on minutes, hours, and days-long timescales.
- Eruptions create their own weather! The extreme heat from the lava or eruption plume changes the wind and precipitation patterns in the local area. These extremely small-scale but important meteorological events are not simulated by regional weather forecasts, which are what is fed into models such as VMAP, creating another source of uncertainty.
- Large and small-scale variations in topography and even vegetation can impact the dispersion of pollutants and are difficult to simulate with high resolution. Computer simulation capabilities are developing extremely rapidly and are amazing, but they are still not exactly like real life.

Why do we use volcanic pollutant models if they have so much uncertainty?
A forecast with some uncertainties is still better than no forecast. Most people prefer to know that there is a chance of poor air quality even if it doesn't end up happening. Real-time measurements from air quality monitoring stations can only tell us what is happening right now, but not what may happen in a few hours or the next day; we need a model to do that. Another important reason is that high-accuracy air quality stations, such as those from HDOH in Hawaii, are very costly to set up and maintain so are sparsely distributed. There are large areas in between them that have no direct measurements and the model can help 'fill in the gaps'.

Further resources:
The Hawaii Interagency Vog Information Dashboard
IVHHN Air quality monitoring for volcanic emissions
IVHHN Briefing note on interpreting volcanic gas measurements
IVHHN General information on volcanic gases and international air quality standards and guidelines
IVHHN The health hazards of volcanic and geothermal gases: a guide for the public

Written by: Evgenia Ilyinskaya (University of Leeds, UK), Claire J. Horwell (Durham University, UK). Reviewed by: Sara Barsotti (Icelandic Meteorological Office), Nadya Moisseeva (University of Hawaii, USA), Diana Felton and Lisa Young (Hawaii State Department of Health, USA).
Version 1.6. Last edited 6 December 2022.